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FINAL REPORT
FOR
PHOTOGRAPHIC CONSULTING SERVICES
TO THE
EARTH RESOURCES PROGRAM

CONTRACT NASW-2317

Submitted to

National Aeronautics and Space Administration
Earth Observation Programs
Washington, D. C. 20546

Prepared by

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Rochester, New York 14650

Approved by

George T. Keene

17 July 1976

Introduction

These reports document the major investigations, studies, and recommendations made by Eastman Kodak Company in its technical consulting services to the Earth Resources Program. This work was done under contract NASW-2317 beginning in January 1972. Many other suggestions and evaluations were reported to NASA, USDA, and USDI personnel in letters, informal reports, and conferences at several agency facilities. In addition Kodak technicians produced numerous targets and test objects on film and glass for use in verifying the performance of printers in government photographic laboratories.

At Mr. L. Jaffe's request, technical assistance was extended beyond NASA facilities to other government agencies (USDA, USDI, NOAA) and to earth resources laboratories in Brazil. This latter work is summarized in our report for Work Order No. 9 on 6 February 1976. Activity at each facility was authorized under a series of Work Orders agreed to by NASA and Kodak.

In accordance with the terms of our contract this Final Report is a bound collection of the reports previously issued for each work order. These reports are assembled in chronological sequence with at least one report for all work orders except No. 1, Exploration, and No. 2, Reports. The following table lists the date and title of the reports which are page-numbered in ten groups, i.e. first report pages 1-1 to 1-50, second report 2-1 to 2-32, etc.

REPORT FOR WORK ORDER NO. 3

PHOTOGRAPHIC CONSULTING SERVICES FOR EARTH RESOURCES PROGRAM

AT

NASA-AMES RESEARCH CENTER

CONTRACT NASW-2317

Submitted to
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Approved by

10 April 1972

Report No.	Date Issued	Work Order No.	Title of Report
1	10 April 72	3	Consulting Services for Ames Research Center
2	1 June 72	4	Consulting Services for Wallops Island Station
3	21 March 73	5	Consulting Services for Goddard Space Flight Center (includes data from First Printer Survey)
4	30 April 74	6	Second Comparison of Printing Facilities for Earth Resources Photography
5	23 August 74	5	Comparison of ERTS Photographs from Three Laboratories
6	25 October 74	6	Evaluation of Flare in Printing ERTS Scenes
7	30 April 75	8	Comparison of ERTS Photography from Four Laboratories
8	26 June 75	7	Calibration of Densitometers and Sensitometers in Earth Resources Laboratories
9	6 February 76	9	Evaluation of Landsat Images from INPE-Brasil
10	31 March 76	8	Third Comparison of Printing Facilities for Earth Resources Photography

This table gives the full names for certain Kodak products that may be designated by an abbreviated title in these reports:

Abbreviations	Product Name
SO-219	KODAK Direct Electron Recording Film (ESTAR Base) SO-219
SO-242	KODAK Aerial Color Film (ESTAR Thin Base) SO-242
SO-355	KODAK Low Contrast Fine Grain Aerographic Duplicating Film (ESTAR Base) SO-355
SO-360	KODAK Aerochrome Duplicating Film (ESTAR Base) SO-360
SO-397	KODAK Ektachrome EF Aerographic Film (ESTAR Base) SO-397
SO-438	Eastman Electron Recording Film (ESTAR Base) SO-438
SO-467	KODAK Aerial Duplicating Film (ESTAR Base) SO-467
2402	KODAK PLUS-X Aerographic Film 2402 (ESTAR Base)
2420	KODAK Aerographic Duplicating Film 2420 (ESTAR Base)
2421	KODAK Aerographic Duplicating Film 2421 (ESTAR Base)
2422	KODAK Aerographic Direct Duplicating Film 2422 (ESTAR Base)
2424	KODAK Infrared AEROGRAPHIC Film 2424 (ESTAR BASE)
2430	KODAK Fine Grain Aerial Duplicating Film 2430 (ESTAR Base)
2443	KODAK Aerochrome Infrared Film 2443 (ESTAR Base)
2445	KODAK Aerocolor Negative Film 2445 (ESTAR Base)
2447	KODAK Aerochrome Duplicating Film 2447 (ESTAR Base)
2448	KODAK Ektachrome MS Aerographic Film 2448 (ESTAR Base)
3400	KODAK PANATOMIC-X Aerial Film 3400 (ESTAR Thin Base)
4109	KODAK Ektacolor Print Film 4109 (ESTAR Thick Base)
Wr. 12, etc.	KODAK WRATTEN Filter, No. 12, etc.
CC20M, etc.	KODAK Color Compensating Filter, CC20M, etc.
EK301	KODAK Infrared Cutoff Filter, No. 301
V-11	KODAK VERSAMAT Film Processor Model 11
1411	KODAK VERSAMAT Film Processor Model 1411M
1811	Ektachrome Film Processor Model 1811
MX641	KODAK VERSAMAT 641 Chemicals
1b	KODAK Intensity Scale Sensitometer, Type 1-B, Mod. V
Mod. 60	Eastman Processing Control Sensitometer, Model 60
31A	Eastman Electronic Densitometer, Model 31A
BPE	KODAK BEACON Precision Enlarger, No. 023-001
Niagara	KODAK NIAGARA PRINTER, No. 008-001
Rainbow	KODAK RAINBOW Continuous Printer, No. 032-001
Colorado	KODAK COLORADO Continuous Printer, No. 037-001
Texas	KODAK TEXAS Continuous Enlarging Printer, No. 1-036-E-001

PHOTOGRAPHIC CONSULTING SERVICES

FOR

EARTH RESOURCES PROGRAM

AT

NASA - AMES RESEARCH CENTER

REPORT ON WORK ORDER NO. 3

Summary

This report summarizes the recommendations, procedures, and techniques provided by the Kodak Apparatus Division to the Ames Research Center to support the Earth Resources Aircraft Program at that facility. This work was defined following a visit to Ames by Kodak engineers on 25-26 January 1972 and implemented in a second session on 22-24 March 1972.

Recommendations, procedures, and calibration data are included for sensitometry, densitometry, laboratory cleanliness, and determination of camera exposure. Additional comments are made regarding process control procedures and general laboratory operations. Calculation of exposure for 2424 film and certain filters will be done when NASA provides Kodak with a transmittance curve for the infrared blocking filter on the I^2S camera.

Use of a regulated voltage supply for densitometers, and installation of equipment to aid in film handling and editing is recommended.

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Introduction

This report summarizes the procedures and recommendations provided by Kodak for the Earth Resources Aircraft Program (ERAP) conducted by NASA at the Ames Research Center. The task was established in Work Order No. 3 issued by NASA Headquarters to Kodak on 31 January 1972. The requirements of Work Order No. 3 were derived from information obtained in a preliminary assessment of the Ames ERAP facilities made by Kodak engineers on 25-26 January 1972. A second visit to implement the recommendations was made on 22-24 March 1972.

The ERAP program uses aerial photography as a tool for scientific measurement rather than as simply a pictorial display. This use requires special calibration and controls. The materials, methods, and recommendations derived under this contract are a unique service that is normally not provided by the Eastman Kodak Company to its commercial customers. A significant part of this work is the establishment of radiometric control for ERAP camera films based on comparison of gray scales exposed on Ames instruments and on calibrated sensitometers at Kodak. After this calibration is established it is expected that NASA will maintain its own sensitometric control by means of proper cross-over procedures between successive emulsions.

This report includes recommendations, procedures, and calibration data for sensitometry, densitometry, laboratory cleanliness, and camera exposure determination. Additional comments are made regarding process control procedures and general laboratory operations.

Photographic Operations

The ERAP program at Ames involves the flow of film and information through two areas - the Photographic Laboratory and the Data Facility. Figure 1 shows the sequence of operations in these areas. Although part of different sections in the Ames organization, the two groups work closely together in order to maintain output and keep image quality high. It is very important that personnel in both areas work to meet equal standards for cleanliness and use the same methods for handling, labeling and storing film. Both groups must appreciate the value of sensitometric controls on film and processing, and work to insure that these controls are not lost at any point in the production cycle.

The Photographic Laboratory should remove from the freezer a preexposed control strip for each flight emulsion at the time the flight film is loaded into the camera. After the flight this strip is spliced to the camera film immediately prior to processing. The Laboratory should verify that a control strip carrying a proper exposure was processed with the camera film and should splice this strip between the edited camera photography and the titling leader. The calibration of this original gray scale should be furnished to all users of either the original film or subsequent prints. Comparison of picture densities with those on the printed-through gray scale is the basis for radiometric calculations for the imagery.

Other gray scales may be exposed by the Photographic Laboratory on the duplicating film for use in controlling the print process. Densities from these strips should be recorded on a control chart but are not fundamentally involved in the radiometric calibration of the photography.

FILM FLOW FOR ERAP PROGRAM

AMES RESEARCH CENTER

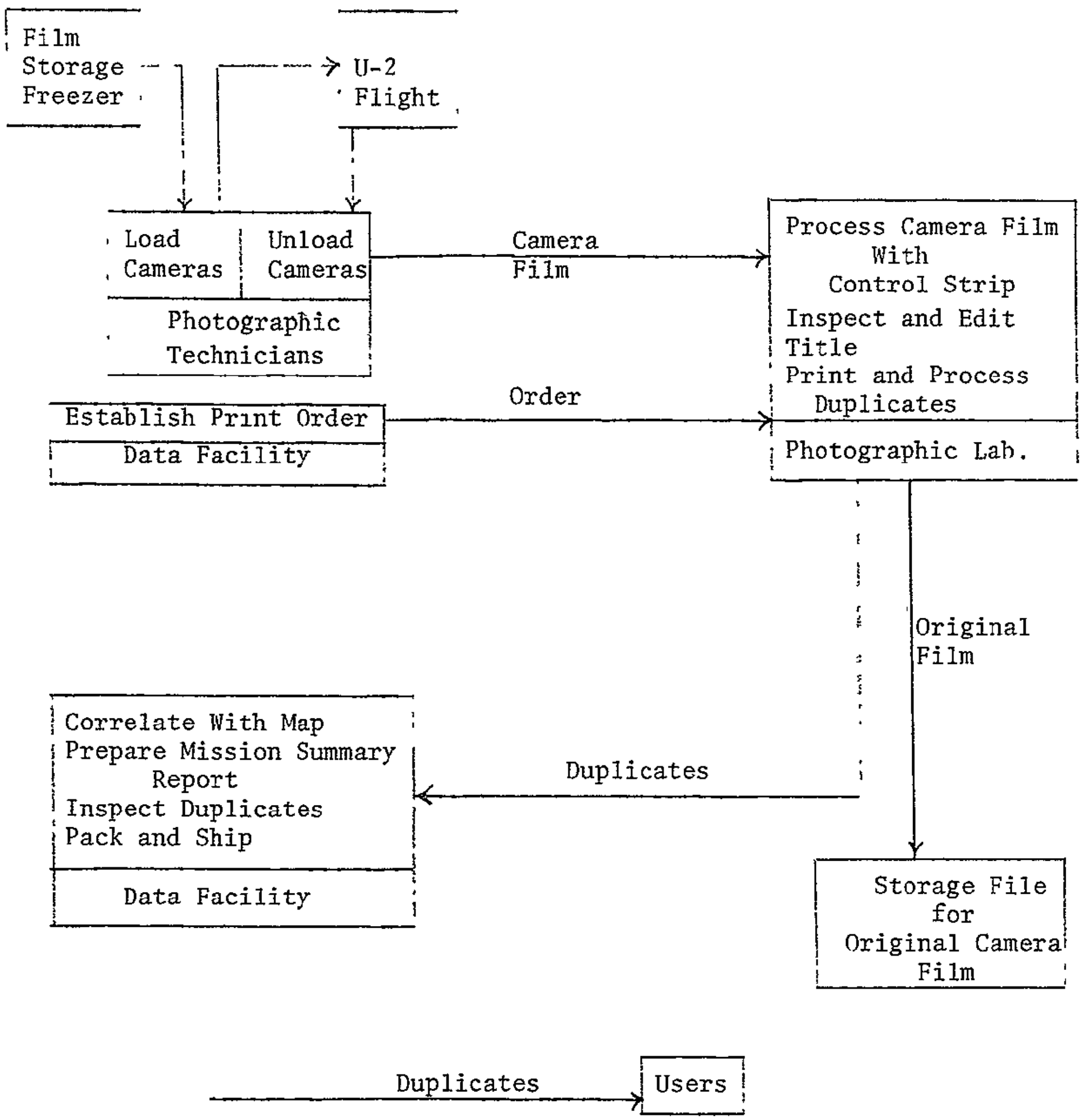

Figure 1

Control of the photographic processor is based on the use of properly mixed, uncontaminated solutions in a machine operated at standard temperatures and mechanical conditions. The status of the process is measured by densitometry of near neutral step scales exposed using a calibrated sensitometer on a control film. Processing of these control strips should immediately precede processing of the camera or print film. Additional control strips should be processed at intervals during the work day.

Usually adequate control is maintained by reading about four steps on a strip and plotting the densities on a chart in which the center line is the standard density. For color film processors, three color densities are plotted along the same control line for a step. The following guides are suggested for the permitted deviation of the observed densities from the control values for color film processes:

	Control Limits	
Portion of D-log E Curve	Density	Color Balance Spread*
D min.	+0.03 No lower limit	No limits
D = 0.5 to 0.7	±0.10	0.08
D = 1.8 to 2.1	±0.15	0.13
D max.	-0.25 No upper limit	No limits

* Color balance spread is the absolute range of the deviation of the three color densities from the aim line.

Note that special considerations may prescribe larger or smaller limits because of requirements placed on the photography by the users or because of unusual processing conditions.

A full characteristic curve should be read and plotted occasionally, but much time will be saved by reading, plotting, and controlling only four density steps. The full curves reveal changes in tone reproduction and allow measurement of speed and gamma as an aid in properly placing the scene image on the D-log E curve.

It is well to correlate sensitometric data with pH or specific gravity measurements and with machine data such as temperature, time in solution, and replenishment rates. These data assist in locating sources of trouble whenever densities fall outside the specified limits. The charting and use of chemical and machine data are well understood by photographic laboratory personnel at Ames. Process control is satisfactory in view of infrequent operation of the processors and a relatively light film load.

Rather than setting arbitrary limits on step densities, it is desirable to establish limits by statistical calculation based on an extended process run. From this run, limits of 2 or 3 standard deviations may be derived for each density value. Control charts showing the average value and appropriate limits must be established for each type of film that is frequently used. A procedure for calculating control limits from statistical analysis of process data is given by Bennett and Franklin.[1]

Printing and processing of duplicates from ERAP films are done very well at Ames. Proper density and color balance are maintained on prints made on SO-360 color film. Black-and-white duplicates are satisfactory but may be too contrasty for some users; possibly use of SO-355, a print film of lower gamma, would be better than the prints on 2420 film in some cases.

[1] C. A. Bennett and N. L. Franklin, Statistical Analysis in Chemistry and the Chemical Industry, J. Wiley and Sons, New York, 1954, pp. 631-644.

Camera Exposure

The recommendations for camera exposure are based on the use of the Kodak Aerial Exposure Computer (R-10) and specially calculated film speeds for the following combinations of lenses, films, and filters:

TABLE I

Film Speeds for Ames Cameras

Camera	Film	Lens	Filters	Effect. Aerial Film Speed
Vinten	2402	1.75 Inch	Schott GG475 + BG18	75
	2402	f/2.8	Schott OG570 + BG38	53
	2424		Schott RG645 + C9830	24
	2443		Wr12 + 30B + 20M	26
A-1/A-2	3400	6-inch f/6	Wr. 12	20
		or		
	SO-242	24 inch f/8	None	7
I^2S	2424		Wr. 88A	68

Note: These film speeds are based on the following processing used at NASA-Ames:

3400 - V-11, 85°F, 2 racks, 10 ft/min., MX641

2402 - V-11, 85°F, 2 racks, 5 ft/min., MX641

2424 - V-11, 85°F, 2 racks, 5 ft/min., MX641

2443 - 1411, Standard process

SO-242 - 1411, Non-standard process

To obtain the film speeds in the right hand column, a previously developed, proprietary computer program was used to relate solar altitude to exposure time at an arbitrary lens f/number. This calculation is a spectral integration that includes the

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effects of nominal lens transmittance, the spectral distribution of sunlight and haze light viewed vertically from very high altitude, and the spectral sensitivity of each film-filter combination. The calculated exposure is sufficient to produce a density of 1.0 on black-and-white films or 1.5 on the green density record of color films from a neutral target of 12% reflectance. This reflectance is a useful average value for setting exposure of aerial scenes.

The R-10 computer was then used "in reverse" by entering the previously calculated f/numbers and exposure times at several solar altitudes and determining the effective aerial film speed. For a given film and filter, these speed values for all solar altitudes were identical to within ± 1/3 stop. An average value of each film speed is given in Table I.

A speed value of 68 was calculated for the I^2S camera using the Wr 88A infrared filter. A transmittance curve for the infrared blocking filter used with the other color filters was not available. We will provide exposure recommendations for these filters on the I^2S camera when this curve is received.

The effective aerial film speeds in Table I should be used along with the correct sun altitude to calculate the proper lens f/number and shutter time using the Kodak R-10 computer. In some instances, photography of unusually light or dark terrain will require deviations from the calculated exposures. These adjustments should be based on previous experience in recording these areas.

Sensitometric Calibration

This section provides standard sensitometric curves for the camera and print films used in the ERAP program, defines a procedure for preparing control strips on flight films, and describes control techniques for two Ames sensitometers.

Calibration Curves

The curves in Appendix I are from exposures made using a calibrated Kodak 1b sensitometer on film in the ERAP program. The $11^{\underline{th}}$ step on each camera film curve is marked in watt-seconds/square meter, while print films are calibrated in meter-candle-seconds. Table II itemizes the films, filters, and sensitometer data for each of these basic exposures. Exposures matching these curves fairly well were made using the Kodak Mod. 60 and EG&G Mk. VI sensitometers at Ames. The EG&G instrument at 0.01 second was used for all color films and for the SO-355 and 2422 black-and-white films. All Mod. 60 exposures are at 0.1 second. The filters used in exposing 2424 and 2402 films simulate the pass band of the filters used on the Vinten and I^2S cameras.

On 22 March about 250 feet of unexposed film and 12 1b exposures were taken to Ames. At least 9 1b exposures and most of the raw stock remain at Ames after matching Ames exposures to the 1b curves. About 700 feet of each film is in Rochester for use in other tests for NASA under this program.

Radiometric calibration of camera films requires an integration of the spectral characteristics of the light incident on the sensitometer film plane, the pass band of any camera filters, and the spectral sensitivity of the film. The following calculation yields the log exposure at Step 11:

Table II

Calibrated Sensitometric Exposures

Ames ERAP Films

Kodak 1b Sensitometer

Film	Filters	Exp. Time, Secs.	*Radiometric Log E Step 11	*Photometric Log E Step 11
B&W				
2402-117-9	Wr.59A + EK301(680) + C5900	0.04	-4.000	-0.78
	Wr.23A + EK301(680) + C5900	0.04	-3.932	-0.78
2424-16-10	Wr.36 + 25 + EK301(760) + C5900 + P2043	0.04	-4.495	-0.78
	Wr.88A + C5900 + P2043	0.04	-4.316	-0.78
3400-188-7-2	C5900	0.01	-3.984	-1.38
2420-215-10-5	None	0.5		1.00
2422-1-16	None	1.0		1.30
SO-355-9-12-7	None	1.0		1.30
Color				
2443-104	C5900 + P2043 + Wr.12 + CC10M	0.04	B/G-4.028 G/R-4.132 R/IR-4.713	-0.78
2443-104	C5900 + P2043 + Wr.12 + CC20M + CC30B	0.04	B/G-4.428 G/R-4.436 R/IR-5.039	-0.78
SO-242-17-2-11	C5900	0.04	B-3.959 G-3.838 R-4.024	-0.78
SO-360-39-31-1	Wr.2B + Inconel 0.29	0.2		0.36

Photometric exposure is in meter-candle seconds; radiometric exposure in in watt-secs/meter^2.
All black and white films processed in Versamat 11, MX641, 10 ft/min, 85°F, two racks except SO-355, 1 rack.
Color films given standard processing in Versamat 1811-1.
These logarithms do not follow the Briggs Convention, i.e., the mantissa has the same sign as the characteristic.

$$\frac{\text{Log E at Step 11 watt-secs}}{\text{meter}^2} = \log_{10}\left[\int_{\lambda_1}^{\lambda_2} H_{1b}\,(f_i \cdots f_n)\; S\; d\lambda\right] + \log_{10} t$$

where H_{1b} = irradiance at the 1b sensitometer film plane [includes the effects of lamp, mirror, cover glass, $11^{\underline{th}}$ step of carbon step tablet, daylight correction filter (C5900 or C5900 + P2043)]

$f_i \cdots f_n$ = filters simulating camera filters

S = peak normalized spectral sensitivity of film

t = exposure time

Appendix II tabulates peak normalized spectral sensitivities for ERAP camera films obtained from published spectral sensitivity graphs. Exposure at the $11^{\underline{th}}$ step for duplicating films is specified in meter-candle-seconds by comparison with a photometrically calibrated light source maintained by the Bureau of Standards. Radiometric calibration of print films is usually unnecessary.

Procedure for Making and Storing Control Strips

In the ERAP program it is important to have calibrated gray scale exposures on the camera film emulsions processed with the rolls of pictures. While it is possible to expose gray scales on the head or tail end of the flight film, these exposures frequently are spoiled by fog light or by camera images. To avoid these losses one can use an alternative method in which preexposed gray scales are made on the flight emulsion and are spliced to the aerial photography immediately prior to processing. This second procedure is recommended for use in the ERAP program.

When a new camera film is received, it should be compared to the previously used film by processing identical sensitometric exposures made on a representative sample taken from each coating. This test evaluates differences in speed, gamma, or color balance to determine any changes in filters or exposure for the new film. After this assessment, the sensitometric test strips should be prepared according to the following procedure:

(1) Cut from the outer convolutions of all or most of the rolls sufficient footage to provide enough 18-inch test strips for all camera runs, process control needs, and crossover tests with other films.

(2) Randomize these 18-inch strips by tumbling in a large container.

(3) Expose the strips on the correct sensitometer. The EGG Model 6 is used for color, 2422, and SO-355 films while the Model 60 instrument is used for all other black and white films. It will help identify strips after processing if code marks denoting the kind of film and color filter (if any) are exposed on the strip along with the gray scale. Such a coding device was given to Photo Laboratory personnel on 23 March 1972.

(4) Package each exposed strip separately in Kodak heat seal foil packages. Label each package with the date and emulsion number.

(5) Keep all strips at room temperature for one day after exposure, then store in a freezer at 0° to 10°F.

(6) Ship to Wallops Island in dry ice a quantity of the strips adequate for tests and control use with ERAP flights originating at WIS.

(7) Control strips should be moved from cold storage to room temperature at the time that the flight film is loaded into the cameras.

Sensitometer Control

Eastman Processing Control Sensitometer, Model 60

The Model 60 sensitometer requires a two minute warm up period to stabilize the light output. The useful life of the sensitometer lamp is 100 to 150 hours. Light output is essentially constant over this time period if the lamp is operated at a constant current. Use of an elapsed time meter or a log book will aid in replacing the lamp before its useful calibration life is expended.

Replacement calibrated lamps may be obtained with specified values of amperage and distance to the film plane so that a known light output is maintained.

A "master lamp" may be inserted at intervals to provide a rigorous check for constant output of the working lamp. These suggestions are detailed in the sensitometer manual.

EG and G Mark VI Sensitometer

This sensitometer has a repeatability of better than ±0.02 log exposure from flash to flash providing a 15 to 30 second delay is used between flashes. If the machine has been turned off for sometime an initial flash should be made before any film is exposed. The output of the EG and G sensitometer is very stable; radiance drops only 15% after 200,000 flashes.

Light intensity on the exposure plane may be nonuniform by as much as 12% (0.07 log exposure) from end to end. If very accurate calibration is required, a uniformity test should be made by exposing a piece of film in the sensitometer exposure plane with the step tablet removed. This film should be exposed to yield a density of about 1.0 and processed to a gamma of 1.0. Density changes in this exposed area now represent variations in log exposure across the step tablet plane. This pattern can be used to calibrate future sensitometric exposures.

Recalibration

A sensitometer can be recalibrated to an absolute value by comparing its output to that from a sensitometer whose output is known at the 11th step. These exposures should be made on the film for which the sensitometer will be used most frequently. The two gray scale exposures are processed together.

The 11th step density from the standard exposure and from the uncalibrated sensitometer are plotted on the D-log E curve from the standard exposure. The log exposure difference between these two densities yields the log exposure value to be assigned to the 11th step exposure of the sensitometer of interest.

Color Densitometer Control

General

Control of a color photographic process is based on measurement of dye densities on processed sensitometric strips. Densitometer control encompasses both calibration against an absolute standard and evaluation of the repeatability of the instrument.

Most densitometers are designed to operate in normal room light and temperatures. However, variations in these factors may influence the results obtained. Some instruments stabilize only after a warm-up time while others are most stable if the circuitry is on continuously. A regulator should be used to provide constant line voltage to the densitometer. Most photomultiplier tubes change sensitivity with age, and some photo tubes change sensitivity rapidly when first exposed to light but reach a stabilized condition when fatigued. The densitometer should be calibrated, controlled, and used under those conditions which produce the most stable operation.

Calibration

Measurements obtained with a densitometer are more meaningful if they can be related to some reference instrument or precisely defined density measurement technique. Density readings obtained on two densitometers may not be comparable unless both instruments have been calibrated in the same manner. The most practical method for this calibration uses a stablized silver step tablet. Calibration density values will be reliable as long as the strips have been properly stored and handled.

Calibrations are required periodically and whenever some critical component in the densitometer is replaced. These components include photomultiplier tubes, rectifier tubes, transformers, capacitors, diodes, or filters.

The detailed procedure for calibrating the densitometer should be in accord with the "Owners Manual" or "Operation and Maintenance Manual" supplied by the manufacturer for that densitometer. Before attempting a calibration, the operator should become familiar with all of the controls and indicators.

Visual Densities

Some color densitometers are also equipped with a "Visual" filter. Densities measured through this filter closely approximate the densities seen by the human eye. When a visual filter is not available, density measurements on color materials should be made with the green filter in the light beam.

A calibrated silver step tablet is used and can be purchased from Eastman Kodak Co. if not provided with the densitometer. The calibration procedure given in the "Owners Manual" or "Operation and Maintenance Manual" should be followed. If such a manual is not available one should be obtained from the densitometer manufacturer.

In lieu of a calibration procedure from the manufacturer, these steps may be used:

1. Plug the densitometer into a regulated source of 110 volts ac.
2. Allow the densitometer to achieve stable operation. This may take from 1/2 hour to 24 hours.

3. Select the correct reading aperture.
   In general, use the largest convenient aperture up to 3 mm in diameter.
4. Turn the filter wheel until the visual or green filter is in the reading position.
5. With no film sample in the aperture, adjust the "zero adjust knob" until the density meter reads 0.00 density.
6. Place the calibrated silver step tablet in the densitometer emulsion surface up.
7. Select a step on this tablet that has a density about 3/4 of the density range of the meter. For Example:

   Usually a density within the range of 2.80 to 3.00 is desirable for instruments which read to 4.00, and 2.20 for instruments which read to 3.00.
8. Read the density of the center of this step of the tablet. If the density obtained on the meter does not agree with the density provided on the calibration sheet, adjust the calibration or sensitivity of the densitometer until the meter reads the specified calibration density.
9. Re-check the zero with the step tablet removed from the aperture. Go back and forth as many times as necessary to get the densitometer reading correctly at zero and at the calibration density.

10. Read each step of the calibrated tablet and compare the results with the calibration supplied. If all steps read within 0.02 of the specified values, the densitometer is calibrated for reading silver densities.

11. If densities do not agree within 0.02, adjust the densitometer to correct for non-linearity as recommended by the manufacturer. If this cannot be done, then the densitometer can be calibrated only at zero and one other density.

12. Some densitometers incorporate a reference calibration filter. If this filter is available, insert it into the beam and take a reading. Record this density on a label placed on the densitometer. This reference filter is used in place of the standard step tablet to monitor the densitometer daily and thus prolong the life of the calibrated step tablet. For densitometers without a built in filter, a uniform silver density of about 2.80 may be used.

Dye Densities

If a processed sensitometric strip on color film is available which represents normal processing for that film, it can be read on the densitometer and density aims established for process control.

If it is desirable to adjust a densitometer for color film so that it will read the color densities of a photographic dye system in the same manner as another color densitometer, the following procedure should be used. Reasonably good agreement is possible if both densitometers use the same filters and have linear amplification.

If available, use the calibration procedure in the "Operations and Maintenance Manual" for the densitometer. If such a procedure is not available, proceed as follows:

1. Plug the densitometer into a regulated source of 110 volts ac.
2. Allow the densitometer to "warm up" until stable operation is achieved. Usually this will take at least 30 minutes.
3. Select the correct reading aperture and place it in the densitometer.
4. Turn the filter selection wheel to position the green color filter in the light beam.
5. With no film in the reading aperture adjust the "zero adjust knob" until the density meter reads 0.00 density.

6. Select a step on a color film sensitometric strip for which densities are known when read on the reference color densitometer. The densities should be about 3/4 of the total density range of the densitometer meter.
7. Place the selected step over the reading aperture emulsion side up. Read the green density. Compare this density with the known value determined on the reference densitometer. If the two values do not agree, adjust the calibration or sensitivity until the density indicated on the meter agrees with the standard value.
8. Remove the strip from the densitometer and re-check the "zero" reading. If an adjustment is necessary, go back and forth until the densitometer reads both zero and the calibration step correctly.
9. If the densitometer being adjusted is equipped with an internal calibration filter, position this filter in the light beam and read the green density. If the densitometer does not have a reference filter, insert a uniform silver density in the beam and read the green density. Record this value on a label attached to the densitometer.

10. Read all steps of the color film sensitometric strip through the blue, green and red filters. Compare these density values to the values from the reference densitometer. If the densities agree within ±0.03 no further calibration is required.

11. If the blue and red densities do not agree with the known values, repeat steps 7, 8, and 9 above for both the blue filter and the red filter.

NOTE:

If the calibration or sensitivity must be adjusted for each color filter, this must be done each time the densitometer is used to read color material.

Densitometer Control

It is important to know if the color densitometer is functioning normally or if a change has occurred which requires re-calibration or maintenance. The KODAK Transmission Densitometer Check Plaque is a valuable tool for detecting densitometer instability and malfunctions.

The procedure for using the Check Plaque is described in detail in Kodak pamphlet 637820. The plaque contains seven reading areas plus one for zeroing the densitometer. Density readings from the plaque are recorded each day for 20 days. The averages of these values are the average performance levels for that densitometer. Subsequent readings are compared by statistical tests to these aim values for evidence of changes in the densitometer. Copies of pamphlet 637820 were given to personnel in the Ames photo lab.

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Laboratory Cleanliness

General

It is very important to maintain clean film web surfaces in a photographic laboratory producing high-quality reproductions. Cleanliness procedures should emphasize careful handling of the original record and successive print masters. Foreign particles attached to the print master are permanently registered as information voids on subsequent copies. In contact printing onto fine grain duplicating emulsions, foreign particles lodged between the films produce the "contact printing measle" artifact. This artifact magnifies the area of image disturbance in the duplicate to many times the size of the foreign particle.

A tightly wound roll of film provides excellent protection against contamination of the inner convolutions. Therefore, maintaining clean film surfaces is most important at those points in the production cycle where the material is unwound.

The sources of particles which impair quality in the photographic laboratory can be divided into three broad categories: 1) airborne particles from the general environment, 2) particles adhering to the surfaces of film handling equipment, and 3) particles and moisture spots originating from those handling the film. These sources must be minimized in the vicinity of open spans of film, as particles of all types are extremely difficult to remove from film surfaces after they have been wound into a roll.

Procedures

Operator Dress Requirements

All personnel working in the general vicinity of open spans of print master material should wear the following outer garments:

(1) Full length smocks made from a lint-free material such as nylon.

(2) Caps which fully cover the hair also made from a lint-free material.

All personnel actually viewing exposed film surfaces or working in close proximity to exposed film surfaces (e.g. printer operators) should wear partial face masks to prevent the possibility of moisture spotting the film surface. In addition all personnel actually handling the image portion of films should wear lint-free gloves. Gloves are not needed for operators of equipment like a continuous printer, as these people handle the extreme ends of the film rolls.

Clean room garments should be worn only in designated clean film handling areas which are described in the next section. Wearing of these garments in break rooms, chemical mix rooms, or offices where smoking is allowed will contaminate the garments and limit their usefulness.

Work Area Restrictions and Housekeeping Requirements

The most important factor in maintaining film cleanliness is to physically separate operations involving open film spans of critical material, such as print masters, from other functions within the laboratory. Therefore, inspection, viewing, titling, splicing, printing, and similar functions should be conducted in designated clean areas. In these areas as in all film handling areas smoking should be strictly forbidden. The storage of dirt-generating matter such as packaging, corregated cardboard and other fiberous material in these areas should be prohibited. Clean room attire should be worn exclusively in these areas.

The work areas should be frequently cleaned during non-production periods. This cleaning should follow good commercial practices with special attention given to film handling hardware which should be thoroughly cleaned prior to each use. This equipment should be cleaned periodically with soap and water followed by wiping with a lint-free cloth moistened with alcohol. Special attention should be given to film contact areas such as horizontal surfaces and idler rollers on viewing tables, titlers, printers, and densitometers. In addition, all idler rollers and spool spindles on film handling equipment should receive frequent cleaning during use.

When film must be unwound in offices or other areas where general cleanliness is difficult to control, the film transport equipment should be on a bench under a laminar air flow hood. These benches provide an extremely clean local environment for the open film span within a general work area.

Film Handling

Film webs should be handled exclusively on equipment designed to minimize the need for touching the image and which provide a uniform tension during winding. Never roll the web from spool to spool by hand.

While most viewing tables are equipped with adequate rewinds, densitometers are often deficient in this respect and are a common source of film damage. Densitometers should be equipped with rewinds that permit slewing to any location within a film strand for convenient densitometry without subjecting the web to a hazardous condition.

The print master film web should be frequently cleaned during the printing operation. It is good practice to clean the print master following every third printing, although some laboratories may require more or less frequent cleaning. The film is usually cleaned by passing it through a tacky roll machine.

Equipment

The following new equipment is recommended for film handling at the NASA Ames facility to insure adequate product cleanliness and safety:

Equipment for the Photographic Laboratory

1 Denver Film Editing Unit, Part Number 250-500

1 Denver Densitometer Assembly, Part Number 250-750

1 Denver Tacky Roll Assembly, Part Number 250-850

1 Laminar Flow Clean Bench, Atmos Tech Corp., Edison, N. J.

Equipment for the Data Facility

1 Denver Film Editing Unit, Motor Wind, Part Number 250-600

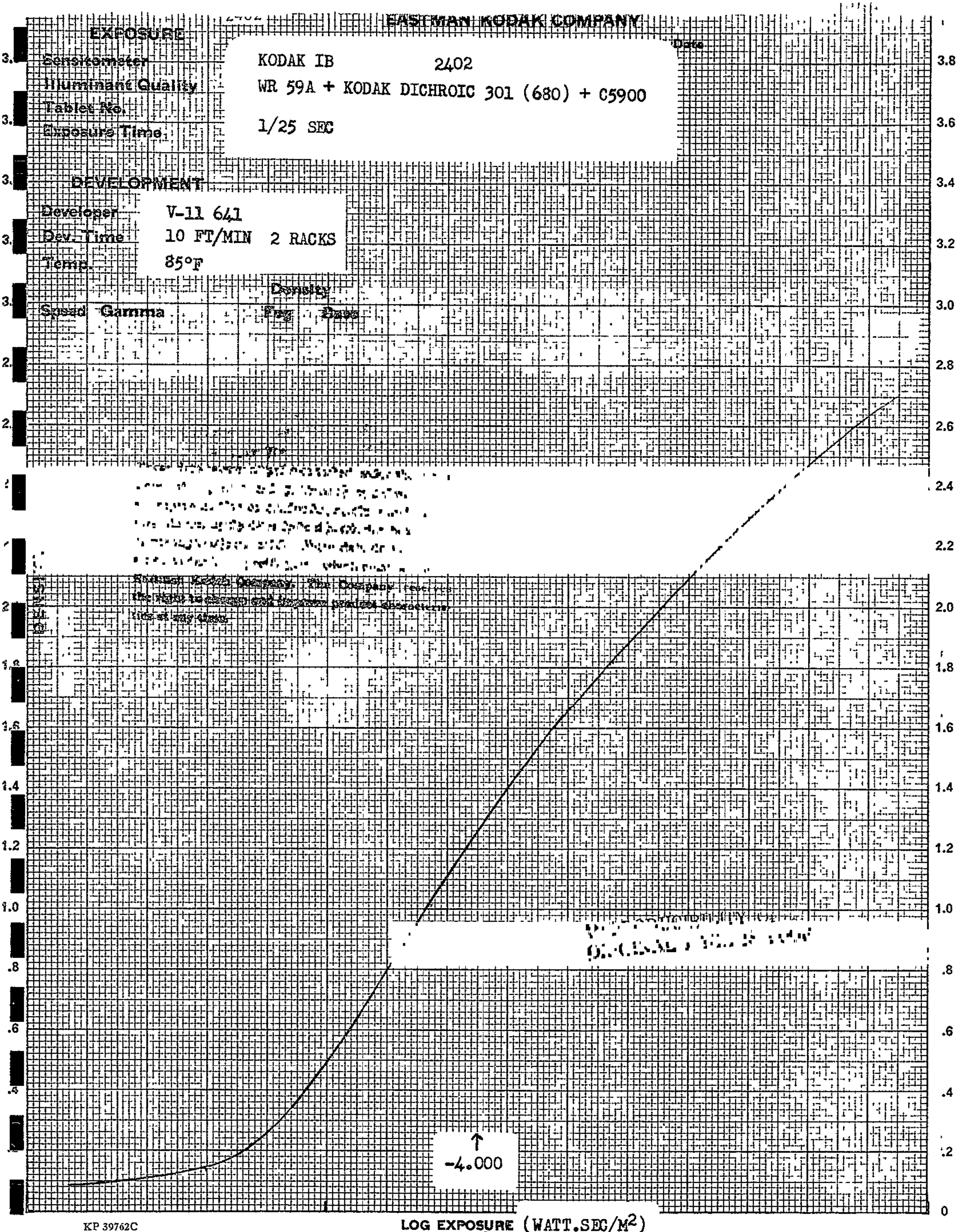
1 Laminar Flow Clean Bench, Atmos Tech Corporation, Edison, N. J.

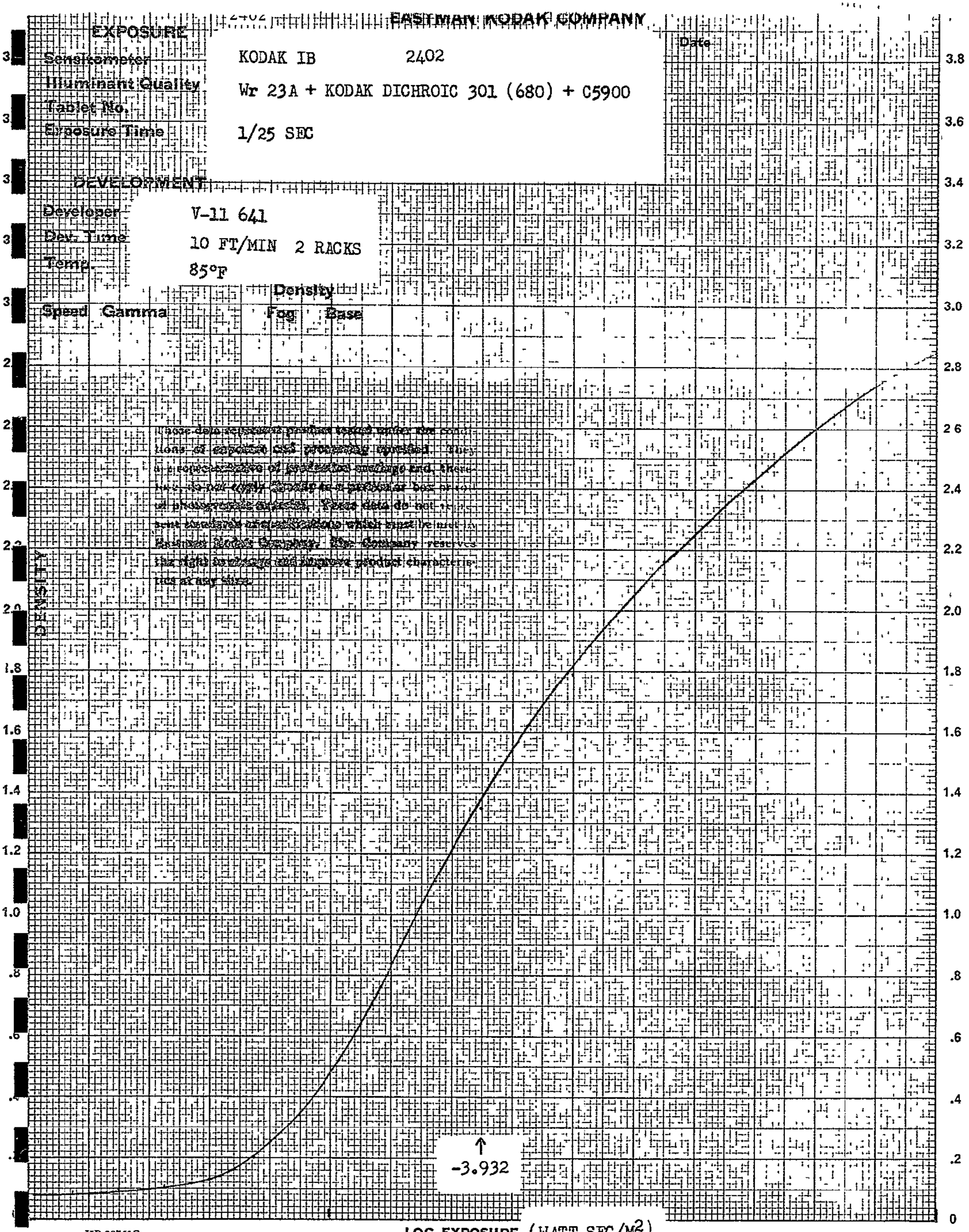
In the Photographic Laboratory the Denver film handling unit should be placed on the clean bench to protect original negatives during inspection, editing, and cleaning. The Delaware Titler should be moved to the Photographic Laboratory so that titling may be done immediately after editing the original negative. For safety, camera negatives should be handled on a hand-powered rewind, while a motor driven unit is useful in the Data Facility for inspecting prints. This rewind should be on the clean bench to protect the prints during inspection and prior to shipment.

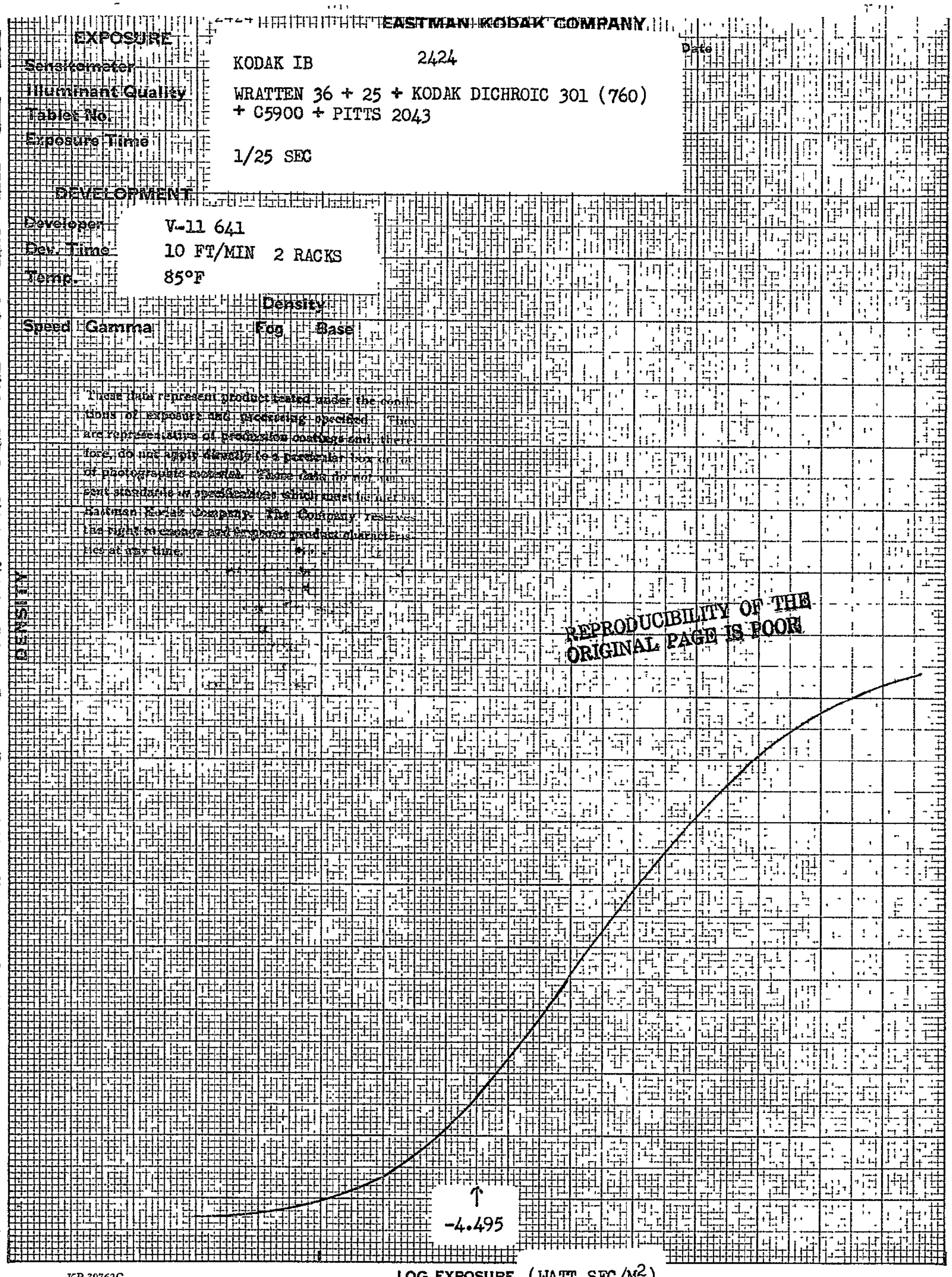
A tacky roller cleaner is recommended in place of repairing the existing ultrasonic cleaner. Titling applied to the camera film may be removed by ultrasonic cleaning.

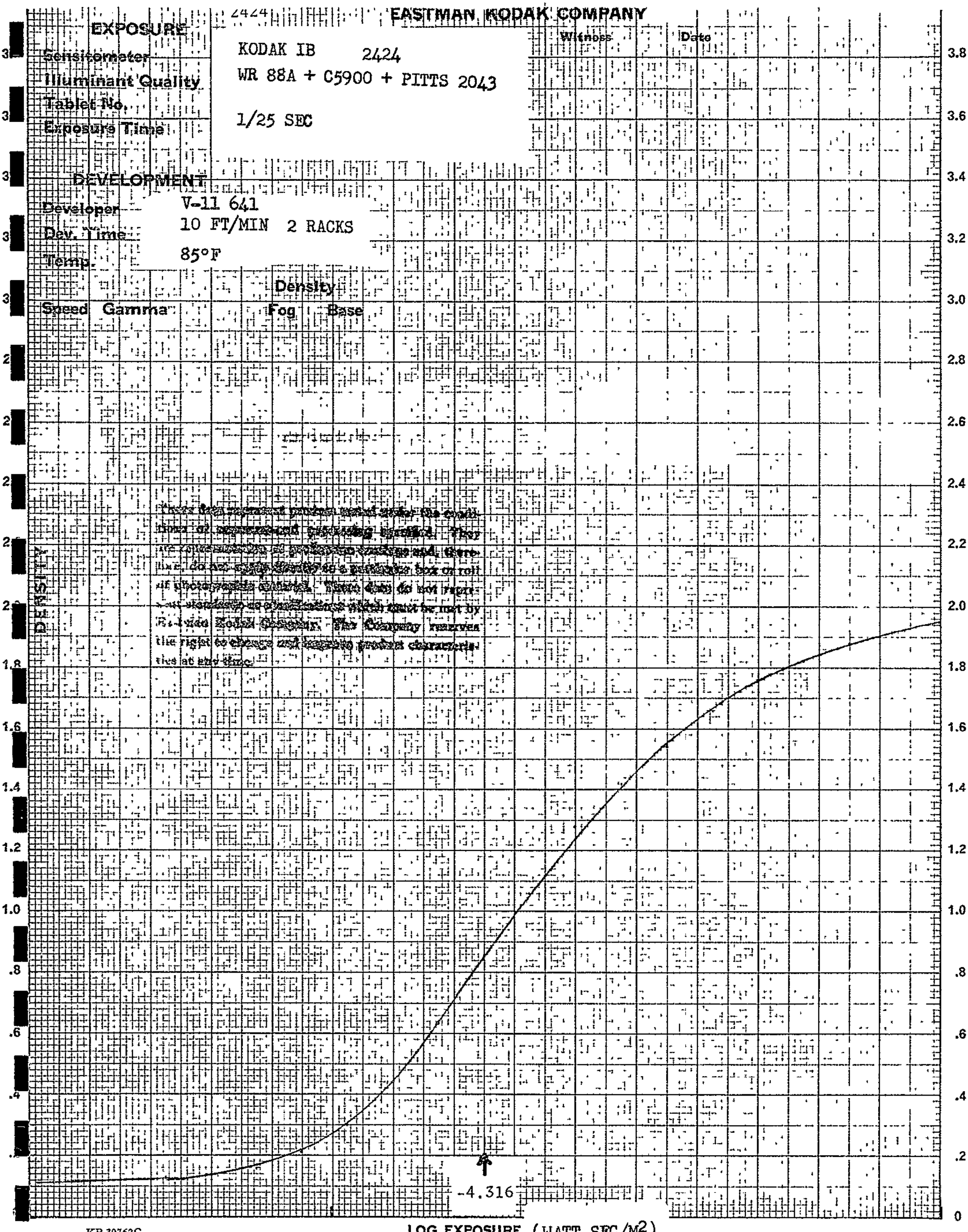
APPENDIX I

Reference Sensitometric Curves

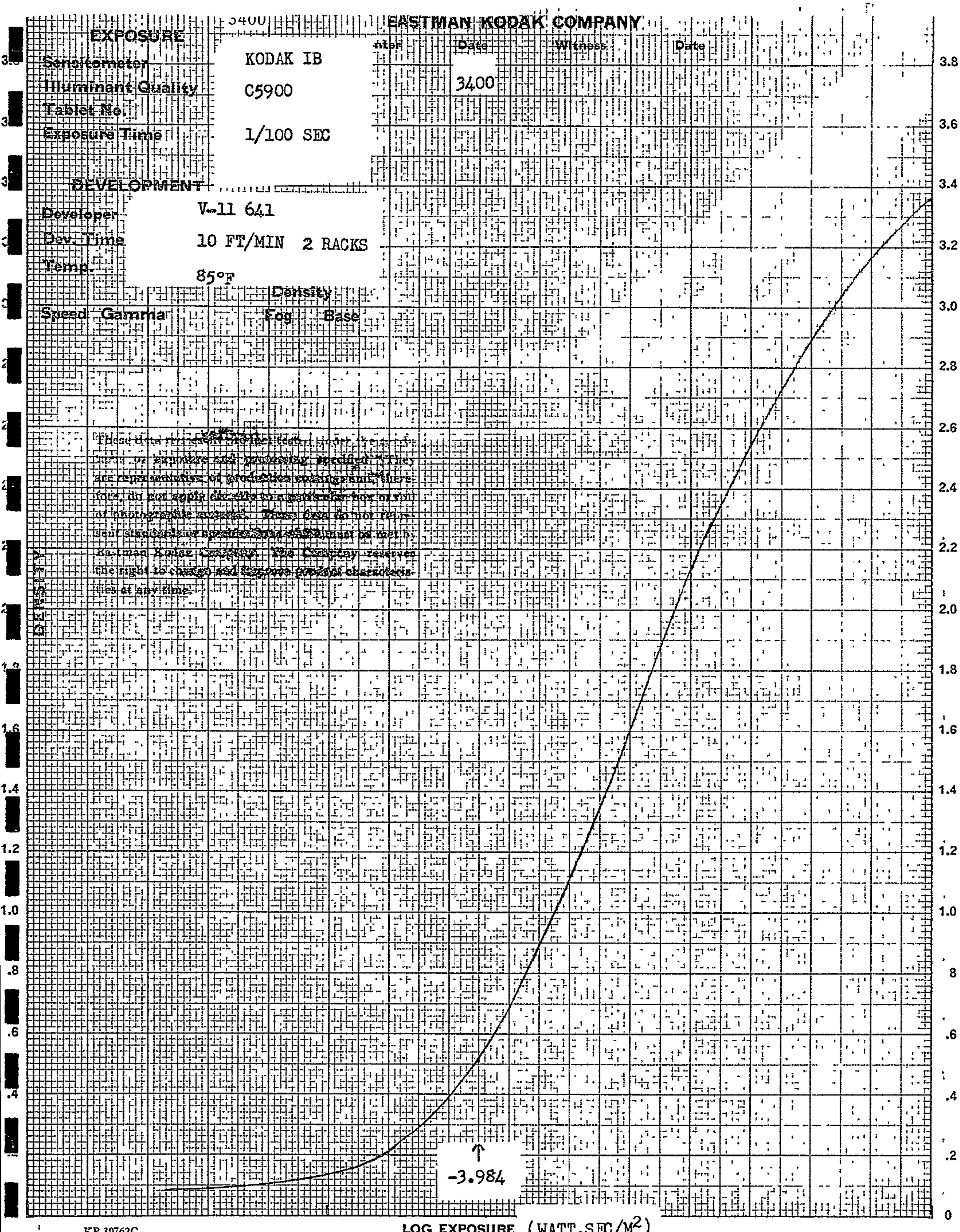

EASTMAN KODAK COMPANY
EXPOSURE
Sensitometer
Illuminant Quality
Tablet No.
Exposure Time
Date
KODAK IB 2402
WR 59A + KODAK DICHROIC 301 (680) + C5900
1/25 SEC
DEVELOPMENT
Developer V-11 641
Dev. Time 10 FT/MIN 2 RACKS
Temp. 85°F
Density
Speed Gamma Fog Base
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
↑
-4.000
KP 39762C
LOG EXPOSURE (WATT.SEC/M2)

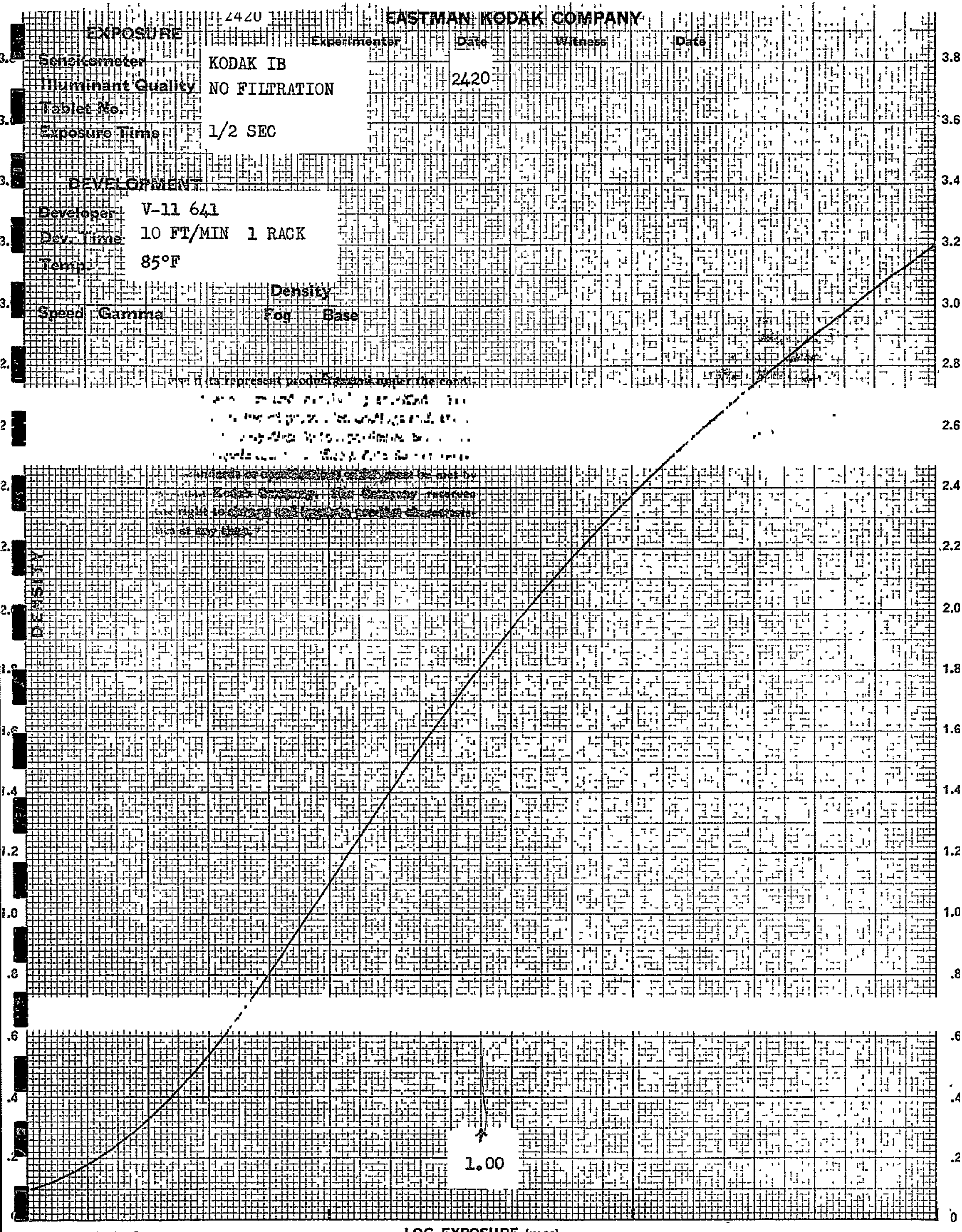

EASTMAN KODAK COMPANY
EXPOSURE
Sensitometer
Illuminant Quality
Tablet No.
Exposure Time
KODAK IB 2402
Wr 23A + KODAK DICHROIC 301 (680) + C5900
1/25 SEC
Date
DEVELOPMENT
Developer
Dev. Time
Temp.
V-11 641
10 FT/MIN 2 RACKS
85°F
Density
Speed Gamma Fog Base
DENSITY
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
-3.932
KP 39762C
LOG EXPOSURE (WATT.SEC/M²)


EASTMAN KODAK COMPANY
EXPOSURE
Sensitometer
Illuminant Quality
Tablet No.
Exposure Time
KODAK IB 2424
WRATTEN 36 + 25 + KODAK DICHROIC 301 (760) + C5900 + PITTS 2043
1/25 SEC
Date
DEVELOPMENT
Developer V-11 641
Dev. Time 10 FT/MIN 2 RACKS
Temp. 85°F
Density
Speed Gamma Fog Base
These data represent product tested under the conditions of exposure and processing specified. They are representative of production coatings and, therefore, do not apply directly to a particular box or roll of photographic material. These data do not represent standards or specifications which must be met by Eastman Kodak Company. The Company reserves the right to change and improve product characteristics at any time.
DENSITY
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR
-4.495
KP 39762C
LOG EXPOSURE (WATT.SEC/M²)

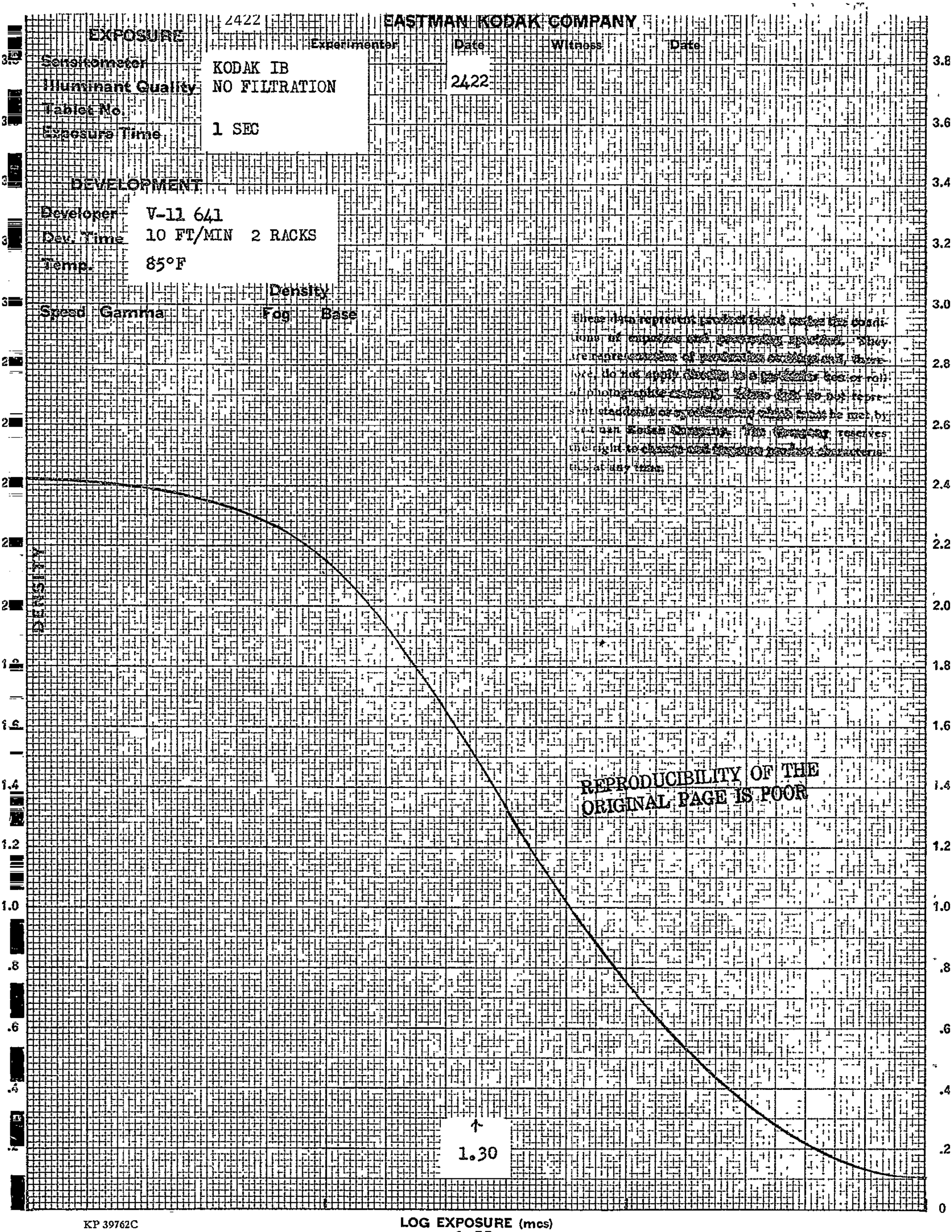


2424
EASTMAN KODAK COMPANY
EXPOSURE
Sensitometer
Illuminant Quality
Tablet No.
Exposure Time
Witness
Date
KODAK IB 2424
WR 88A + C5900 + PITTS 2043
1/25 SEC
DEVELOPMENT
Developer
Dev. Time
Temp.
V-11 641
10 FT/MIN 2 RACKS
85°F
Density
Speed
Gamma
Fog
Base
DENSITY
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
-4.316
KP 39762C
LOG EXPOSURE (WATT.SEC/M^2)

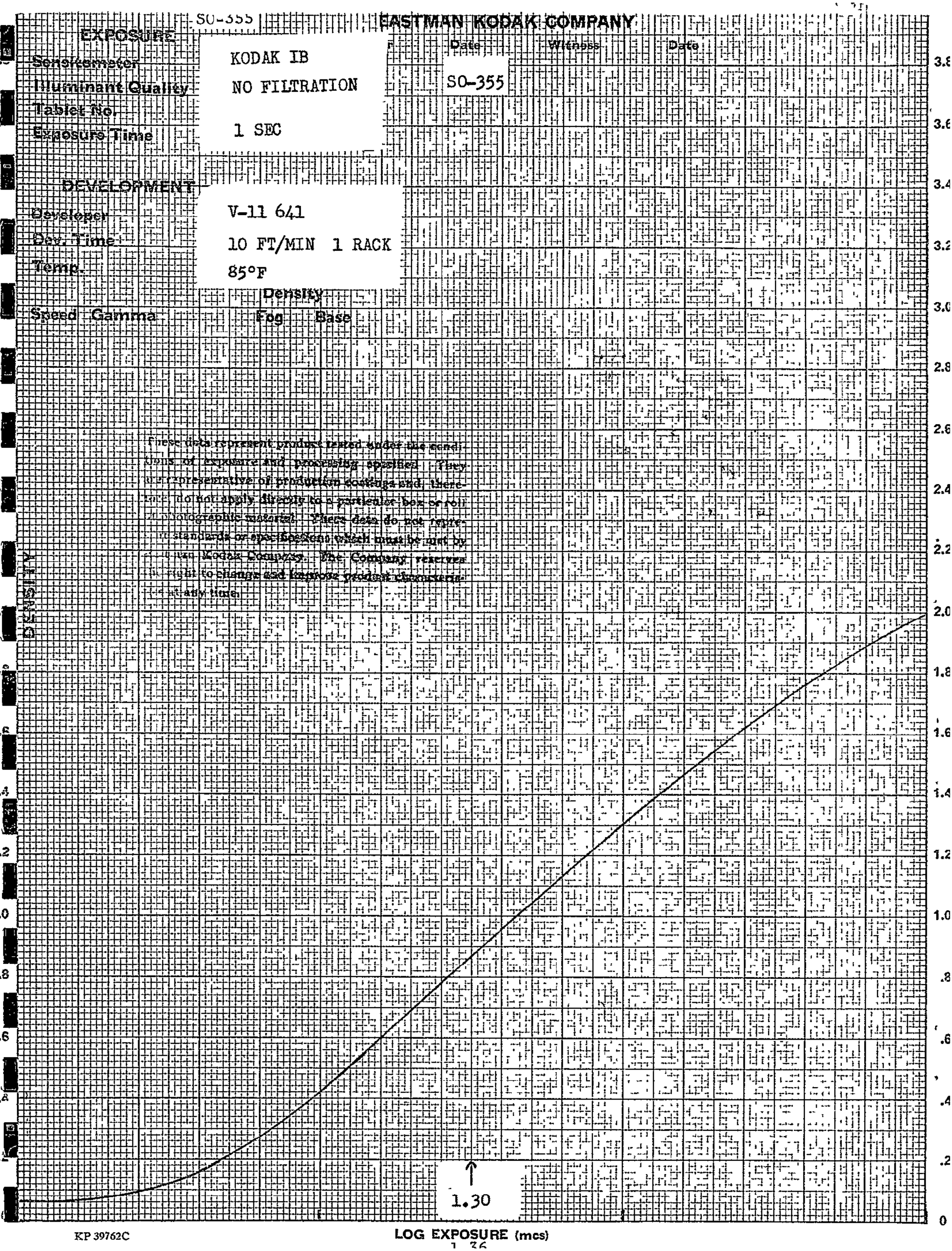

EASTMAN KODAK COMPANY
EXPOSURE
Sensitometer KODAK IB
Illuminant Quality C5900
Tablet No.
Exposure Time 1/100 SEC
3400
DEVELOPMENT
Developer V-11 641
Dev. Time 10 FT/MIN 2 RACKS
Temp. 85°F
Speed Gamma Density Fog Base
Date Witness Date
DENSITY
-3.984
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8 3.0 3.2 3.4 3.6 3.8
LOG EXPOSURE (WATT.SEC/M2)
KP 39762C


2420
EASTMAN KODAK COMPANY
EXPOSURE
Experimenter
Date
Witness
Date
Sensitometer KODAK IB
Illuminant Quality NO FILTRATION
Tablet No.
Exposure Time 1/2 SEC
2420
DEVELOPMENT
Developer V-11 641
Dev. Time 10 FT/MIN 1 RACK
Temp. 85°F
Density
Speed Gamma Fog Base
DENSITY
1.00
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
LOG EXPOSURE (mcs)

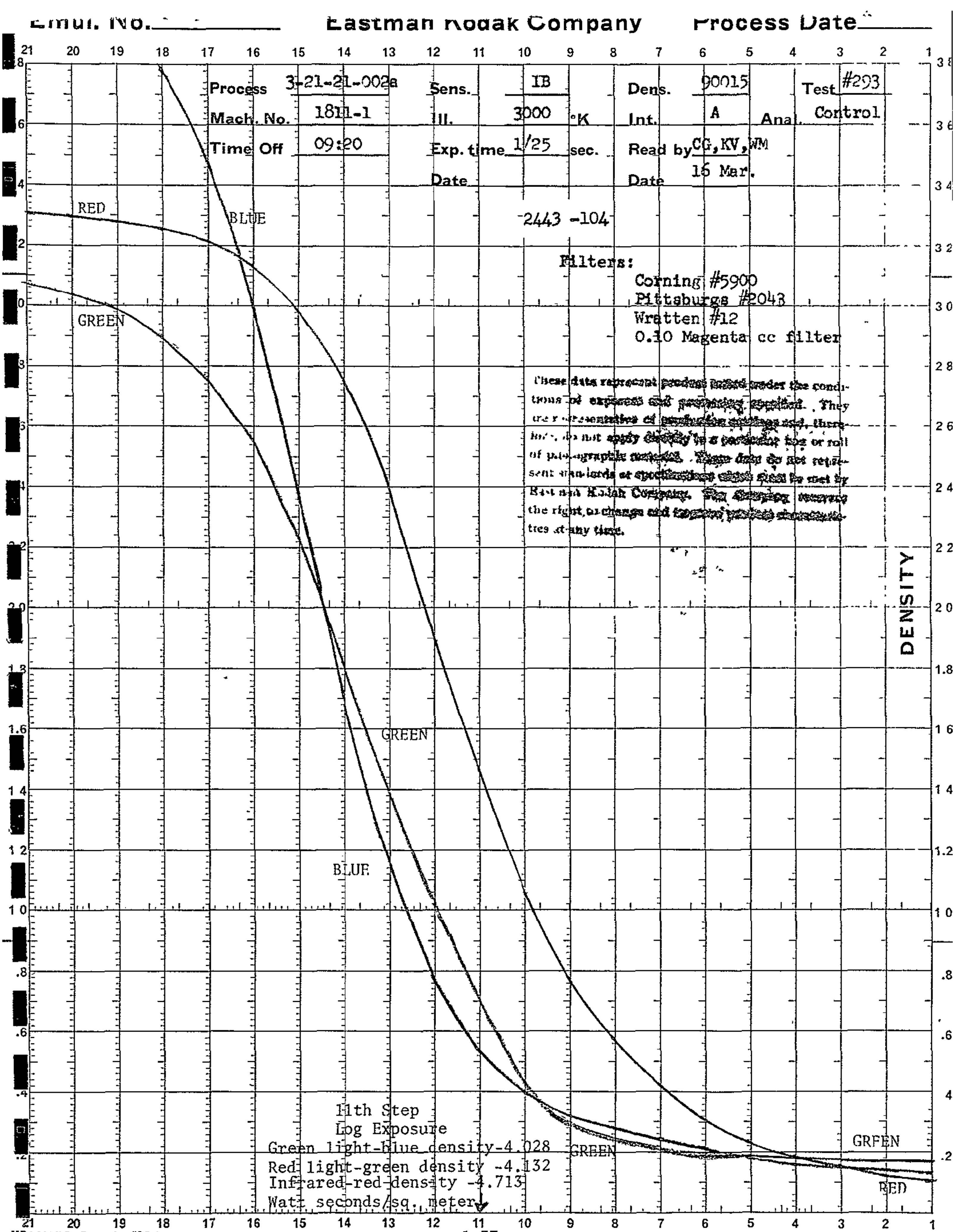
KP 39762C



REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

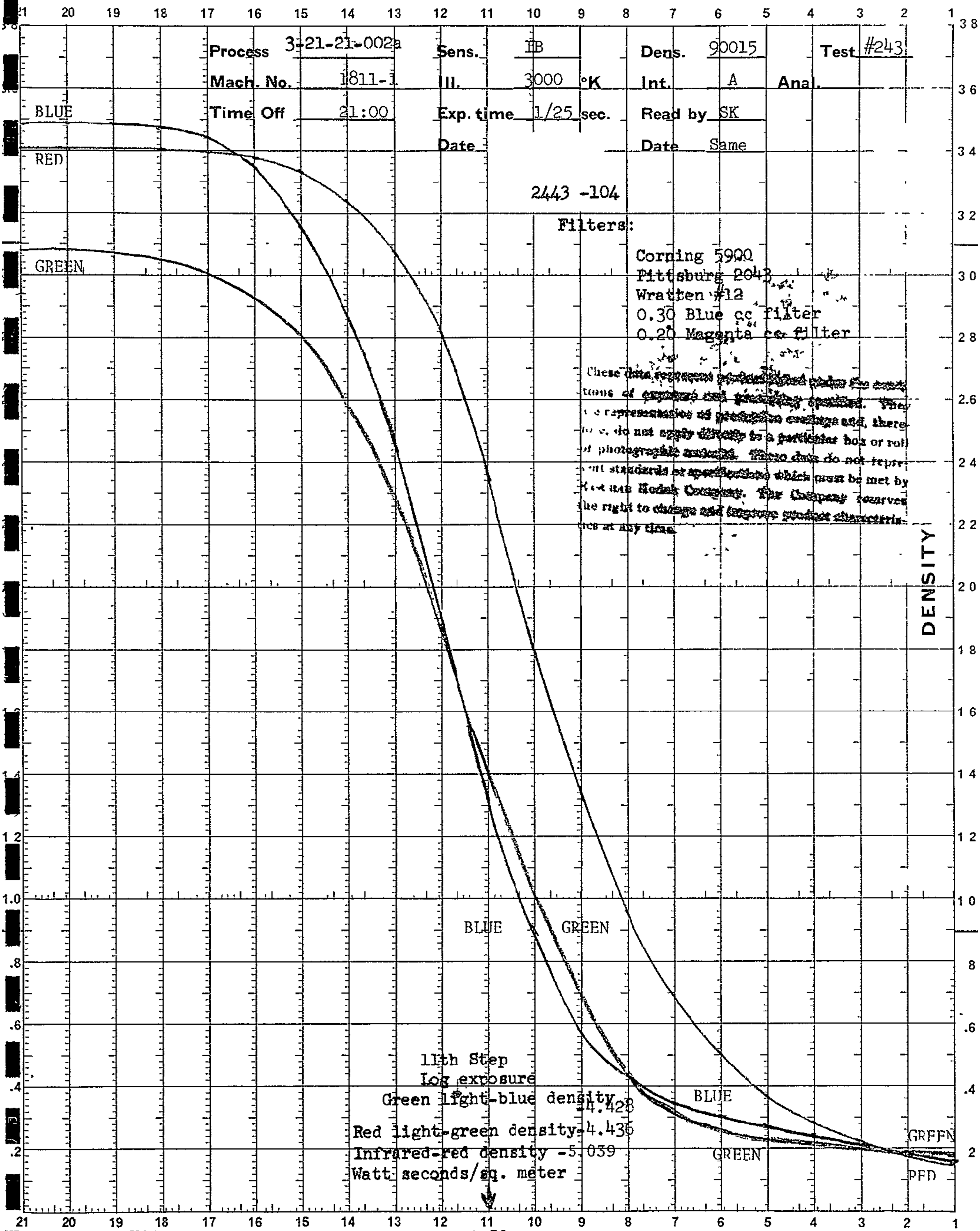

EASTMAN KODAK COMPANY
Date
Witness
Date
EXPOSURE
Sensitometer KODAK IB
Illuminant Quality NO FILTRATION
Tablet No.
Exposure Time 1 SEC
SO-355
DEVELOPMENT
Developer V-11 641
Dev. Time 10 FT/MIN 1 RACK
Temp. 85°F
Density
Speed Gamma Fog Base
These data represent product tested under the conditions of exposure and processing specified. They are representative of production coatings and, therefore, do not apply directly to a particular box or roll of photographic material. These data do not represent standards or specifications which must be met by Eastman Kodak Company. The Company reserves the right to change and improve product characteristics at any time.
DENSITY
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
1.30
LOG EXPOSURE (mcs)

KP 39762C



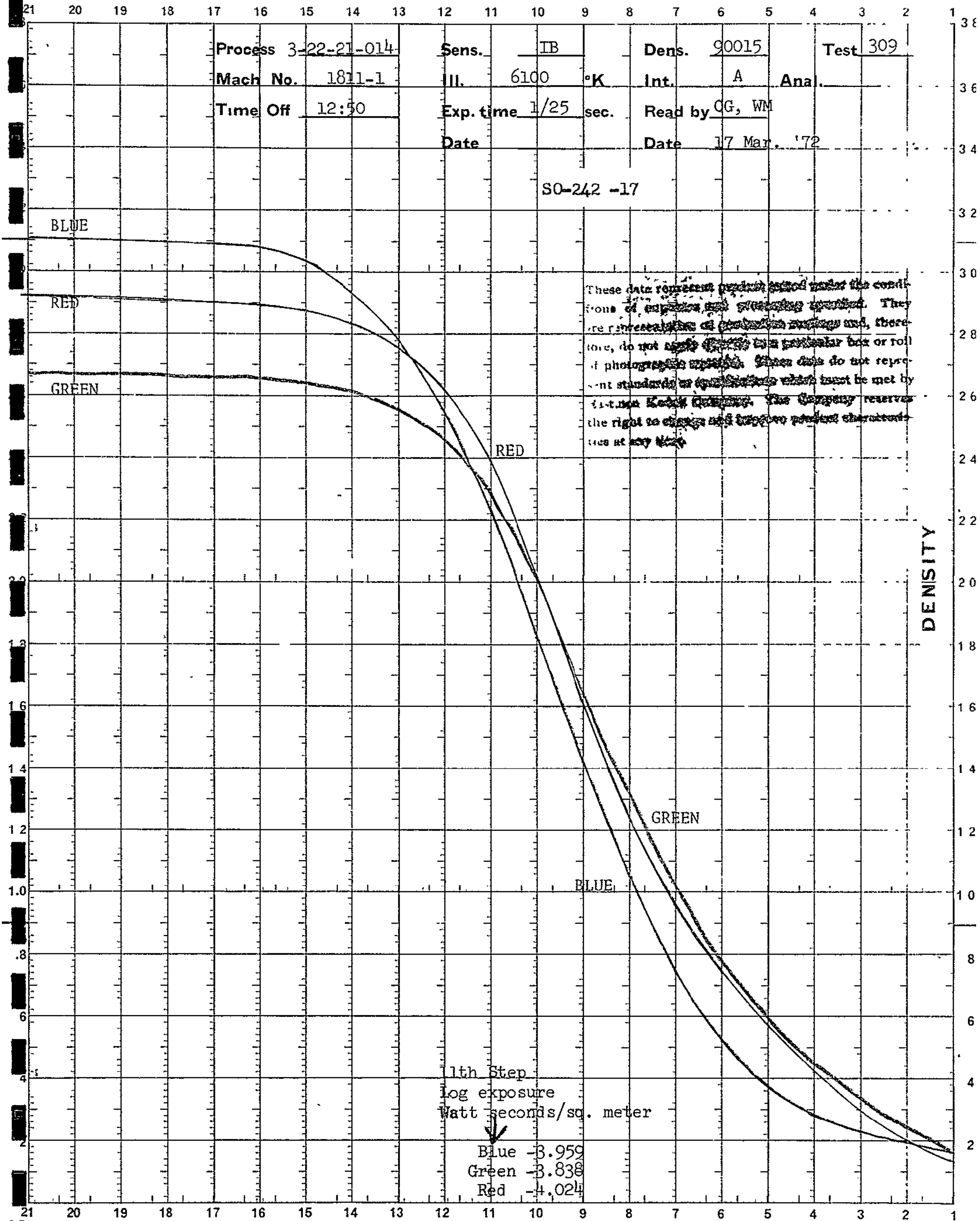
Emul. No.
Eastman Kodak Company
Process Date
Process 3-21-21-002a
Mach. No. 1811-1
Time Off 09:20
Sens. IB
Ill. 3000 °K
Exp. time 1/25 sec.
Date
Dens. 90015
Int. A
Read by CG, KV, WM
Date 16 Mar.
Test #293
Anal. Control
2443 -104
Filters:
Corning #5900
Pittsburgs #2043
Wratten #12
0.10 Magenta cc filter
These data represent product tested under the conditions of exposure and processing specified. They are representative of production coatings and, therefore, do not apply directly to a particular box or roll of photographic material. These data do not represent standards or specifications which must be met by Eastman Kodak Company. The Company reserves the right to change and improve product characteristics at any time.
RED
BLUE
GREEN
GREEN
BLUE
GREEN
GREEN
RED
DENSITY
11th Step
Log Exposure
Green light-blue density-4.028
Red light-green density -4.132
Infrared-red-density -4.713
Watt seconds/sq. meter
KPϕ 39467B Printed in USA

Emul. No. Eastman Kodak Company Process Date



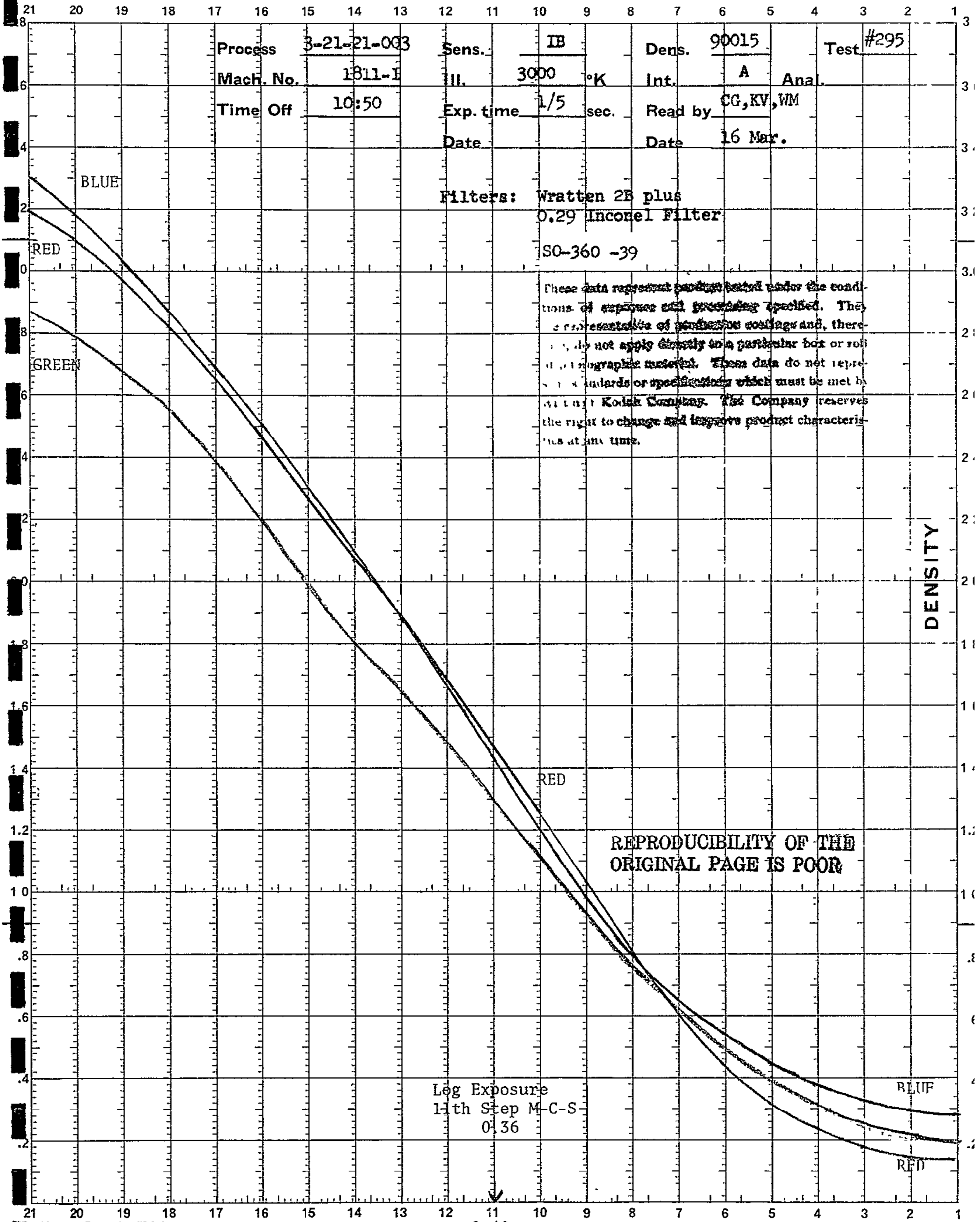
KP# 30467B Printed in U.S.A.

Emul. No. SO-242 -17 Eastman Kodak Company Process Date 17 Mar.



KPφ 39467B Printed in U.S.A.

Emul. No. Eastman Kodak Company Process Date



APPENDIX II

Peak Normalized Spectral
Sensitivities for Ames
ERAP Camera Films

PEAK NORMALIZED SPECTRAL SENSITIVITY: 2402

WAVE GTH	VALUE	LOG OF VALUE	WAVE LGTH	VALUE	LOG OF VALUE	WAVE LGTH	VALUE	LOG OF VALUE
300	3.467E-01	-4.600E-01	535	5.754E-01	-2.400E-01			
305	3.802E-01	-4.200E-01	540	5.888E-01	-2.300E-01			
310	3.802E-01	-4.200E-01	545	6.310E-01	-2.000E-01			
315	4.266E-01	-3.700E-01	550	6.761E-01	-1.700E-01			
320	4.467E-01	-3.500E-01	555	7.413E-01	-1.300E-01			
325	4.571E-01	-3.400E-01	560	8.128E-01	-9.000E-02			
330	4.571E-01	-3.400E-01	565	8.710E-01	-6.000E-02			
335	4.467E-01	-3.500E-01	570	8.913E-01	-5.000E-02			
340	4.074E-01	-3.900E-01	575	8.913E-01	-5.000E-02			
345	3.981E-01	-4.000E-01	580	8.710E-01	-6.000E-02			
350	4.074E-01	-3.900E-01	585	8.128E-01	-9.000E-02			
355	4.266E-01	-3.700E-01	590	7.586E-01	-1.200E-01			
360	4.571E-01	-3.400E-01	595	7.413E-01	-1.300E-01			
365	4.898E-01	-3.100E-01	600	7.244E-01	-1.400E-01			
370	5.248E-01	-2.800E-01	605	6.918E-01	-1.600E-01			
375	5.495E-01	-2.600E-01	610	6.607E-01	-1.800E-01			
380	5.754E-01	-2.400E-01	615	6.310E-01	-2.000E-01			
385	6.166E-01	-2.100E-01	620	5.888E-01	-2.300E-01			
390	6.607E-01	-1.800E-01	625	5.495E-01	-2.600E-01			
39[illegible]	6.918E-01	-1.600E-01	630	5.129E-01	-2.900E-01			
400	7.413E-01	-1.300E-01	635	5.129E-01	-2.900E-01			
405	7.943E-01	-1.000E-01	640	5.370E-01	-2.700E-01			
410	8.511E-01	-7.000E-02	645	5.248E-01	-2.800E-01			
415	8.913E-01	-5.000E-02	650	5.495E-01	-2.600E-01			
420	9.333E-01	-3.000E-02	655	5.623E-01	-2.500E-01			
425	9.772E-01	-1.000E-02	660	6.166E-01	-2.100E-01			
430	1.000E 00	0.0	665	6.457E-01	-1.900E-01			
435	1.000E 00	0.0	670	6.918E-01	-1.600E-01			
440	9.772E-01	-1.000E-02	675	7.413E-01	-1.300E-01			
445	9.550E-01	-2.000E-02	680	7.943E-01	-1.000E-01			
450	9.120E-01	-4.000E-02	685	7.943E-01	-1.000E-01			
455	8.318E-01	-8.000E-02	690	7.413E-01	-1.300E-01			
460	7.586E-01	-1.200E-01	695	6.166E-01	-2.100E-01			
465	6.918E-01	-1.600E-01	700	4.365E-01	-3.600E-01			
470	6.166E-01	-2.100E-01	705	1.995E-01	-7.000E-01			
475	5.495E-01	-2.600E-01	710	8.511E-02	-1.070E 00			
480	5.012E-01	-3.000E-01	715	3.311E-02	-1.480E 00			
485	4.467E-01	-3.500E-01	720	1.905E-03	-2.720E 00			
490	4.169E-01	-3.800E-01						
495	3.981E-01	-4.000E-01						
500	3.981E-01	-4.000E-01						
505	4.169E-01	-3.800E-01						
510	4.467E-01	-3.500E-01						
515	4.677E-01	-3.300E-01						
52[illegible]	5.012E-01	-3.000E-01						
525	5.248E-01	-2.800E-01						
530	5.495E-01	-2.600E-01						

PEAK NORMALIZED SPECTRAL SENSITIVITY: 2424

WAVE [redacted]TH	VALUE	LOG OF VALUE	WAVE LGTH	VALUE	LOG OF VALUE	WAVE LGTH	VALUE	LOG OF VALUE
300	3.631E-01	-4.400E-01	535	3.090E-02	-1.510E 00	770	2.630E-01	-5.800E-01
[redacted]5	3.548E-01	-4.500E-01	540	3.631E-02	-1.440E 00	775	2.692E-01	-5.700E-01
[redacted]0	3.467E-01	-4.600E-01	545	4.266E-02	-1.370E 00	780	2.754E-01	-5.600E-01
315	3.350E-01	-4.750E-01	550	5.012E-02	-1.300E 00	785	2.818E-01	-5.500E-01
320	3.236E-01	-4.900E-01	555	5.623E-02	-1.250E 00	790	2.884E-01	-5.400E-01
[redacted]5	3.428E-01	-4.650E-01	560	6.310E-02	-1.200E 00	795	2.917E-01	-5.350E-01
[redacted]0	3.631E-01	-4.400E-01	565	6.998E-02	-1.155E 00	800	2.951E-01	-5.300E-01
335	4.121E-01	-3.850E-01	570	7.762E-02	-1.110E 00	805	2.917E-01	-5.350E-01
[redacted]0	4.677E-01	-3.300E-01	575	8.318E-02	-1.080E 00	810	2.884E-01	-5.400E-01
[redacted]5	5.432E-01	-2.650E-01	580	8.913E-02	-1.050E 00	815	2.851E-01	-5.450E-01
350	6.310E-01	-2.000E-01	585	9.550E-02	-1.020E 00	820	2.818E-01	-5.500E-01
[redacted]5	6.918E-01	-1.600E-01	590	1.023E-01	-9.900E-01	825	2.754E-01	-5.600E-01
[redacted]0	7.586E-01	-1.200E-01	595	1.084E-01	-9.650E-01	830	2.692E-01	-5.700E-01
365	8.128E-01	-9.000E-02	600	1.148E-01	-9.400E-01	835	2.661E-01	-5.750E-01
370	8.710E-01	-6.000E-02	605	1.189E-01	-9.250E-01	840	2.630E-01	-5.800E-01
[redacted]5	9.016E-01	-4.500E-02	610	1.230E-01	-9.100E-01	845	2.570E-01	-5.900E-01
[redacted]0	9.333E-01	-3.000E-02	615	1.274E-01	-8.950E-01	850	2.512E-01	-6.000E-01
385	9.550E-01	-2.000E-02	620	1.318E-01	-8.800E-01	855	2.427E-01	-6.150E-01
[redacted]	9.772E-01	-1.000E-02	625	1.365E-01	-8.650E-01	860	2.344E-01	-6.300E-01
[redacted]	9.886E-01	-5.000E-03	630	1.413E-01	-8.500E-01	865	2.427E-01	-6.150E-01
400	1.000E 00	0.0	635	1.429E-01	-8.450E-01	870	2.512E-01	-6.000E-01
[redacted]5	9.772E-01	-1.000E-02	640	1.445E-01	-8.400E-01	875	2.570E-01	-5.900E-01
[redacted]0	9.550E-01	-2.000E-02	645	1.462E-01	-8.350E-01	880	2.630E-01	-5.800E-01
415	9.441E-01	-2.500E-02	650	1.479E-01	-8.300E-01	885	2.483E-01	-6.050E-01
420	9.333E-01	-3.000E-02	655	1.496E-01	-8.250E-01	890	2.344E-01	-6.300E-01
[redacted]5	9.016E-01	-4.500E-02	660	1.514E-01	-8.200E-01	895	1.972E-01	-7.050E-01
[redacted]0	8.710E-01	-6.000E-02	665	1.549E-01	-8.100E-01	900	1.660E-01	-7.800E-01
435	8.222E-01	-8.500E-02	670	1.585E-01	-8.000E-01	905	1.230E-01	-9.100E-01
[redacted]0	7.762E-01	-1.100E-01	675	1.622E-01	-7.900E-01	910	9.120E-02	-1.040E 00
[redacted]5	7.413E-01	-1.300E-01	680	1.660E-01	-7.800E-01	915	6.457E-02	-1.190E 00
450	7.079E-01	-1.500E-01	685	1.718E-01	-7.650E-01	920	4.571E-02	-1.340E 00
455	6.383E-01	-1.950E-01	690	1.778E-01	-7.500E-01	925	2.541E-02	-1.595E 00
[redacted]0	5.754E-01	-2.400E-01	695	1.799E-01	-7.450E-01	930	1.413E-02	-1.850E 00
[redacted]5	5.070E-01	-2.950E-01	700	1.820E-01	-7.400E-01	935	6.998E-03	-2.155E 00
470	4.467E-01	-3.500E-01	705	1.928E-01	-7.150E-01	940	3.467E-03	-2.460E 00
[redacted]5	3.508E-01	-4.550E-01	710	2.042E-01	-6.900E-01	945	1.549E-03	-2.810E 00
[redacted]0	2.754E-01	-5.600E-01	715	2.113E-01	-6.750E-01	950	6.918E-04	-3.160E 00
485	2.113E-01	-6.750E-01	720	2.188E-01	-6.600E-01			
[redacted]0	1.622E-01	-7.900E-01	725	2.291E-01	-6.400E-01			
[redacted]5	1.135E-01	-9.450E-01	730	2.399E-01	-6.200E-01			
500	7.943E-02	-1.100E 00	735	2.483E-01	-6.050E-01			
505	5.689E-02	-1.245E 00	740	2.570E-01	-5.900E-01			
[redacted]0	4.074E-02	-1.390E 00	745	2.512E-01	-6.000E-01			
[redacted]5	3.236E-02	-1.490E 00	750	2.455E-01	-6.100E-01			
520	2.570E-02	-1.590E 00	755	2.455E-01	-6.100E-01			
[redacted]5	2.600E-02	-1.585E 00	760	2.455E-01	-6.100E-01			
[redacted]0	2.630E-02	-1.580E 00	765	2.541E-01	-5.950E-01			

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

3/20/72

PEAK NORMALIZED SPECTRAL SENSITIVITY: 3400

WAVE LGTH	VALUE	LOG OF VALUE	WAVE LGTH	VALUE	LOG OF VALUE	WAVE LGTH	VALUE	LOG OF VALUE
300	4.027E-01	-3.950E-01	535	4.955E-01	-3.050E-01			
305	4.519E-01	-3.450E-01	540	5.070E-01	-2.950E-01			
310	4.732E-01	-3.250E-01	545	5.370E-01	-2.700E-01			
315	4.955E-01	-3.050E-01	550	5.623E-01	-2.500E-01			
320	5.012E-01	-3.000E-01	555	5.888E-01	-2.300E-01			
325	5.559E-01	-2.550E-01	560	6.237E-01	-2.050E-01			
330	6.095E-01	-2.150E-01	565	6.761E-01	-1.700E-01			
335	6.683E-01	-1.750E-01	570	6.839E-01	-1.650E-01			
340	7.161E-01	-1.450E-01	575	6.457E-01	-1.900E-01			
345	7.852E-01	-1.050E-01	580	6.026E-01	-2.200E-01			
350	8.222E-01	-8.500E-02	585	5.623E-01	-2.500E-01			
355	8.610E-01	-6.500E-02	590	5.433E-01	-2.650E-01			
360	9.016E-01	-4.500E-02	595	5.188E-01	-2.850E-01			
365	9.333E-01	-3.000E-02	600	5.188E-01	-2.850E-01			
370	9.550E-01	-2.000E-02	605	5.070E-01	-2.950E-01			
375	9.772E-01	-1.000E-02	610	4.677E-01	-3.300E-01			
380	9.886E-01	-5.000E-03	615	4.121E-01	-3.850E-01			
385	9.886E-01	-5.000E-03	620	3.589E-01	-4.450E-01			
390	1.000E 00	0.0	625	3.428E-01	-4.650E-01			
395	9.886E-01	-5.000E-03	630	3.273E-01	-4.850E-01			
400	9.886E-01	-5.000E-03	635	3.236E-01	-4.900E-01			
405	9.661E-01	-1.500E-02	640	3.273E-01	-4.850E-01			
410	9.333E-01	-3.000E-02	645	3.388E-01	-4.700E-01			
415	9.016E-01	-4.500E-02	650	3.673E-01	-4.350E-01			
420	8.810E-01	-5.500E-02	655	4.217E-01	-3.750E-01			
425	8.610E-01	-6.500E-02	660	4.624E-01	-3.350E-01			
430	8.222E-01	-8.500E-02	665	5.070E-01	-2.950E-01			
435	7.852E-01	-1.050E-01	670	5.559E-01	-2.550E-01			
440	7.328E-01	-1.350E-01	675	6.095E-01	-2.150E-01			
445	6.998E-01	-1.550E-01	680	6.531E-01	-1.850E-01			
450	6.531E-01	-1.850E-01	685	6.998E-01	-1.550E-01			
455	6.095E-01	-2.150E-01	690	7.499E-01	-1.250E-01			
460	5.623E-01	-2.500E-01	695	7.413E-01	-1.300E-01			
465	5.188E-01	-2.850E-01	700	4.121E-01	-3.850E-01			
470	5.070E-01	-2.950E-01	705	2.065E-01	-6.850E-01			
475	4.315E-01	-3.650E-01	710	8.222E-02	-1.085E 00			
480	4.121E-01	-3.850E-01	715	3.936E-02	-1.405E 00			
485	3.846E-01	-4.150E-01						
490	3.715E-01	-4.300E-01						
495	3.589E-01	-4.450E-01						
500	3.589E-01	-4.450E-01						
505	3.715E-01	-4.300E-01						
510	3.936E-01	-4.050E-01						
515	4.121E-01	-3.850E-01						
520	4.315E-01	-3.650E-01						
525	4.416E-01	-3.550E-01						
530	4.624E-01	-3.350E-01						

PEAK NORMALIZED SPECTRAL SENSITIVITY: 2443 GREEN

WAVE [redacted]H	VALUE	LOG OF VALUE	WAVE LGTH	VALUE	LOG OF VALUE	WAVE LGTH	VALUE	LOG OF VALUE
			535	9.550E-01	-2.000E-02			
			540	9.772E-01	-1.000E-02			
			545	1.000E 00	0.0			
			550	1.000E 00	0.0			
			555	9.772E-01	-1.000E-02			
			560	9.550E-01	-2.000E-02			
			565	8.913E-01	-5.000E-02			
			570	7.943E-01	-1.000E-01			
			575	6.166E-01	-2.100E-01			
			580	3.236E-01	-4.900E-01			
			585	1.318E-01	-8.800E-01			
			590	5.248E-02	-1.280E 00			
			595	2.344E-02	-1.630E 00			
			600	1.122E-02	-1.950E 00			
			605	6.457E-03	-2.190E 00			
			610	3.548E-03	-2.450E 00			
400	6.457E-01	-1.900E-01						
405	6.918E-01	-1.600E-01						
4[redacted]0	7.413E-01	-1.300E-01						
4[redacted]5	7.762E-01	-1.100E-01						
420	8.128E-01	-9.000E-02						
4[redacted]5	8.318E-01	-8.000E-02						
4[redacted]0	8.511E-01	-7.000E-02						
435	8.710E-01	-6.000E-02						
4[redacted]0	8.710E-01	-6.000E-02						
4[redacted]5	8.511E-01	-7.000E-02						
450	8.318E-01	-8.000E-02						
455	7.943E-01	-1.000E-01						
4[redacted]0	7.762E-01	-1.100E-01						
4[redacted]5	7.413E-01	-1.300E-01						
470	6.918E-01	-1.600E-01						
4[redacted]5	6.457E-01	-1.900E-01						
4[redacted]0	6.166E-01	-2.100E-01						
485	5.623E-01	-2.500E-01						
4[redacted]0	5.370E-01	-2.700E-01						
4[redacted]5	5.370E-01	-2.700E-01						
500	5.754E-01	-2.400E-01						
505	6.310E-01	-2.000E-01						
5[redacted]0	6.918E-01	-1.600E-01						
5[redacted]5	7.413E-01	-1.300E-01						
52'	8.128E-01	-9.000E-02						
5[redacted]5	8.511E-01	-7.000E-02						
5[redacted]0	9.120E-01	-4.000E-02						

PEAK NORMALIZED SPECTRAL SENSITIVITY: 2443 RED

WAVE LGTH	VALUE	LOG OF VALUE	WAVE LGTH	VALUE	LOG OF VALUE	WAVE LGTH	VALUE	LOG OF VALUE
			535	2.399E-02	-1.620E 00			
			540	2.630E-02	-1.580E 00			
			545	2.951E-02	-1.530E 00			
			550	3.467E-02	-1.460E 00			
			555	4.169E-02	-1.380E 00			
			560	5.012E-02	-1.300E 00			
			565	6.026E-02	-1.220E 00			
			570	7.413E-02	-1.130E 00			
			575	9.333E-02	-1.030E 00			
			580	1.148E-01	-9.400E-01			
			585	1.349E-01	-8.700E-01			
			590	1.585E-01	-8.000E-01			
			595	1.820E-01	-7.400E-01			
			600	2.138E-01	-6.700E-01			
			605	2.399E-01	-6.200E-01			
			610	2.818E-01	-5.500E-01			
			615	3.388E-01	-4.700E-01			
			620	4.074E-01	-3.900E-01			
			625	4.898E-01	-3.100E-01			
			630	5.888E-01	-2.300E-01			
400	1.259E-01	-9.000E-01	635	7.244E-01	-1.400E-01			
405	1.318E-01	-8.800E-01	640	8.318E-01	-8.000E-02			
410	1.445E-01	-8.400E-01	645	9.333E-01	-3.000E-02			
415	1.514E-01	-8.200E-01	650	1.000E 00	0.0			
420	1.585E-01	-8.000E-01	655	8.913E-01	-5.000E-02			
425	1.660E-01	-7.800E-01	660	6.166E-01	-2.100E-01			
430	1.738E-01	-7.600E-01	665	3.162E-01	-5.000E-01			
435	1.778E-01	-7.500E-01	670	1.047E-01	-9.800E-01			
440	1.820E-01	-7.400E-01	675	3.631E-02	-1.440E 00			
445	1.778E-01	-7.500E-01	680	1.738E-02	-1.760E 00			
450	1.778E-01	-7.500E-01	685	8.710E-03	-2.060E 00			
455	1.698E-01	-7.700E-01	690	4.571E-03	-2.340E 00			
460	1.549E-01	-8.100E-01						
465	1.445E-01	-8.400E-01						
470	1.288E-01	-8.900E-01						
475	1.096E-01	-9.600E-01						
480	9.120E-02	-1.040E 00						
485	7.413E-02	-1.130E 00						
490	5.754E-02	-1.240E 00						
495	4.266E-02	-1.370E 00						
500	3.548E-02	-1.450E 00						
505	3.020E-02	-1.520E 00						
510	2.692E-02	-1.570E 00						
515	2.399E-02	-1.620E 00						
52	2.239E-02	-1.650E 00						
525	2.239E-02	-1.650E 00						
530	2.291E-02	-1.640E 00						

PEAK NORMALIZED SPECTRAL SENSITIVITY: 2443 INFRARED

WAVE LGTH	VALUE	LOG OF VALUE
400	8.318E-01	-8.000E-02
4[redacted]5	8.913E-01	-5.000E-02
[redacted]0	9.772E-01	-1.000E-02
[redacted]5	1.000E 00	0.0
420	9.120E-01	-4.000E-02
[redacted]5	8.710E-01	-6.000E-02
[redacted]0	8.128E-01	-9.000E-02
435	7.586E-01	-1.200E-01
[redacted]0	6.918E-01	-1.600E-01
[redacted]5	6.166E-01	-2.100E-01
450	5.370E-01	-2.700E-01
455	4.677E-01	-3.300E-01
[redacted]0	3.890E-01	-4.100E-01
[redacted]5	3.311E-01	-4.800E-01
470	2.692E-01	-5.700E-01
[redacted]5	2.239E-01	-6.500E-01
[redacted]0	1.778E-01	-7.500E-01
485	1.380E-01	-8.600E-01
4[redacted]0	1.000E-01	-1.000E 00
[redacted]5	7.244E-02	-1.140E 00
[redacted]	5.623E-02	-1.250E 00
505	4.571E-02	-1.340E 00
[redacted]0	3.715E-02	-1.430E 00
[redacted]5	3.631E-02	-1.440E 00
52	4.074E-02	-1.390E 00
[redacted]5	5.754E-02	-1.240E 00
[redacted]0	7.413E-02	-1.130E 00
535	5.370E-02	-1.270E 00
540	3.631E-02	-1.440E 00
545	3.020E-02	-1.520E 00
550	2.884E-02	-1.540E 00
555	2.951E-02	-1.530E 00
560	3.020E-02	-1.520E 00
565	3.162E-02	-1.500E 00
570	3.388E-02	-1.470E 00
575	3.631E-02	-1.440E 00
580	3.802E-02	-1.420E 00
585	4.074E-02	-1.390E 00
590	4.266E-02	-1.370E 00
595	4.467E-02	-1.350E 00
600	4.786E-02	-1.320E 00
605	5.012E-02	-1.300E 00
610	5.248E-02	-1.280E 00
615	5.495E-02	-1.260E 00
620	5.754E-02	-1.240E 00
625	6.026E-02	-1.220E 00
630	6.310E-02	-1.200E 00
635	6.607E-02	-1.180E 00
640	6.918E-02	-1.160E 00
645	7.244E-02	-1.140E 00
650	7.586E-02	-1.120E 00
655	7.943E-02	-1.100E 00
660	8.318E-02	-1.080E 00
665	8.710E-02	-1.060E 00
670	9.120E-02	-1.040E 00
675	9.550E-02	-1.020E 00
680	1.000E-01	-1.000E 00
685	1.023E-01	-9.900E-01
690	1.072E-01	-9.700E-01
695	1.096E-01	-9.600E-01
700	1.148E-01	-9.400E-01
705	1.175E-01	-9.300E-01
710	1.202E-01	-9.200E-01
715	1.259E-01	-9.000E-01
720	1.259E-01	-9.000E-01
725	1.288E-01	-8.900E-01
730	1.318E-01	-8.800E-01
735	1.318E-01	-8.800E-01
740	1.288E-01	-8.900E-01
745	1.230E-01	-9.100E-01
750	1.175E-01	-9.300E-01
755	1.096E-01	-9.600E-01
760	1.047E-01	-9.800E-01
765	1.000E-01	-1.000E 00
770	9.550E-02	-1.020E 00
775	9.333E-02	-1.030E 00
780	9.120E-02	-1.040E 00
785	9.120E-02	-1.040E 00
790	9.120E-02	-1.040E 00
795	9.120E-02	-1.040E 00
800	8.913E-02	-1.050E 00
805	8.710E-02	-1.060E 00
810	8.511E-02	-1.070E 00
815	8.318E-02	-1.080E 00
820	8.128E-02	-1.090E 00
825	7.762E-02	-1.110E 00
830	7.413E-02	-1.130E 00
835	7.079E-02	-1.150E 00
840	6.761E-02	-1.170E 00
845	6.310E-02	-1.200E 00
850	5.888E-02	-1.230E 00
855	5.370E-02	-1.270E 00
860	4.786E-02	-1.320E 00
865	4.074E-02	-1.390E 00
870	3.388E-02	-1.470E 00
875	2.692E-02	-1.570E 00
880	1.995E-02	-1.700E 00
885	1.445E-02	-1.840E 00
890	9.120E-03	-2.040E 00

PEAK NORMALIZED SPECTRAL SENSITIVITY: SO-242 BLUE

WAVE LGTH	VALUE	LOG OF VALUE	WAVE LGTH	VALUE	LOG OF VALUE	WAVE LGTH	VALUE	LOG OF VALUE
			535	5.751E-03	-2.240E 00			
			540	3.499E-03	-2.456E 00			
			545	1.930E-03	-2.714E 00			
			550	1.108E-03	-2.955E 00			
365	8.760E-04	-3.057E 00						
370	1.455E-03	-2.837E 00						
375	2.703E-03	-2.568E 00						
380	4.166E-03	-2.380E 00						
385	7.388E-03	-2.131E 00						
390	1.890E-02	-1.724E 00						
395	4.375E-02	-1.359E 00						
400	8.700E-02	-1.060E 00						
405	1.470E-01	-8.327E-01						
410	3.436E-01	-4.639E-01						
415	5.444E-01	-2.641E-01						
420	7.613E-01	-1.184E-01						
425	9.307E-01	-3.119E-02						
430	1.000E 00	0.0						
435	9.126E-01	-3.972E-02						
440	7.861E-01	-1.045E-01						
445	6.808E-01	-1.670E-01						
450	5.778E-01	-2.382E-01						
455	5.046E-01	-2.971E-01						
460	4.355E-01	-3.610E-01						
465	3.867E-01	-4.126E-01						
470	3.410E-01	-4.672E-01						
475	2.974E-01	-5.267E-01						
480	2.700E-01	-5.686E-01						
485	2.366E-01	-6.260E-01						
490	2.083E-01	-6.813E-01						
495	1.753E-01	-7.562E-01						
500	1.469E-01	-8.330E-01						
505	1.136E-01	-9.446E-01						
510	8.354E-02	-1.078E 00						
515	5.943E-02	-1.226E 00						
520	3.790E-02	-1.421E 00						
525	1.928E-02	-1.715E 00						
530	1.135E-02	-1.945E 00						

PEAK NORMALIZED SPECTRAL SENSITIVITY: SO-242 GREEN

[redacted]	VALUE	LOG OF VALUE	WAVE LGTH	VALUE	LOG OF VALUE	WAVE LGTH	VALUE	LOG OF VALUE
			535	8.007E-01	-9.651E-02			
			540	9.075E-01	-4.215E-02			
			545	9.808E-01	-8.441E-03			
			550	1.000E 00	0.0			
			555	9.015E-01	-4.502E-02			
			560	8.302E-01	-8.081E-02			
			565	7.283E-01	-1.377E-01			
			570	6.479E-01	-1.885E-01			
			575	5.107E-01	-2.918E-01			
			580	3.777E-01	-4.229E-01			
			585	1.933E-01	-7.138E-01			
			590	4.813E-02	-1.318E 00			
			595	8.610E-03	-2.065E 00			
			600	3.827E-03	-2.417E 00			
[redacted]	3.446E-03	-2.463E 00						
400	5.600E-03	-2.252E 00						
405	1.024E-02	-1.990E 00						
[redacted]	2.389E-02	-1.622E 00						
415	4.606E-02	-1.337E 00						
420	6.500E-02	-1.187E 00						
[redacted]	7.682E-02	-1.115E 00						
[redacted]	8.085E-02	-1.092E 00						
435	7.583E-02	-1.120E 00						
[redacted]	6.828E-02	-1.166E 00						
[redacted]	5.789E-02	-1.237E 00						
450	5.165E-02	-1.287E 00						
455	4.649E-02	-1.333E 00						
[redacted]	4.455E-02	-1.351E 00						
465	4.425E-02	-1.354E 00						
470	4.579E-02	-1.339E 00						
[redacted]	4.985E-02	-1.302E 00						
[redacted]	5.845E-02	-1.233E 00						
485	6.815E-02	-1.167E 00						
490	8.283E-02	-1.082E 00						
[redacted]	1.066E-01	-9.723E-01						
500	1.366E-01	-8.647E-01						
505	1.760E-01	-7.546E-01						
[redacted]	2.248E-01	-6.482E-01						
[redacted]	3.118E-01	-5.061E-01						
52	3.819E-01	-4.180E-01						
[redacted]	5.111E-01	-2.915E-01						
[redacted]	6.492E-01	-1.876E-01						

PEAK NORMALIZED SPECTRAL SENSITIVITY: SO-242 RED

WAVE LGTH	VALUE	LOG OF VALUE	WAVE LGTH	VALUE	LOG OF VALUE	WAVE LGTH	VALUE	LOG OF VALUE
			535	1.075E-02	-1.969E 00			
			540	1.233E-02	-1.909E 00			
			545	1.475E-02	-1.831E 00			
			550	1.719E-02	-1.765E 00			
			555	2.086E-02	-1.681E 00			
			560	2.505E-02	-1.601E 00			
			565	2.958E-02	-1.529E 00			
			570	3.793E-02	-1.421E 00			
			575	4.647E-02	-1.333E 00			
			580	5.937E-02	-1.226E 00			
			585	7.311E-02	-1.136E 00			
			590	8.978E-02	-1.047E 00			
			595	1.210E-01	-9.172E-01			
			600	1.503E-01	-8.230E-01			
			605	1.845E-01	-7.340E-01			
			610	2.411E-01	-6.178E-01			
			615	3.163E-01	-4.999E-01			
385	2.314E-03	-2.636E 00	620	3.956E-01	-4.027E-01			
390	2.839E-03	-2.547E 00	625	4.718E-01	-3.262E-01			
395	3.369E-03	-2.472E 00	630	6.280E-01	-2.020E-01			
400	4.062E-03	-2.391E 00	635	7.668E-01	-1.153E-01			
405	5.024E-03	-2.299E 00	640	8.840E-01	-5.355E-02			
410	6.338E-03	-2.198E 00	645	9.679E-01	-1.417E-02			
415	7.557E-03	-2.122E 00	650	1.000E 00	0.0			
420	9.198E-03	-2.036E 00	655	9.070E-01	-4.239E-02			
425	1.075E-02	-1.969E 00	660	6.368E-01	-1.960E-01			
430	1.202E-02	-1.920E 00	665	3.533E-01	-4.519E-01			
435	1.055E-02	-1.977E 00	670	1.617E-01	-7.913E-01			
440	9.272E-03	-2.033E 00	675	7.433E-02	-1.129E 00			
445	7.862E-03	-2.104E 00	680	3.784E-03	-2.422E 00			
450	6.973E-03	-2.157E 00	685	1.831E-02	-1.737E 00			
455	6.006E-03	-2.221E 00	690	9.619E-03	-2.017E 00			
460	5.288E-03	-2.277E 00	695	4.111E-03	-2.386E 00			
465	4.646E-03	-2.333E 00	700	2.871E-03	-2.542E 00			
470	4.305E-03	-2.366E 00						
475	3.868E-03	-2.413E 00						
480	3.628E-03	-2.440E 00						
485	3.432E-03	-2.464E 00						
490	3.272E-03	-2.485E 00						
495	3.230E-03	-2.491E 00						
500	3.271E-03	-2.485E 00						
505	3.502E-03	-2.456E 00						
510	3.838E-03	-2.416E 00						
515	4.626E-03	-2.335E 00						
52	5.743E-03	-2.241E 00						
525	7.188E-03	-2.143E 00						
530	8.757E-03	-2.058E 00						

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REPORT FOR WORK ORDER NO. 4

PHOTOGRAPHIC CONSULTING SERVICES FOR EARTH RESOURCES PROGRAM

AT

NASA-WALLOPS ISLAND STATION

CONTRACT NASW-2317

Submitted to
National Aeronautics and Space Administration
Earth Observation Programs
Washington, D. C. 20546

Prepared by

EASTMAN KODAK COMPANY
Kodak Apparatus Division
901 Elmgrove Road
Rochester, New York 14650

Approved by

[signature]

1 June 1972

PHOTOGRAPHIC CONSULTING SERVICES

FOR

EARTH RESOURCES PROGRAM

AT

NASA-WALLOPS ISLAND STATION

--

REPORT ON WORK ORDER NO. 4

Summary

There is good agreement in a single comparison of processes for ERAP films at Wallops Island, Ames, and Kodak. Densitometry at WIS is adequate but would be more reliable if a new McBeth instrument were obtained. Radiometric controls for WIS processing of ERAP camera films will be exposed and provided by the Ames laboratory. Aerial Film Speeds for six ERAP films were calculated based on WIS processing. Suggested improvements in laboratory materials and procedures should produce cleaner operations, a factor of increased importance when WIS begins printing aerial films.

TABLE OF CONTENTS

Introduction

On 7 March 1972 NASA Headquarters issued Work Order No. 4 directing Kodak to assist personnel at Wallops Island Station (WIS) in establishing sensitometric controls on several photographic processes used in the ERAP program and to insure that other laboratory procedures were compatible with those used for ERAP at NASA-Ames. Kodak engineers visited WIS on 1 March 1972 and again on 17-18 May 1972. On the last trip, control strips exposed at Ames and at Kodak were run in WIS processes to compare these results to a reference standard and to processing used at Ames for ERAP camera films.

The relationship between densitometers at WIS, Ames, and Kodak was measured. However, primary radiometric control was not established at WIS as NASA had agreed to use Ames sensitometry for this purpose. Based on WIS processing, Kodak engineers calculated exposure recommendations for several WIS camera films.

These data and recommendations for improvements in laboratory equipment and procedures are included in this report. In general, process control and film handling procedures at WIS follow good laboratory practice and yield useful film records for the ERAP program.

Sensitometry

This section defines a procedure for using control and calibration strips on flight films and compares processing of several ERAP films at WIS and Ames.

Radiometric Control

Radiometric calibration of camera films requires an integration of the spectral characteristics of the light incident on the sensitometer film plane, the pass band of any camera filters, and the spectral sensitivity of the film. The following calculation yields the log exposure at Step 11:

$$\text{Log E at Step 11} = \log_{10}\left[\int_{\lambda_1}^{\lambda_2} H_{1b}\,(f_i \cdots f_n)\; S\; d\lambda\right] + \log_{10} t$$

where H_{1b} = irradiance at the 1b sensitometer film plane [includes the effects of lamp, mirror, cover glass, 11^{th} step of carbon step tablet, daylight correction filter (C5900 or C5900 + P2043)], watts/square meter

$f_i \cdots f_n$ = filters simulating camera filters, transmittance

S = peak normalized spectral sensitivity of film

t = exposure time, seconds

In the ERAP program it is important to have calibrated gray scale exposures on the camera film emulsions processed with the rolls of pictures. While it is possible to expose gray scales on the head or tail end of the flight film, these exposures frequently are spoiled by fog light or by camera images. To avoid these losses one can use an alternative method in which preexposed gray scales are made on the flight emulsion and are spliced to the aerial photography immediately prior to processing. This second procedure is recommended for use in the ERAP program.

These calibrated radiometric control strips will be provided by the NASA Ames installation. The sensitometers at Ames have been previously calibrated by Kodak for the flight films of interest.

Process Control

Control of the photographic processor is based on the use of properly mixed, uncontaminated solutions in a machine operated at standard temperatures and mechanical conditions. The status of the process is measured by densitometry of near neutral step scales exposed using a calibrated sensitometer on a control film. Processing of these control strips should immediately precede processing of the camera or print film. Additional control strips should be processed at intervals during the work day.

Usually adequate control is maintained by reading about four steps on a strip and plotting the densities on a chart in which the center line is the standard density. For color film processors, three color densities are plotted along the same control line for a step. The following guides are suggested for the permitted deviation of the observed densities from the control values for color film processes:

	Control Limits	
Portion of D-log E Curve	Density	Color Balance Spread*
D min.	+0.03 No lower limit	No limits
D = 0.5 to 0.7	±0.10	0.08
D = 1.8 to 2.1	±0.15	0.13
D max.	-0.25 No upper limit	No limits

* Color balance spread is the absolute range of the deviation of the three color densities from the aim line.

Note that special considerations may prescribe larger or smaller limits because of requirements placed on the photography by the users or because of unusual processing conditions.

A full characteristic curve should be read and plotted occasionally, but much time will be saved by reading, plotting, and controlling only four density steps. The full curves reveal changes in tone reproduction and allow measurement of speed and gamma as an aid in properly placing the scene image on the D-log E curve.

It is well to correlate sensitometric data with pH or specific gravity measurements and with machine data such as temperature, time in solution, and replenishment rates. These data assist in locating sources of trouble whenever densities fall outside the specified limits. Process control at WIS is satisfactory in view of infrequent operation of the processors and a relatively light film load.

Rather than setting arbitrary limits on step densities, it is desirable to establish limits by statistical calculation based on an extended process run. From this run, limits of 2 or 3 standard deviations may be derived for each density value. Control charts showing the average value and appropriate limits must be established for each type of film that is frequently used. A procedure for calculating control limits from statistical analysis of process data is given by Bennett and Franklin.[1]

Figures 1 to 8 compare the WIS and Ames processes for several black-and-white and color films. The strips for Figure 1 were exposed at Ames while all other comparisons were exposed at Kodak.

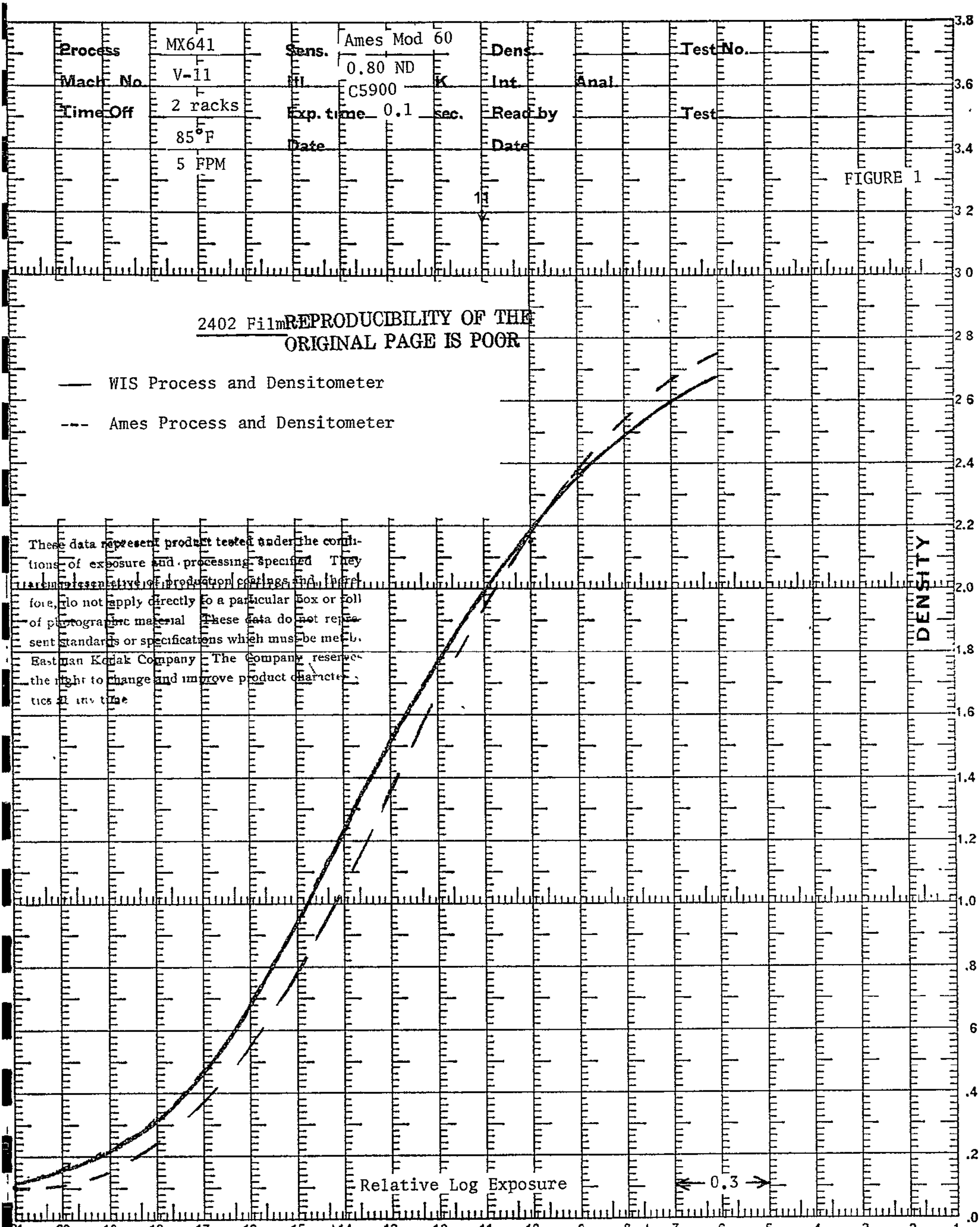
(1) C. A. Bennett and N. L. Franklin, Statistical Analysis in Chemistry and the Chemical Industry, J. Wiley and Sons, New York, 1954, pp. 631-644.

For the black-and-white films the differences shown in the figures include both processing and densitometry at Ames and at Wallops Island. The laboratory at WIS uses a Densichron 400 instrument while Ames uses an Ansco-McBeth densitometer. See the Densitometry section below for the relationship between these two instruments. When differences in densitometry are allowed for, the processes at each laboratory are nearly identical. The WIS process is slightly faster for each of the black and white films. However, these results are based on only one observation of each process. Consequently the observed differences may not be exactly the same in subsequent comparisons.

Color aerial films are processed on an Fktachrome Processor Model 1811 at Wallops Island, and Kodak EA-5 control strips are used to monitor the process.

After the 115°F processing cycle recommended for Ektachrome MS Type 2448 and EF Type SO-397 was brought within control limits, Eastman 1b exposures on each of the products were processed. Densities on the processed strips were measured at Wallops Island and by Kodak, and similar exposures were also processed by Kodak. Figures 5 and 6 show that the Wallops Island process is slightly slower than the Kodak process for these films.

FIGURE 1



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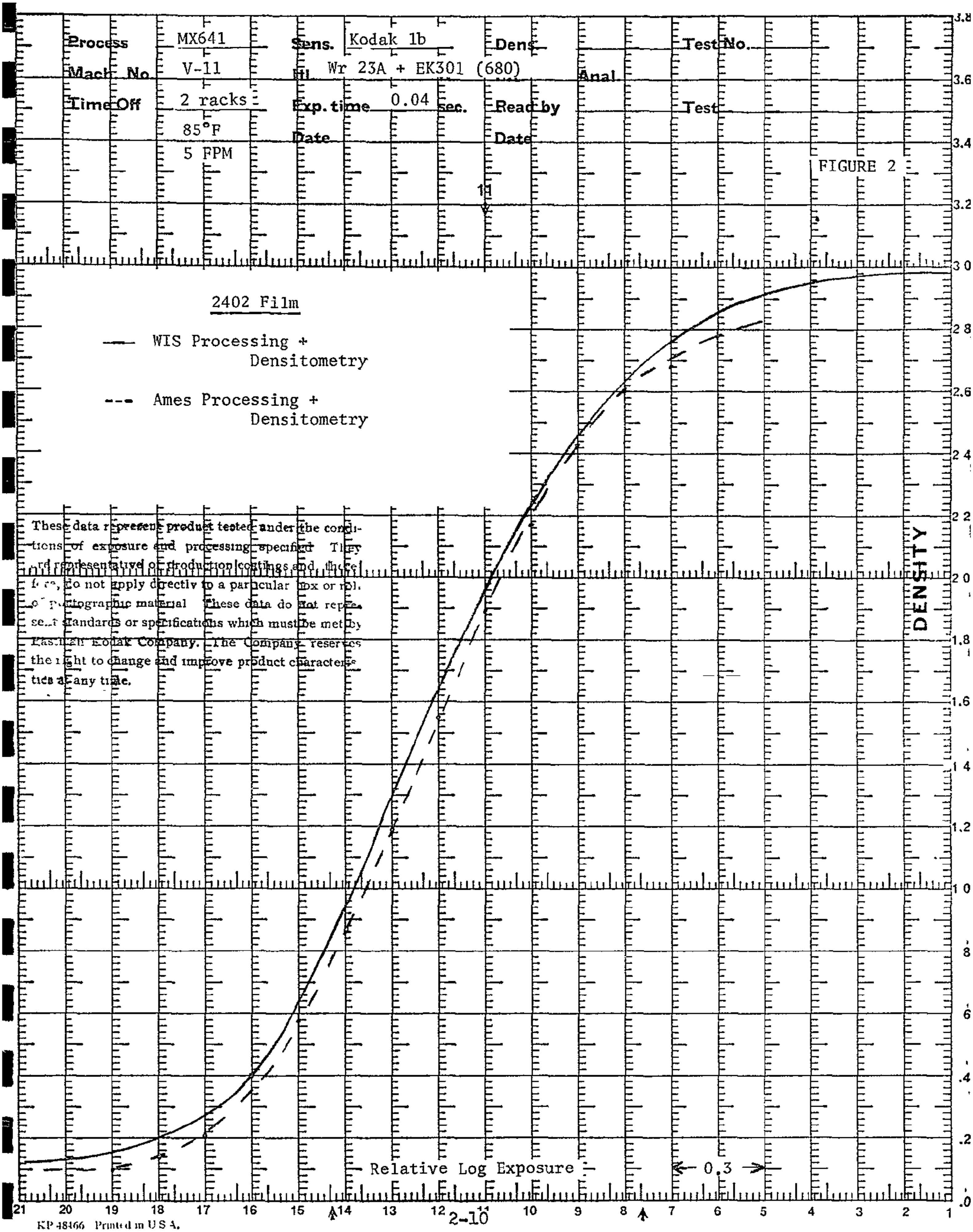
Process MX641
Mach. No. V-11
Time Off 2 racks
85°F
5 FPM
Sens. Kodak 1b
Fil. Wr 23A + EK301 (680)
Exp. time 0.04 sec.
Date
Dens.
Anal.
Read by
Date
Test No.
Test
FIGURE 2
2402 Film
WIS Processing + Densitometry
Ames Processing + Densitometry
These data represent product tested under the conditions of exposure and processing specified. They are representative of production coatings and, therefore, do not apply directly to a particular box or roll of photographic material. These data do not represent standards or specifications which must be met by Eastman Kodak Company. The Company reserves the right to change and improve product characteristics at any time.
Relative Log Exposure
0.3
DENSITY
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
.0
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
KP 48466 Printed in U.S.A.

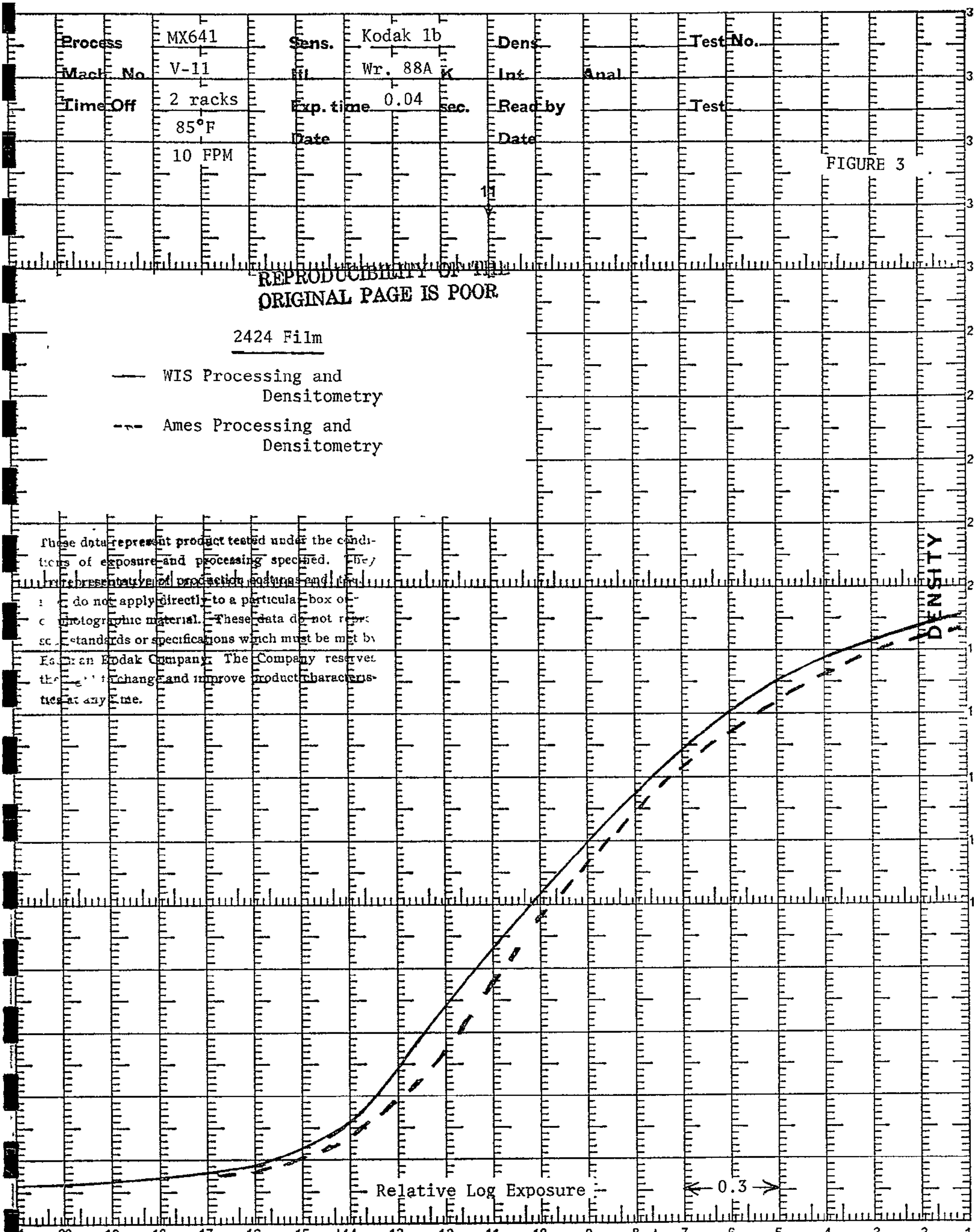

FIGURE 3

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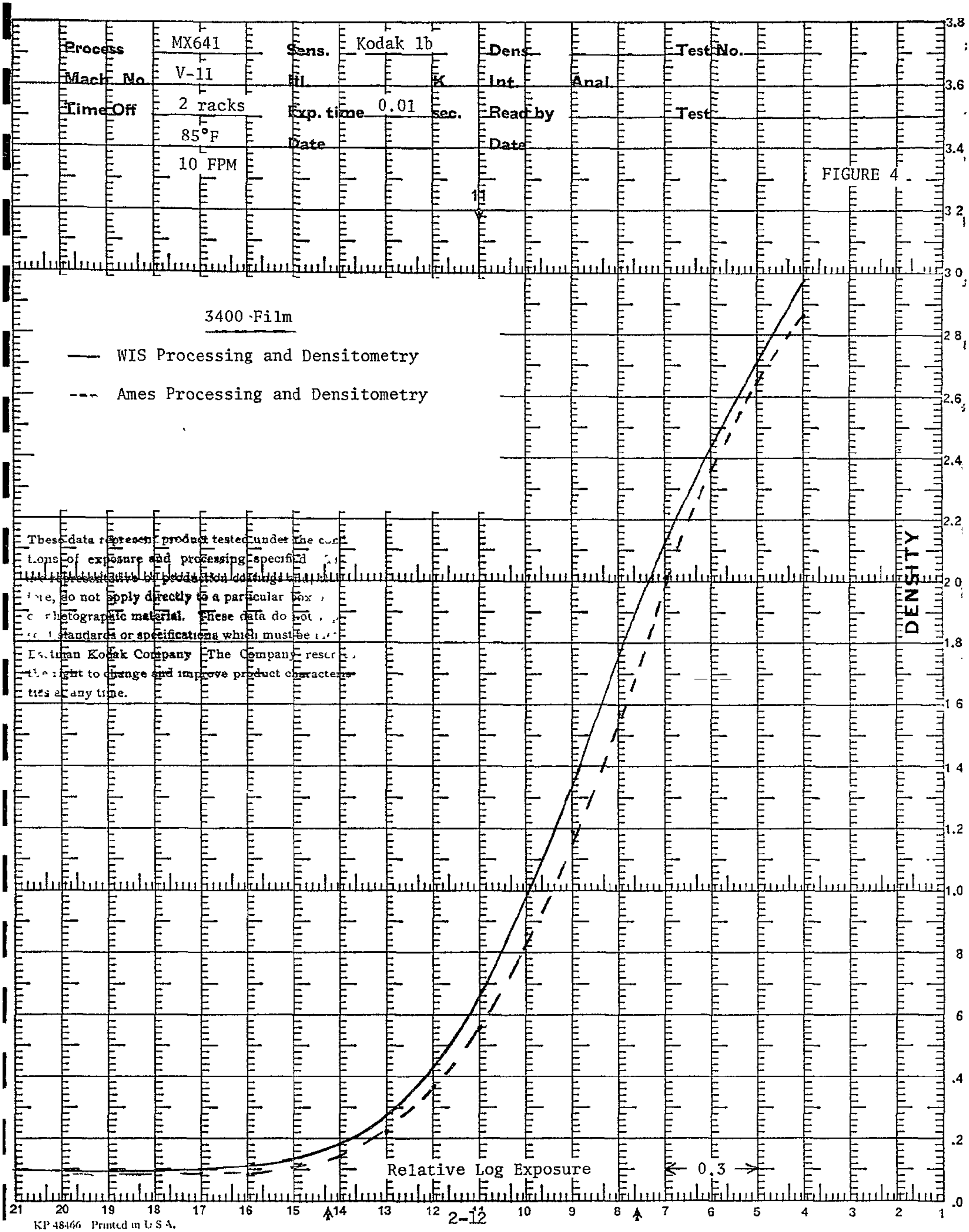
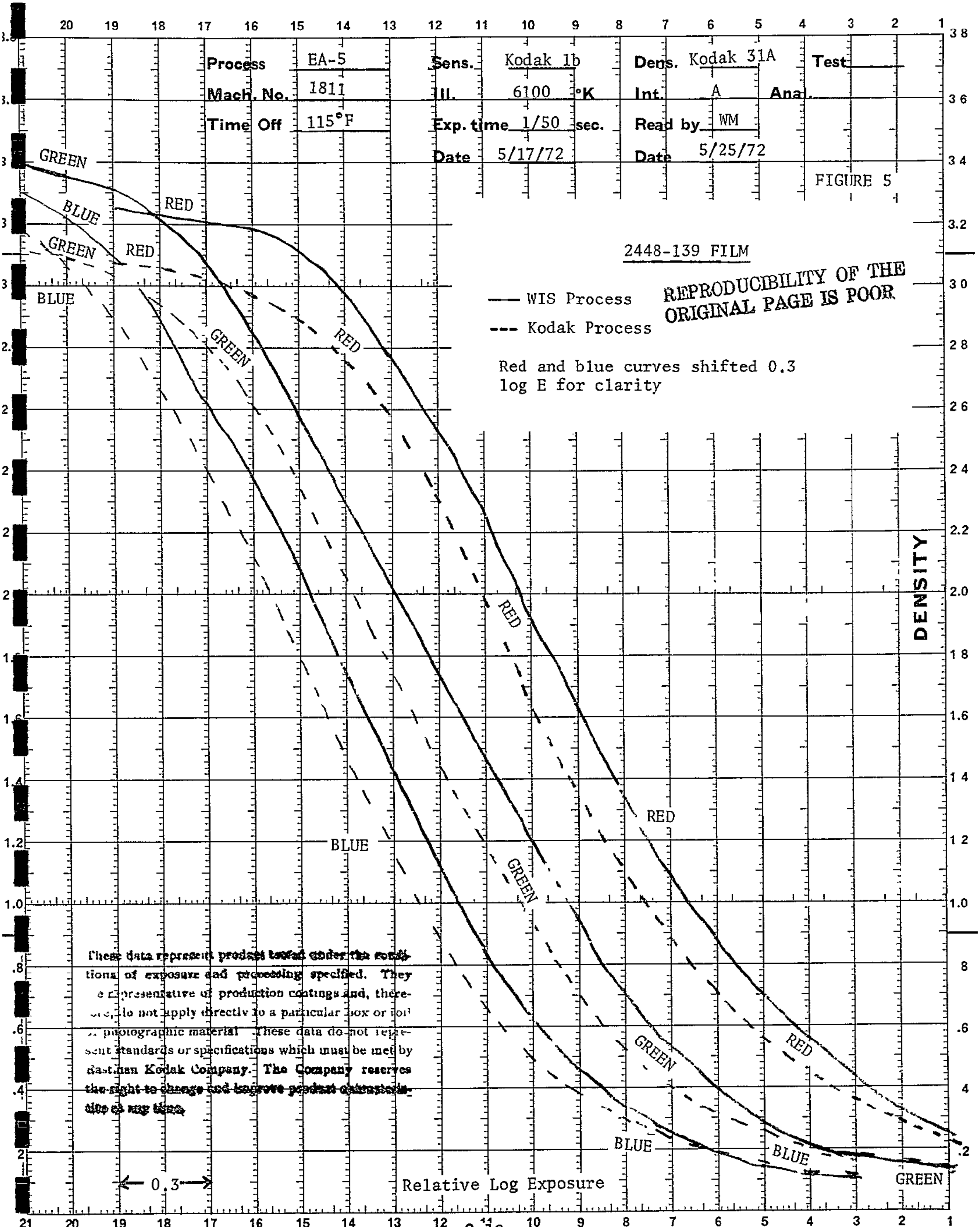
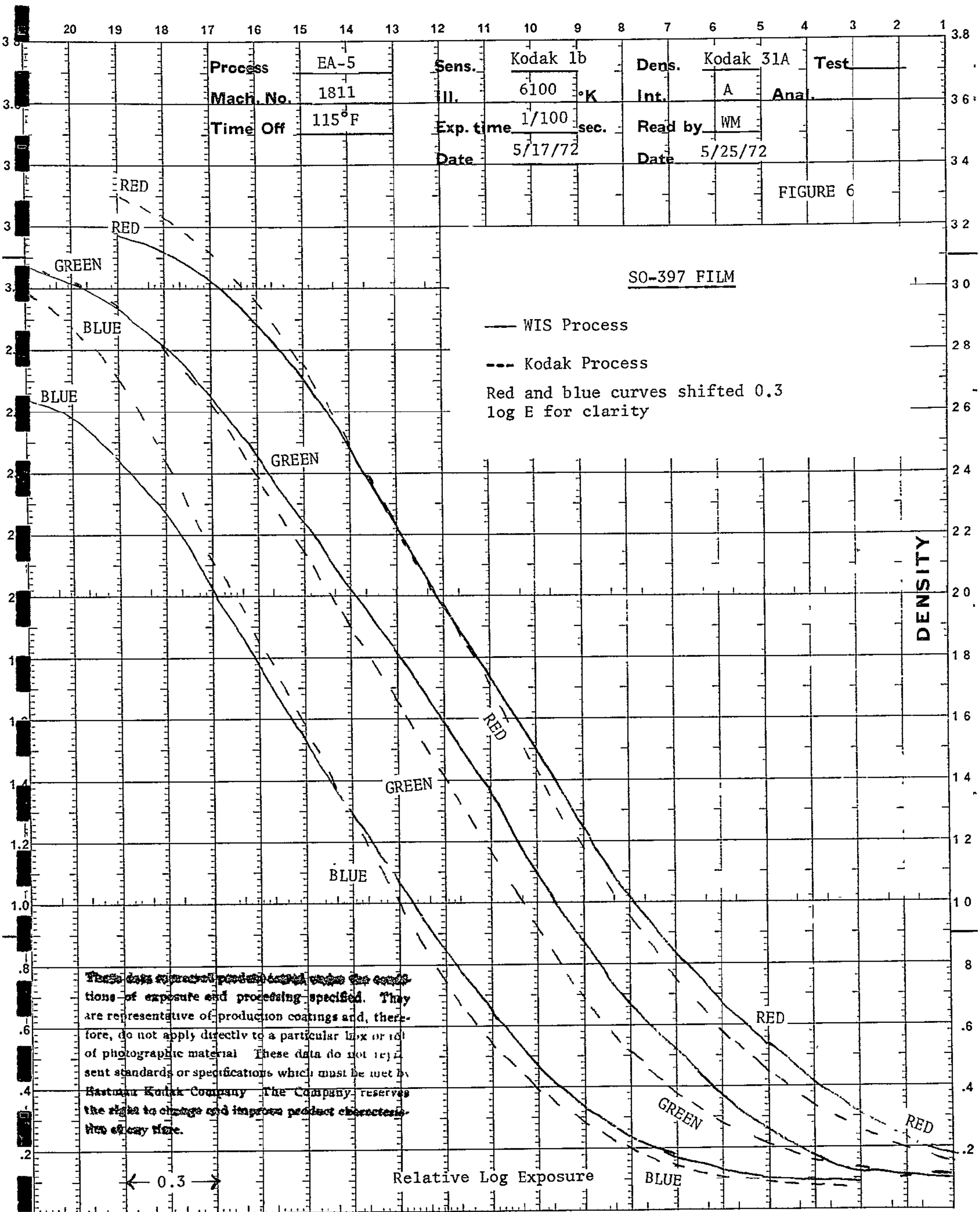
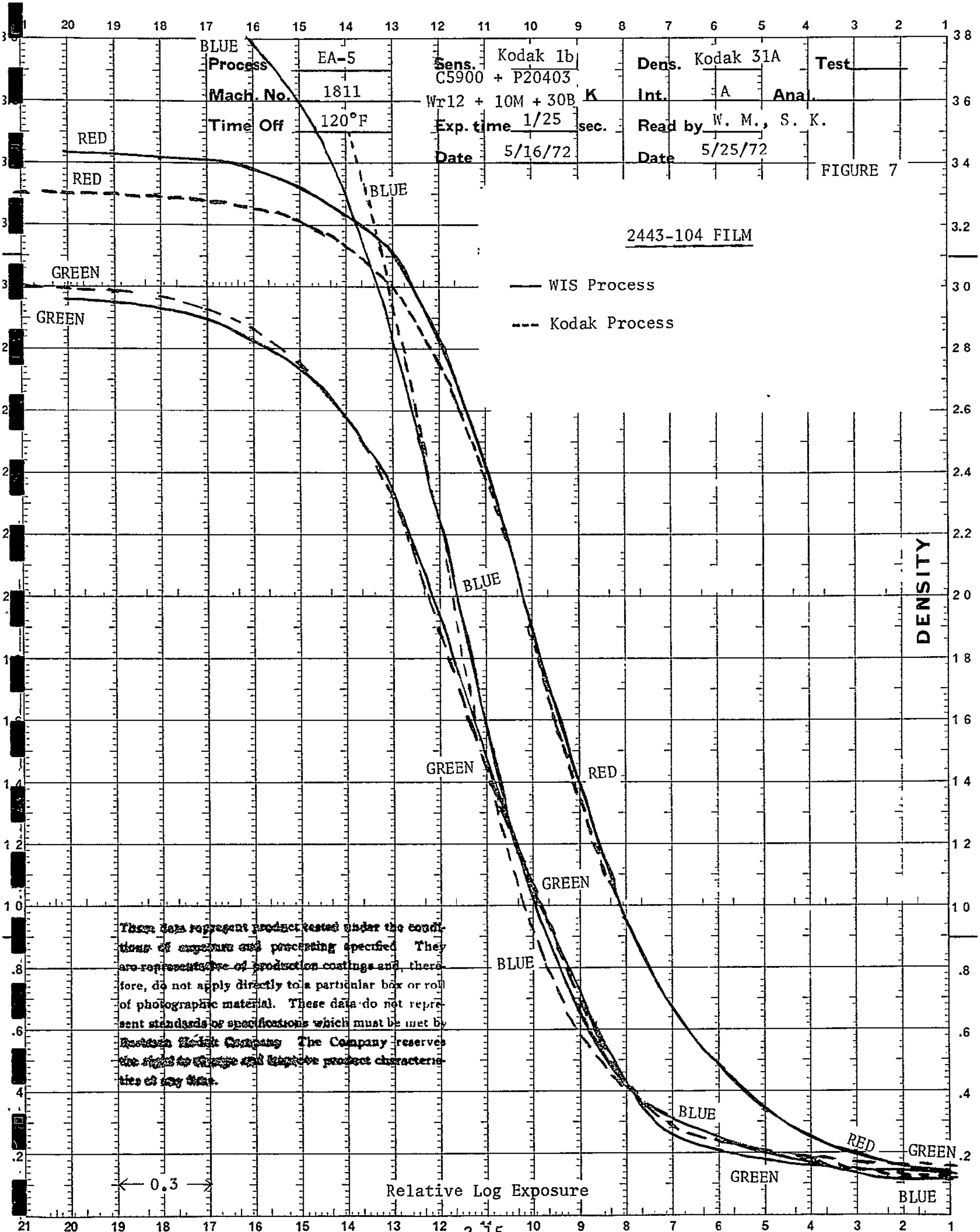
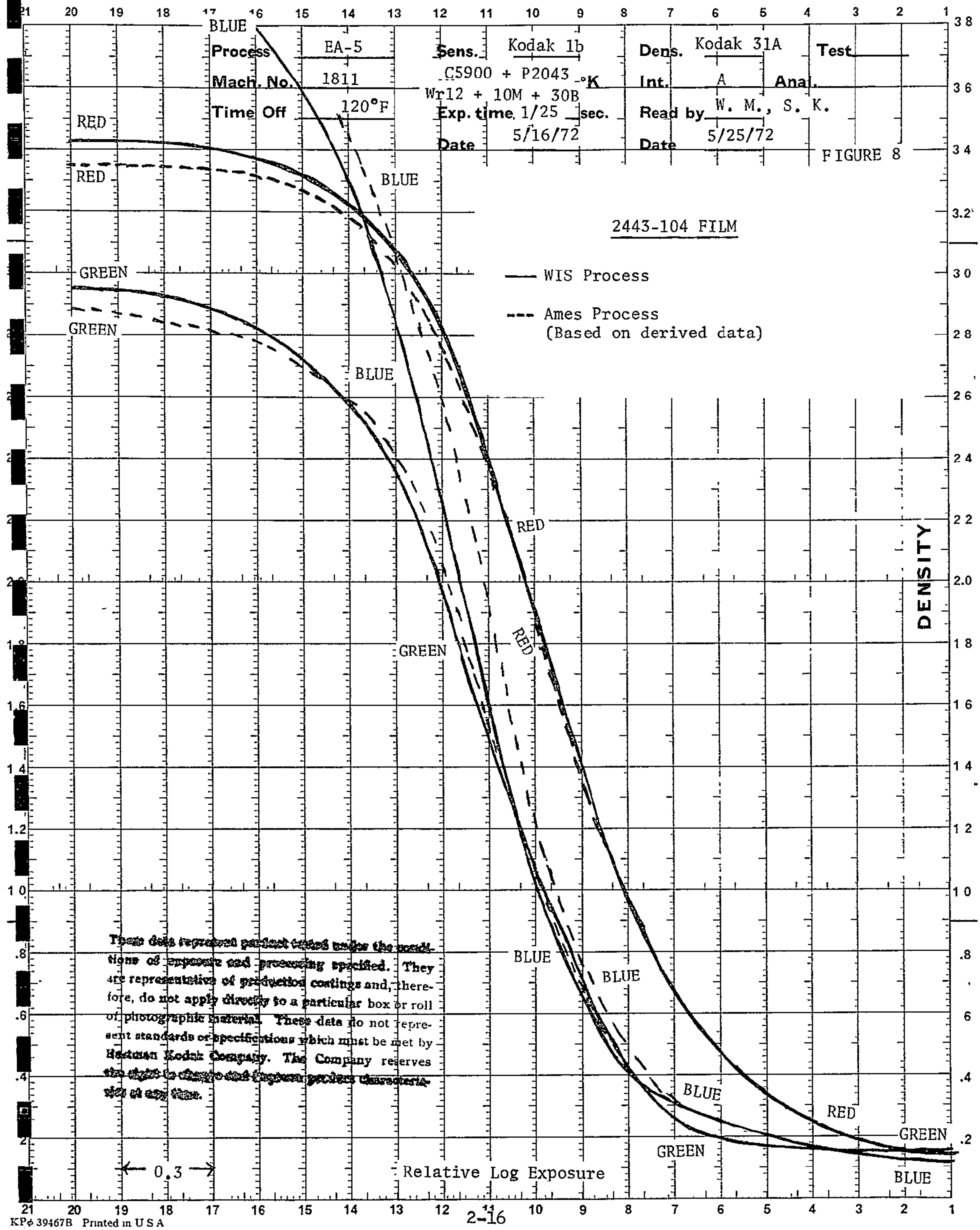

Process MX641
Mach. No. V-11
Time Off 2 racks
85°F
10 FPM
Sens. Kodak 1b
Exp. time 0.01 sec.
Dens.
Int.
Anal.
Read by
Date
Test No.
Test
FIGURE 4
3400 Film
WIS Processing and Densitometry
Ames Processing and Densitometry
Relative Log Exposure
0.3
DENSITY
KP 48466 Printed in U.S.A.



KPφ 39467B Printed in U S A


Process EA-5
Mach. No. 1811
Time Off 115°F
Sens. Kodak 1b
Ill. 6100 °K
Exp. time 1/100 sec.
Date 5/17/72
Dens. Kodak 31A
Int. A
Read by WM
Date 5/25/72
Test
Anal.
FIGURE 6
SO-397 FILM
WIS Process
Kodak Process
Red and blue curves shifted 0.3 log E for clarity
RED
GREEN
BLUE
DENSITY
Relative Log Exposure
0.3
These data represent product tested under the conditions of exposure and processing specified. They are representative of production coatings and, therefore, do not apply directly to a particular box or roll of photographic material. These data do not represent standards or specifications which must be met by Eastman Kodak Company. The Company reserves the right to change and improve product characteristics at any time.
KP 39467B Printed in U.S.A.


Process EA-5
Mach. No. 1811
Time Off 120°F
Sens. Kodak 1b C5900 + P20403 Wr12 + 10M + 30B K
Exp. time 1/25 sec.
Date 5/16/72
Dens. Kodak 31A
Int. A
Read by W. M., S. K.
Date 5/25/72
Test
Anal.
FIGURE 7
2443-104 FILM
WIS Process
Kodak Process
RED
GREEN
BLUE
DENSITY
Relative Log Exposure
0.3
These data represent product tested under the conditions of exposure and processing specified. They are representative of production coatings and, therefore, do not apply directly to a particular box or roll of photographic material. These data do not represent standards or specifications which must be met by Eastman Kodak Company. The Company reserves the right to change and improve product characteristics at any time.


Process EA-5
Mach. No. 1811
Time Off 120°F
Sens. Kodak 1b
C5900 + P2043 °K
Wr12 + 10M + 30B
Exp. time 1/25 sec.
Date 5/16/72
Dens. Kodak 31A
Test
Int. A
Anal.
Read by W. M., S. K.
Date 5/25/72
FIGURE 8
2443-104 FILM
WIS Process
Ames Process
(Based on derived data)
RED
GREEN
BLUE
DENSITY
Relative Log Exposure
0.3
These data represent product tested under the conditions of exposure and processing specified. They are representative of production coatings and, therefore, do not apply directly to a particular box or roll of photographic material. These data do not represent standards or specifications which must be met by Eastman Kodak Company. The Company reserves the right to change and improve product characteristics at any time.
KPφ 39467B Printed in U S A

The 1811 machine was then adjusted to the 120°F processing cycle recommended for Ektachrome Infrared Film Type 2443, and Kodak 1b exposures on this film were processed. Figure 7 compares the results obtained at Wallops Island with that obtained on a similar machine at Kodak. The curves in Figure 8 compare 2443-104 film processed on the Model 1411 machine at Ames and on the Model 1811 machine at WIS. Since the 1b exposures for process comparison at the two bases were made using different filters, the comparison in Figure 8 was derived from similar exposures put through a single process at Kodak. All three processes for 2443 film are very close together.

Again note that these data represent a single sample of the color processes at both the NASA installations and at Kodak. However, process differences for most of the films are very small.

Camera Exposure

Recommendations for camera exposure are based on the use of the Kodak Aerial Exposure Computer (R-10) and the specially calculated film speeds given in Table I for the following films and filters:

Table I

Film Speeds for WIS Cameras

CAMERA	FILM	FILTERS	EFFECTIVE AERIAL FILM SPEED
VINTEN	2402	SCHOTT GG475 + BG18	75
	2402	SCHOTT OG570 + BG38	53
	2424	SCHOTT RG645 + C9830	24
	2443	Wr. 12 + 30B + 20M	26
A-1/A-2	3400	Wr. 12	20
HASSELBLAD	SO-397	NONE	92
	2448	NONE	40
I^2S	2424	Wr. 88A	68

NOTE: These film speeds are based on the following processing used at NASA-Wallops Island Station:

2402: V-11, 85°F, 2 RACKS, 5 ft/min., MX-641

2424: V-11, 85°F, 2 RACKS, 5 ft/min., MX-641

3400: V-11, 85°F, 2 RACKS, 10 ft/min., MX-641

2443: 1811, EA-5 Process, 120°F

2448: 1811, EA-5 Process, 115°F

SO-397: 1811, EA-5 Process, 115°F

To obtain the film speeds in the right hand column of Table I, a previously developed, proprietary computer program was used to relate solar altitude to exposure time at an arbitrary lens f/number. This calculation is a spectral integration that includes the effects of nominal lens transmittance, the spectral distribution of sunlight and haze light viewed vertically from very high altitude, and the spectral sensitivity of each film-filter combination. The calculated exposure is sufficient to produce a density of 1.0 on black-and-white films or 1.5 on the green density record of color films from a neutral target of 12% reflectance. This reflectance is a useful average value for setting exposure of aerial scenes imaged by high altitude aerial cameras.

The R-10 computer was then used "in reverse" by entering the previously calculated f/numbers and exposure times at several solar altitudes and determining the effective aerial film speed. For a given film and filter, these speed values for all solar altitudes were identical to within ±1/3 stop. An average value of each film speed is given in Table I.

The effective aerial film speeds in Table I should be used along with the correct sun altitude to calculate the proper lens f/number and shutter time using the Kodak R-10 computer. In some instances, photography of unusually light or dark terrain will require deviations from the calculated exposures. These adjustments should be based on previous experience in recording these areas.

Densitometry

This section describes procedures for routine control of the WIS densitometer and compares densitometry on WIS, Ames and Kodak instruments for both color and black-and-white films.

Control Procedures

Control of a color photographic process is based on measurement of dye densities on processed sensitometric strips. Densitometer control includes calibration of the instrument and an evaluation of repeatability.

Most densitometers are designed to operate in normal room light and temperatures. However, variations in these factors may influence the results obtained. The densitometer should be calibrated, controlled, and used under those conditions which produce the most stable operation.

Measurements obtained with a densitometer are more meaningful if they can be related to a reference instrument or to a precisely defined technique for measuring density. In the ERTS program, a practical densitometer calibration program would be an intercomparison of the densitometers used in laboratories doing similar work. For example, since Ames and Wallops Island both process IR Ektachrome film, a processed gray scale on 2443 film could be shipped routinely between the NASA bases and read on the color densitometer at each laboratory. A comparison of this type was made during the visit to Wallops Island, and the results are reported below.

At the time of the visit to Wallops Island, we were told that the Densichron 400 instrument had a "discontinuity" between density ranges. This condition should be corrected by adjustment of the instrument if possible.

It is important to know if the color densitometer is functioning normally or if a change has occurred which requires re-calibration or maintenance. The KODAK Transmission Densitometer Check Plaque is a valuable tool for detecting densitometer instability and malfunctions. The procedure for using the Check Plaque is described in Kodak pamphlet 637820. The plaque contains seven reading areas plus one for zeroing the densitometer. Density readings from the plaque are recorded each day for 20 days. The averages of these values are the average performance levels for that densitometer. Subsequent readings are compared by statistical tests to these aim values for evidence of changes in the densitometer. Copies of phamphlet 637820 have been given to laboratory personnel at Wallops Island.

Comparison With Kodak and Ames Instruments

Prior to our second visit to WIS we requested that processed gray scales on color and black-and-white films be read at Ames and shipped to WIS with the Ames density readings. Other strips were read at Kodak and carried to WIS where all gray scales were reread using the WIS densitometer.

Density values from 2402 and 2424 films are displayed in Figure 9 where the solid line denotes WIS density and the dashed line is Ames density compared to readings made at Kodak on a 31A densitometer. Readings made on the Ansco-McBeth densitometer at Ames match very well the densities read on the Kodak 31A machine. However, this Ansco instrument gives erratic readings and soon will be replaced with a newer McBeth densitometer.

Readings on the WIS Densichron 400 are about 0.06 higher than the Kodak values above a density of 1.0. While this is reasonably good agreement, the Densichron instrument requires considerable attention in order to achieve consistent results. A new, more versatile McBeth densitometer should be considered for this laboratory.

Relationships between the three color densitometers are shown in Figures 10 and 11. The Kodak instrument gives readings between those obtained at WIS and at Ames. Agreement is good between the Kodak 31 A and the WIS Densichron, although there is a small discontinuity in the blue record at a density of 1.0.

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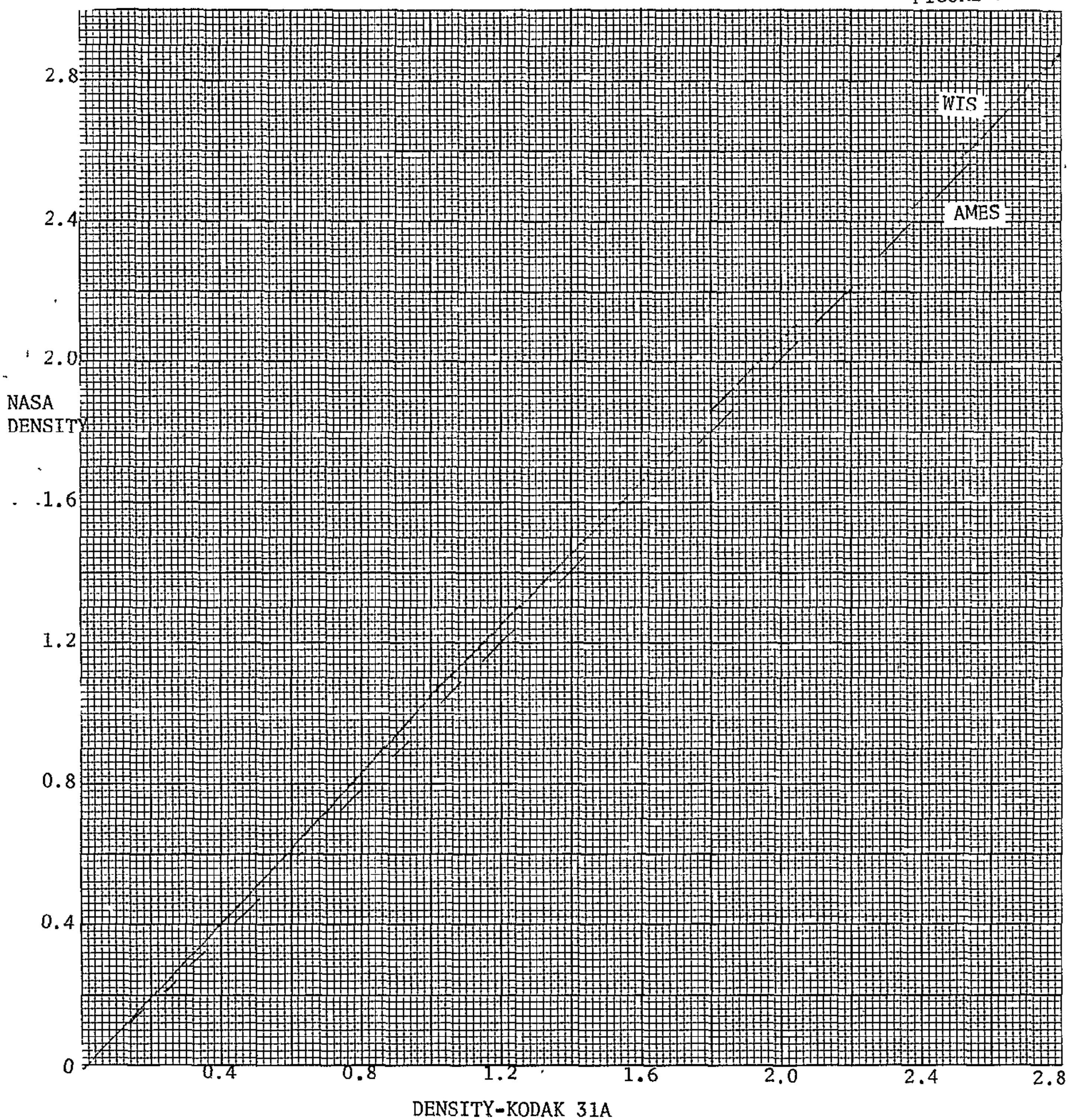
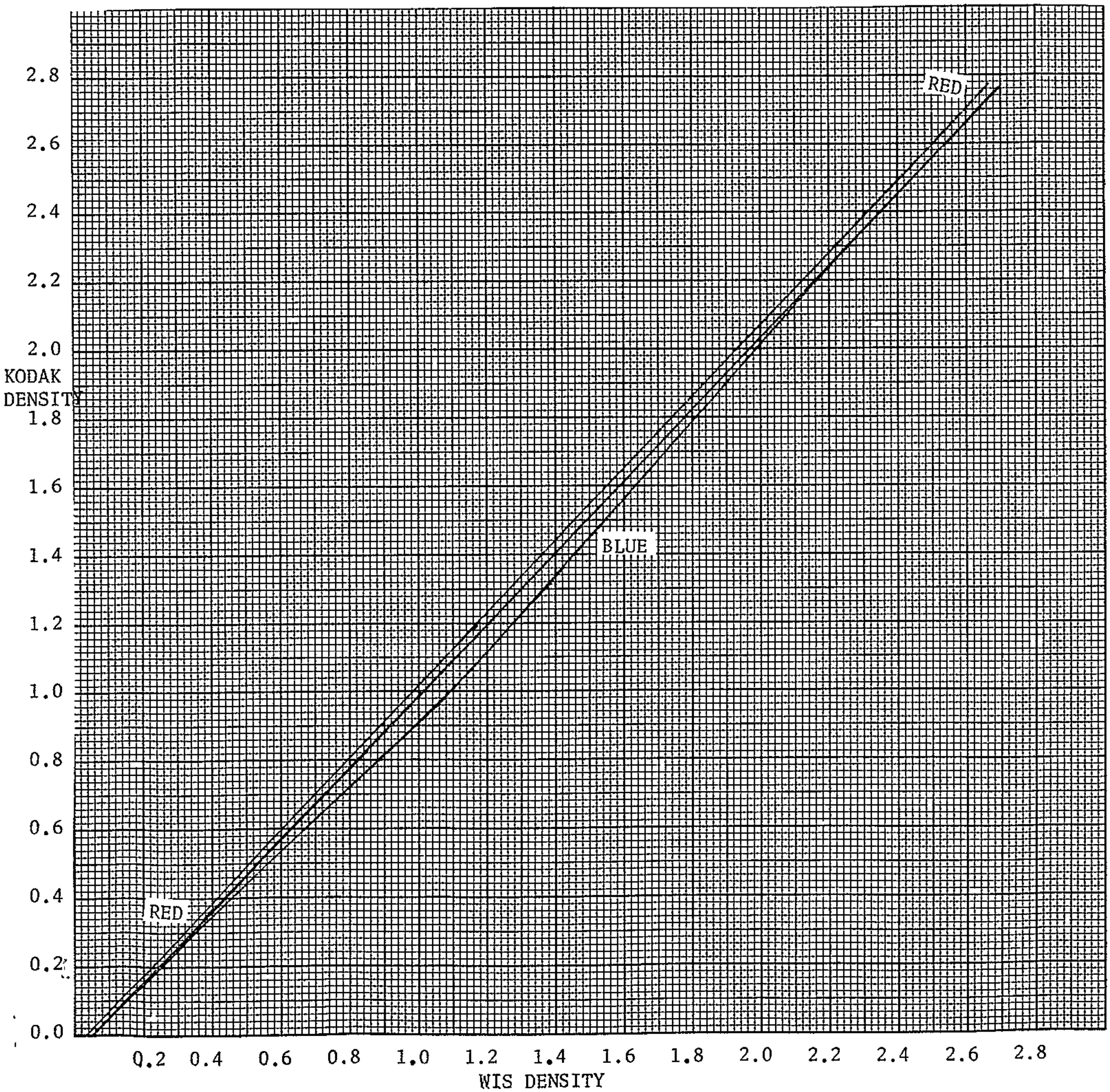
DENSITOMETER COMPARISON
BLACK-AND-WHITE
FILMS
WIS-KODAK-AMES

FIGURE 9



DENSITOMETER COMPARISON
COLOR FILM
KODAK 31A - WALLOPS ISLAND
DENSICHRON 400

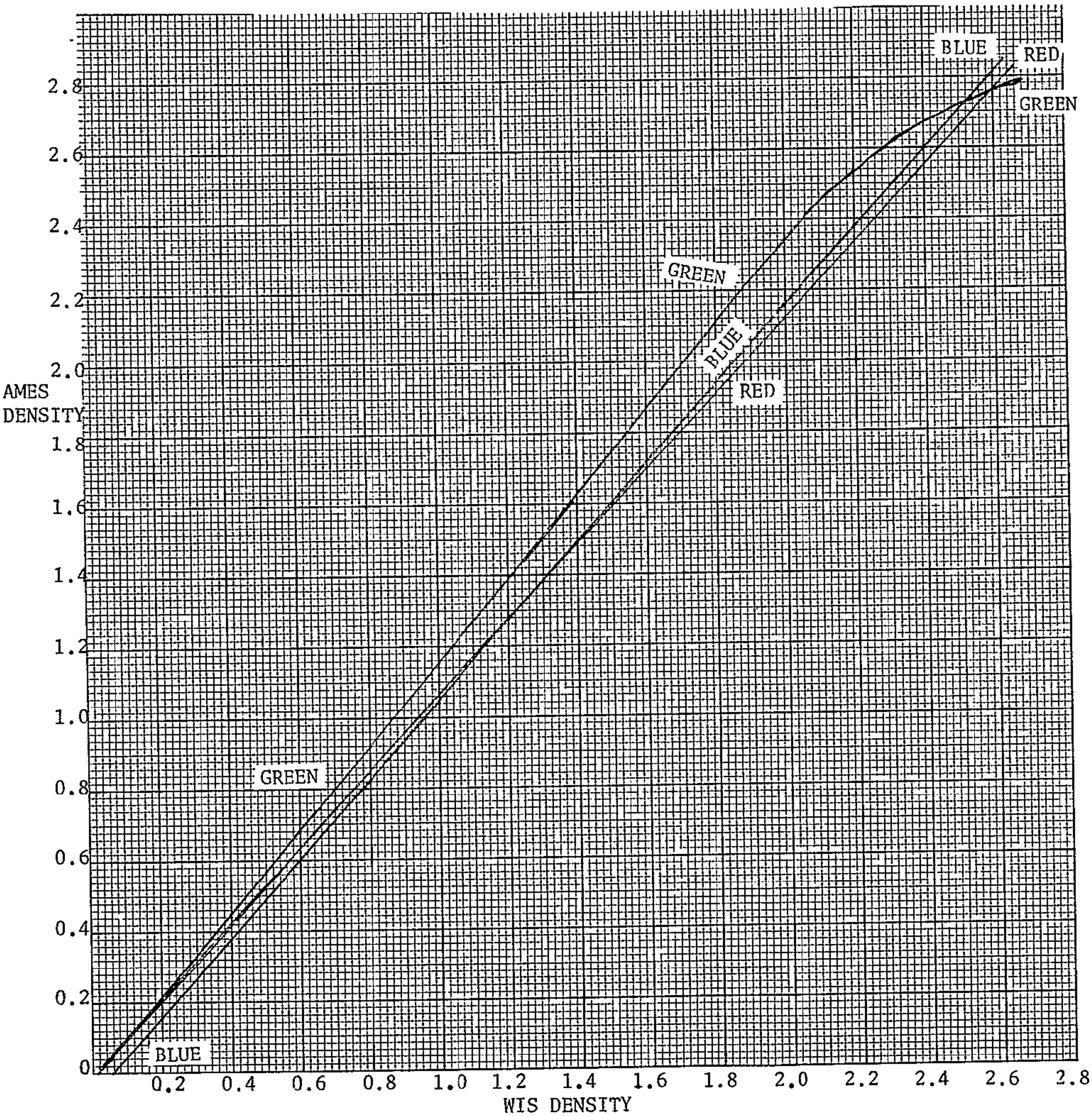
FIGURE 10



DENSITOMETER COMPARISON
COLOR FILM

AMES - WALLOPS ISLAND
ANSCO-MCBETH DENSICHRON 400

FIGURE 11



The Ames instrument reads higher densities than the WIS Densichron at all points. The green contrast in particular is nearly 20 percent high for the Ames readings. Note that the comparison between Ames and WIS is based on reading only one gray scale on 2443 film; average results may differ from this single comparison. In addition, the Ames instrument has been giving erratic readings recently and its performance may not be fairly represented by the data in Figure 11.

Laboratory Practice

Mixing and Storage of Film and Chemicals

At the Wallops Island lab, the date of receipt is stamped on EA-5 chemical mix kits. The laboratory then follows a procedure of "first in - first out" and avoids the likelihood of using outdated chemicals. This is a good practice which should be continued. Space for storage of EA-5 chemical kits is limited and somewhat congested. The addition of shelves for storage of chemical kits would permit better utilization of available space. A refurbishment of the walls and ceilings in this area would reduce flaking of the concrete and eliminate a source of dirt.

The Wallops Island photo lab uses separate mix tanks for making the 1st Developer and Color Developer for the Ektachrome Processes. This is a good practice which should be continued. The EA-5 replenisher supply tanks are equipped with both floating lids and tank covers, both of which are desirable. The floating lids contain cavities on the upper surface in which solution can be trapped on the top of the lid when a freshly made mix is pumped into the storage tank. The floating lid should be removed from the storage tank during the transfer operation and carefully replaced afterwards to avoid leaving solution on the top.

Replenisher mixes for the Versamat Model 11 are mixed and stored in the same room as the processor. Space limitations may dictate this practice. If this procedure is continued, precautions should be taken to avoid any accidental contamination of the film by the processing solutions.

The Wallops Island laboratory has a large cold room that is kept at 5°F for storage of films. Storage at these temperatures will extend the useful life of films either before or after exposure. Some refurbishment of the walls and ceiling of this storage vault would be beneficial.

Working Area and Conditions

Since it is very near the ocean, the Wallops Island laboratory may encounter unusual corrosion of equipment. Corrosion of components in the dryer on the Ektachrome Processor Model 1811 illustrates this point. In this case high humidity from the film is combined with high temperatures in the dryer and perhaps a corrosive atmosphere. Corrective measures include frequent cleaning plus a reduction of the humidity in the drying cabinet. To reduce the humidity in the dryer, more make up air is required and more air must be exhausted from the dryer system. A fan should be added to the discharge end of the square exhaust duct which originates at the head end of the processor.

Sensitometers, densitometers, printers, and enlargers require nearly constant electrical voltage. The Nash Compressors which supply compressed air to the processors have large electrical motors. When these start or stop they could cause fluctuations in the electrical voltage throughout the laboratory. To avoid problems in the lab instruments, the compressors should be separated in operating time or electrically. Voltage regulators on the laboratory equipment might solve the problem. If not, separate electrical sources for instruments and compressors may be necessary.

It is very important to maintain clean film web surfaces in a photographic laboratory. Cleanliness procedures should emphasize careful handling of the original record, as foreign particles attached to the original are permanently registered as information voids on subsequent copies. In contact printing onto fine grain duplicating emulsions, foreign particles lodged between the films produce the "contact printing measle" artifact. This artifact magnifies the area of image disturbance in the duplicate to many times the size of the foreign particle.

A tightly wound roll of film provides excellent protection against contamination of the inner convolutions. Therefore, maintaining clean film surfaces is most important at those points in the production cycle where the material is unwound.

The sources of particles which impair quality in the photographic laboratory can be divided into three broad categories:

1. Airborne
2. Equipment, facilities, and materials
3. People

The introduction of dirt into the laboratory through the ventilation supply can be largely controlled by filtration of inlet air. Normally this is done in all ventilation systems.

Equipment usually does not generate dirt but may get dirty. Periodically film handling equipment should be cleaned. This is especially true of processing machines.

In the Wallops Island laboratory the ceiling material is a source of dirt. The ceiling tile may have been selected more for acoustical properties than for cleanliness. In those areas where cleanliness is required, a different ceiling material is recommended.

Packaging materials are a source of dirt in a photographic laboratory. The cardboard boxes in which film is purchased should be stored outside the laboratory. Rooms in which cardboard containers have been used should be cleaned before the area is used to rewind film.

People can be a major source of dirt and are perhaps the source most difficult to control. Where "clean room" operation is required, proper operator dress is an important factor. All personnel working in the general vicinity of open spans of film should wear the following outer garments:

(1) Full length smocks made from a lint-free material such as nylon.

(2) Caps which fully cover the hair also made from a lint-free material.

All personnel actually viewing exposed film surfaces or working in close proximity to exposed film surfaces should wear partial face masks to prevent the possibility of moisture spotting the film surface. In addition all personnel handling the image portion of films should wear lint-free gloves. Gloves are not needed for operators of equipment like a continuous printer, as these people handle the extreme ends of the film rolls. Clean room garments should be worn only in designated clean areas. Wearing of these garments in break rooms, chemical mix rooms, or offices where smoking is allowed will contaminate the garments and limit their usefulness.

Even with concerted effort to keep a laboratory clean, film will get dirty. When it does, it should be cleaned. The original film should be frequently cleaned during a printing operation. It is good practice to clean the print master following every third printing, although some laboratories may require more or less frequent cleaning. The film is usually cleaned by passing it through a tacky roll machine. If Wallops Island should begin extensive duplication of aerial film, the purchase of a cleaner for wide aerial film should be considered.

Wallops Island is about to receive a Kodak Colorado Printer. When an area is prepared for this equipment, a constant voltage electrical supply should be considered. Other equipment requiring critical voltage control could be added to the same supply, possibly in the same area. Cleanliness should be a major consideration in selecting the ventilation and materials of construction for this facility.

Recommendations

Laboratory conditions at WIS are satisfactory but might be improved by adding new surfaces to walls and ceiling in the film and chemical storage areas. As the laboratory begins to print aerial films more attention must be given to dirt control. Important factors include air filtering, replacement of acoustical ceiling tile, use of nylon smocks and hats, and control of traffic and cleaning operations in the laboratory. A tacky roller film cleaner and improved voltage control are also needed.

Processing of ERAP films at WIS agrees very well with that at Ames and at Kodak. Densitometry at WIS is adequate, but purchase of a new McBeth instrument would reduce maintenance time and improve confidence in process control procedures.

REPORT FOR WORK ORDER NO. 5

PHOTOGRAPHIC CONSULTING SERVICES FOR EARTH
RESOURCES PROGRAM

AT

NASA-GODDARD SPACE FLIGHT CENTER

CONTRACT NASW-2317

Submitted to
National Aeronautics and Space Administration
Earth Observation Programs
Washington, D. C. 20546

Prepared by

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Approved by

March 21, 1973

PHOTOGRAPHIC CONSULTING SERVICES

FOR

EARTH RESOURCES PROGRAM

AT

NASA-GODDARD SPACE FLIGHT CENTER

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REPORT ON WORK ORDER NO. 5

Summary

A comparison of prints from ERTS photography revealed significant differences in the image quality produced at GSFC, the EROS facility at Sioux Falls, and Eastman Kodak in Rochester. Based on this survey photographic quality was improved significantly at Sioux Falls, and improvements were suggested for optical and contact printers at the GSFC.

Based on a test in which 365 meters of Eastman Electron Recording Film (ESTAR Base) SO-438 were processed the 1-sigma variation in process control from all sources is about ± 0.04 at a density of 1.0. Variations from film and from processing were approximately equal contributors to the overall tolerance.

Distortion produced by the Kodak Colorado printer at GSFC covers a range of about 0.04%, a small value compared to that caused by other factors in the ERTS system. The edge fringing inherent in the color film materials used at GSFC also seems to be a small factor in the unsharpness of ERTS color prints.

MTF and granularity measurements were made on processed film samples supplied by GSFC. MTF values were above 0.70 out to 42 cycles/mm for all stages of contact printing in the ERTS system.

TABLE OF CONTENTS

Introduction

This report summarizes tasks accomplished under Work Order No. 5 for the NASA-Goddard Space Flight Center from April 1972 to February 1973. Although technical services by Kodak continue to be provided for GSFC under this work order, it seems useful to report on those tasks completed to date. All of the calculations, test data, and film images derived from this work were immediately given to personnel at the GSFC photographic laboratory for their review and action. This insured timely consideration of the test results prior to issuing a formal report.

Included in this summary are the results of the inter-laboratory survey using ERTS photography that was reported separately on 7 February 1973. In addition, details are given regarding measurement of film granularity and MTF, printer distortion, sources of variability in processing the film from the Electron Beam Recorder, and sensitometric and sharpness factors in the color film system used at GSFC.

During the 10 month period of Work Order 5 specific recommendations for improved performance were made directly to the laboratory personnel and were noted in the monthly reports to NASA Headquarters. Microdensitometer service and other technical photographic analysis will continue for the GSFC during 1973.

Comparison of Printing Facilities Using ERTS Photography

Summary

A survey was made of prints produced in photographic laboratories at Goddard Space Flight Center and Sioux Falls. At Sioux Falls, losses from flare light and low resolution were substantially reduced in a second test run on 10 January 1973. Adjustments are needed to improve off-axis resolution in both optical and contact prints made at GSFC. The fidelity of tone and geometric reproduction is similar in all printers in this survey, and is probably satisfactory for most users of ERTS imagery. However, precise radiometric measurements are difficult from densitometry of ERTS pictures. The requirements should be reevaluated for sharpness, granularity, tone scale, and printing contrast in the 70mm N-2 print used to make 9.5-inch enlargements.

Because of the need for timely distribution of these test results, the data and conclusions from this work were issued as a separate report on 7 February 1973.

Introduction

An evaluation of printing and processing facilities for handling ERTS photography was initiated at Goddard Space Flight Center on 13 October 1972 in a meeting of personnel from several ERTS laboratories. With assistance from NASA management and Kodak engineers, test materials and procedures were defined that would yield a quantitative measure of photographic quality in contact and enlarged black and white transparencies. A representative ERTS scene image was produced on Eastman Electron Recording Film (ESTAR Base) SO-438 using the Electron Beam Recorder at GSFC. On the same film, Kodak made a special test frame containing gray scales, low contrast tribar targets, and log periodic patterns for measurement of modulation transfer function.

The test images were printed at GSFC, Kodak, and Sioux Falls in November 1972. Representatives from the NOAA laboratory at Suitland, Maryland attended the original planning meeting but no prints were made at this laboratory. A second print was made at Sioux Falls on 10 January 1973 after improvements were made to their Bessler enlarger.

This report describes the analysis made by Kodak from the printed pictures and test frames.

Procedure

The test scene on SO-438 film was the red light image of the Seattle, Washington area recorded by the Return Beam Vidicon on 29 July 1972. Although the gray scale at the edge of the scene runs from 0.12 to 2.02, scene limits measured with a 1.5mm aperture are D min 0.14 and D max 1.71; average scene density is near 1.0. This scene includes snow, clouds, water, and both rural and urban areas. An image area showing suburban Seattle located about half way to the edge of the scene was enlarged from the original film and all print films.

The test frame is shown in Figure 1 along with density data for the areas indicated. From this frame we can measure modulation transfer function and low contrast tribar resolution in two orthogonal directions on axis and at each corner. MTF is calculated by computer analysis of log periodic bar patterns. Eight small squares plus the background density near the middle of the frame comprise a 9-step gray scale for measurement of tone reproduction. Tone distortion is measured by comparison of densities from two patches near each edge of the frame with similar patches in the center.

Four large squares permit measurement of granularity at four density levels, but these areas were not used in this test. Geometric distortion was measured by comparing the length of the full tribar pattern in the center of the frame with the same length in each corner.

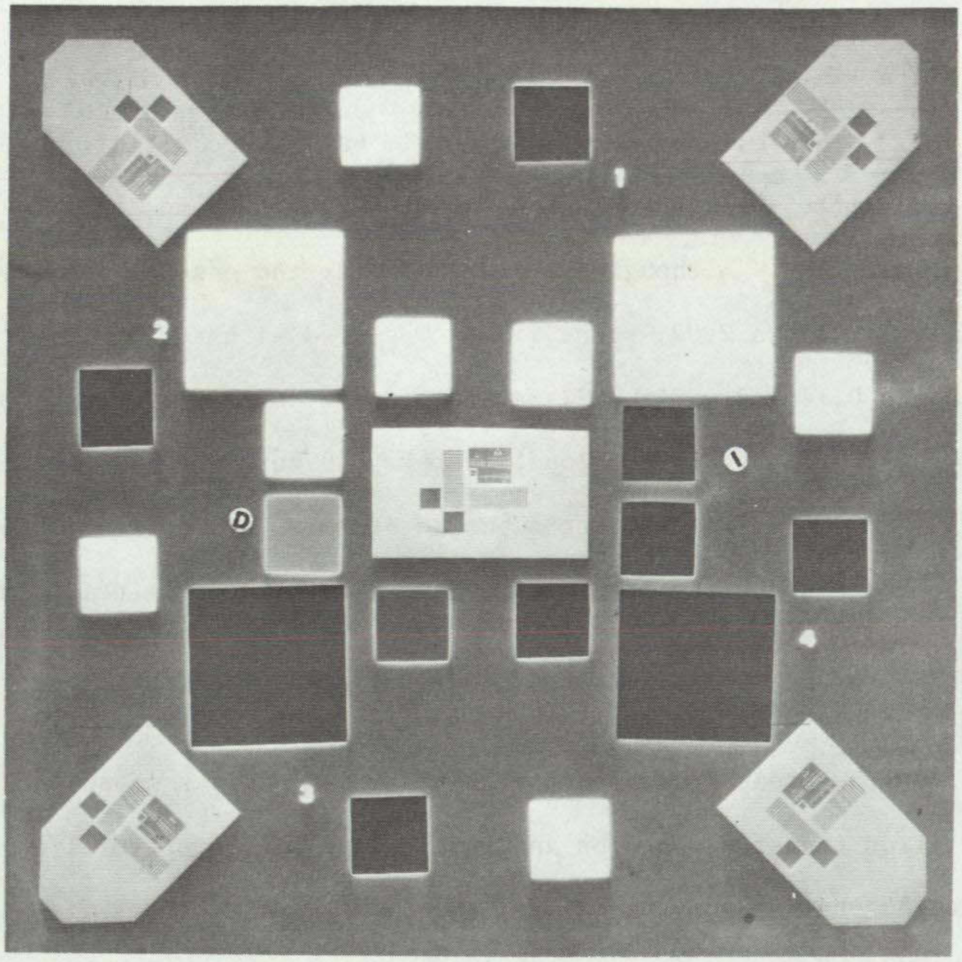


FIGURE 1

P-1 ORIGINAL TEST FRAME
KODAK SO-438 FILM

Central Gray Scale

	Density	
A	0.07	
B	0.28	
C	0.49	
D	0.83	
E	0.96	Background
F	1.16	
G	1.56	
H	2.12	
I	2.47	

Numbered Off-Axis Test Areas

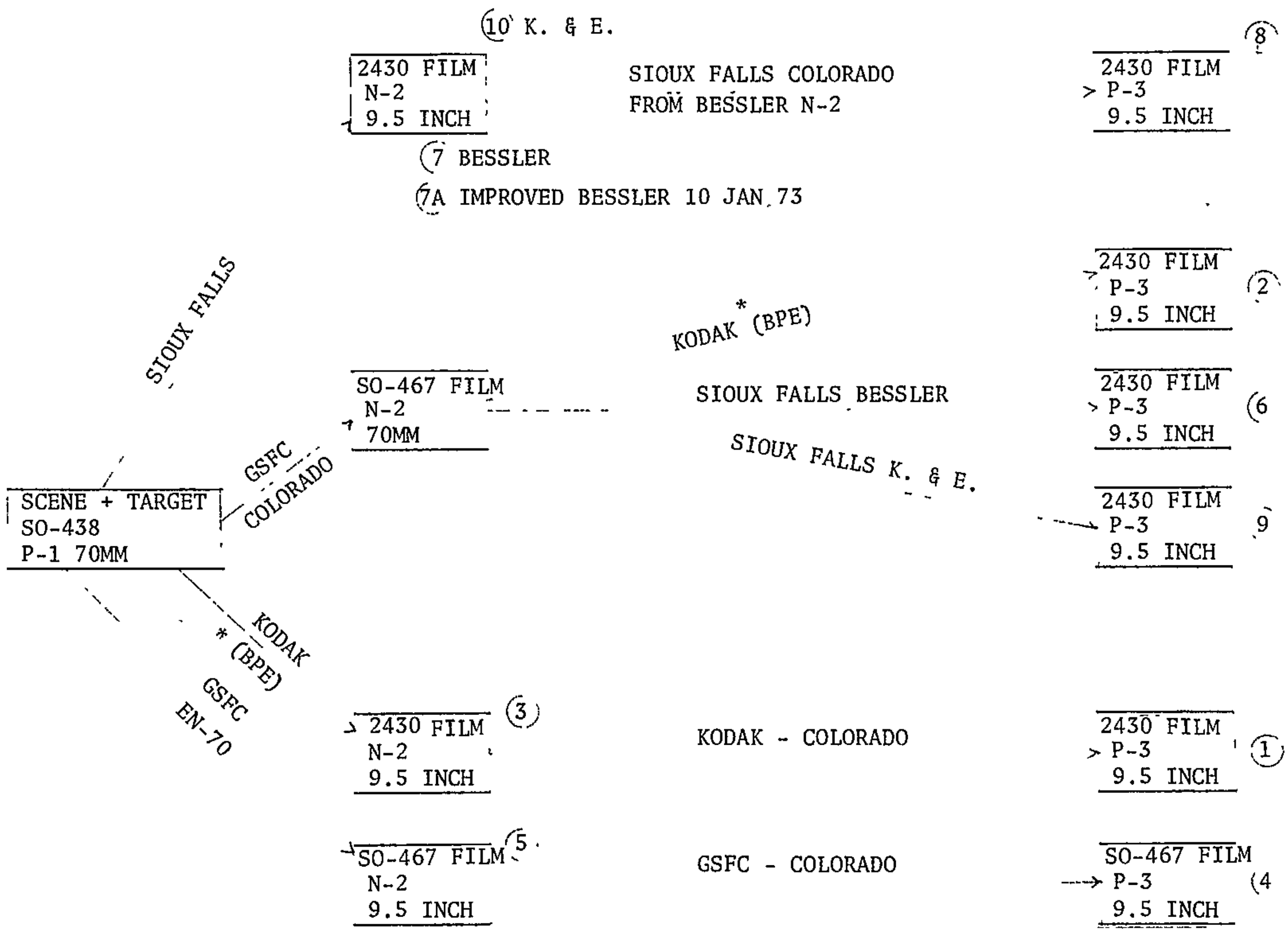
Corner or Edge	Edge Uniformity Patches	Large Granularity Test Patch	*2.4:1 Tribar Targets Limiting Resolution line pairs/mm	
1	0.25	0.26	H	188
	1.60		V	188
2	0.27	0.48	H	188
	1.59		V	178
3	0.27	1.55	H	168
	1.62		V	200
4	0.26	2.48	H	158
	1.58		V	178
Center	----	----	H	200
			V	200

* Background density = 0.93; tribar density = 0.55

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

ERTS INTERLABORATORY SURVEY

FIGURE 2



* BPE IS THE KODAK BEACON PRECISION ENLARGER.

TABLE I

ERTS PRINTERS
TRIBAR RESOLUTION READINGS

Values are in line pairs per mm for a target contrast of 2.4·1.

Print No.	Printing System	Print Polarity	Tribar Orientation	Axial	CORNERS 1	2	3	4
1	EK P-3 from 9.5" EK N-2	P	H	23	21	21	22	22
			V	21	21	21	22	23
2	EK P-3 from 70mm N-2	P	H	18	9	12	10	10
			V	19	12	14	13	12
3	EK 9.5" N-2 from 70mm P-1	N	H	22	23	25	25	25
			V	23	23	26	26	25
4	GSFC P-3 from 9.5" N-2	P	H	26	21	19	22	20
			V	24	19	19	11	15
5	GSFC 9.5" N-2 from 70mm P-1	N	H	24	19	15	17	20
			V	24	15	14	11	14
6	SF-Bessler P-3 from 70mm N-2	P	H	9	8	10	8	9
			V	13	8	7	7	7
7	SF-Bessler 9.5" N-2 from 70mm P-1	N	H	10	16	13	10	14
			V	11	10	11	10	8
7A	SF-Improved Bessler 9.5" N-2 from 70mm P-1	N	H	20	18	19	20	22
			V	22	18	20	18	21
8	SF P-3 from 9.5" SF-Bessler N-2	P	H	7	16	10	10	11
			V	11	10	9	7	8
9	SF-K&E P-3 from 70mm N-2	P	H	7	7	7	7	7
			V	11	7	7	8	7
10	SF-K&E 9.5" N-2 from 70mm P-1	N	H	10	11	13	10	14
			V	17	12	14	15	12
N-2	GSFC 70mm contact print from P-1	N	*H	25	11	13	14	14
			*V	24	13	15	13	15
N-2	† EK 70mm 2420 film contact print from P-1	N	*H	25	23	23	25	25
			*V	25	23	26	26	25
N-2	† EK 70mm 2430 film contact print from P-1	N	*H	42	42	42	40	37
			*V	42	40	35	40	47
P-1	Original Test Target on Kodak SO-438 film	P	*H	60	56	56	47	47
			*V	60	56	53	60	53

* Resolution values are those that would be observed on a perfect 9.5 inch enlargement made with no losses at 3.369X.

† 2420 is KODAK Aerographic Duplicating Film 2420 (ESTAR Base)
2430 is KODAK Fine Grain Aerial Duplicating Film 2430 (ESTAR Base)

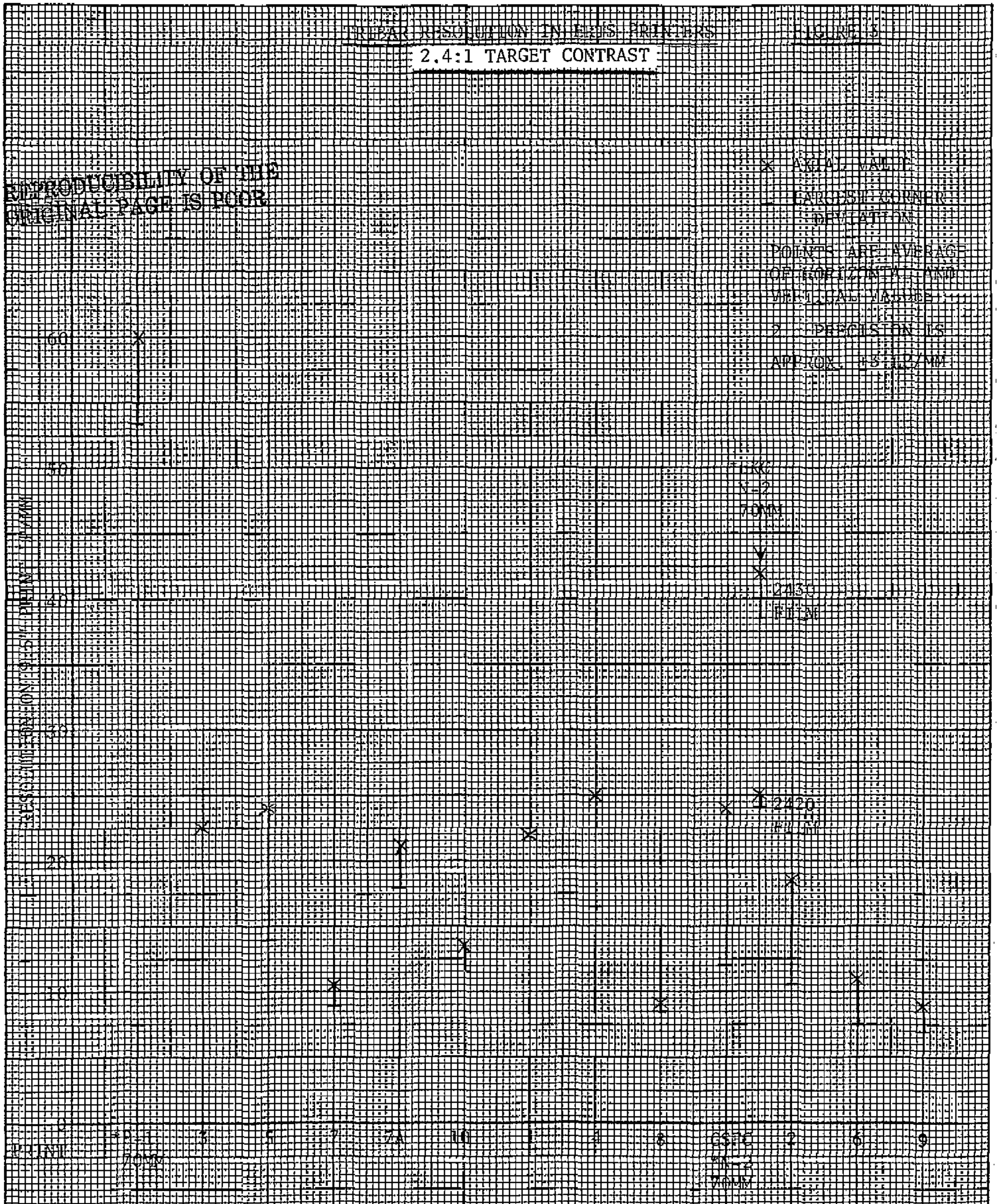


FIGURE 3
2.4:1 TARGET CONTRAST
REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR
AXIAL VALUE
LARGEST CORNER DEVIATION
POINTS ARE AVERAGE OF HORIZONTAL AND VERTICAL VALUES
PRECISION IS APPROX. ±3 L/MM
RESOLUTION ON 9.5" PRINT L/MM
0
10
20
30
40
50
60
70MM
2430 FILM
2420 FILM
POINT
*P-1 70MM
3
5
7
7A
10
1
4
8
GSFC 70MM
2
6
9
POLARITY
P
N
N
N
N
N
P
P
P
N
P
P
P
FROM P-1
FROM 70MM
* VALUES EQUIVALENT TO THOSE ON A PERFECT 9.5 INCH ENLARGEMENT

80 lp/mm by contact printing and to 25 lp/mm by optical printing, but in both cases this limit is about the same test chart. Apparently for this target contrast the losses due to the enlarger lens at 25 lp/mm are approximately equal to the loss caused by the Kodak 2420 (or SO-467) film in contact printing at 80 lp/mm.

Both negatives made by GSFC on SO-467 film (5 and N-2) falloff in resolution at the corners. While the drop in sharpness on the optical print (5) might be expected, the loss at the edges of the contact N-2 is surprising. Apparently improper web tension or roller alignment on the Kodak Colorado printer at GSFC is causing a slight separation between original and print film at the edges of the 70mm strand. Adjustment to lower and more nearly equal tension on the supply and takeup strands of the P-1 should cure this problem. Examination of 5 of the 8 contact N-2 prints made by GSFC revealed low corner resolution (12 to 14 lp/mm) on all, and one showed double imagery even on axis. Parallel alignment between the drum and pressure roller should remove any slippage or chatter.

As a check on the potential quality of contact prints from a P-1 original, Kodak made 70mm N-2 prints using the Colorado printer on 2420 film (similar to SO-467 film) and 2430 film. Low contrast tribar resolution values from these prints are plotted on Figure 3 near the data from the GSFC N-2. The print on 2420 film showed the equivalent of 24-25 lp/mm uniformly at all 5 check points, while the finer-grained 2430 film yielded about 40 lp/mm. Since the spacecraft scanning system limits resolution on 9.5 inch prints to a maximum of 15 lp/mm, it is not clear that use of 2430 film would give improved 70mm N-2 prints.

Even a small improvement in sharpness would be useful as the Kodak enlargement (2) made from the 70mm N-2 is poorer than the print (3) made directly from the P-1. Prints (1) and (4) made by contact from enlarged N-2's are also better than print (2).

All prints made at Sioux Falls (7), (10), (8), (6), and (9) show a resolution of about 10 lp/mm regardless of whether the P-1 or 70mm N-2 is used as a starting point. However, a later test (7A) made on 10 January 1973 after the Bessler enlarger had been modified, showed 21 lp/mm, a great improvement over the first test. These changes included correct placement of the condensers and light source, removal of the glass negative carrier, and precise alignment of the enlarging lens and film planes. An enlarging lens of higher quality is on order and when installed should yield an output close to 25 lp/mm as obtained at Kodak and GSFC.

Modulation Transfer Function

MTF is a more significant measurement than tribar resolution in that it gives information on image quality at all frequencies of interest to the system. In this test MTF was calculated for two orthogonal orientations on axis; these values were averaged to obtain the curves shown in Figure 4. MTF test patterns were imaged at the corners but were not analyzed.

Figure 4 reveals three groups of curves:

P-1 and N-2	Original target and contact print
1, 2, 3, 4, 5	Enlargements made by Kodak and GSFC
6, 7, 8, 9, 10	Enlargements made by Sioux Falls in first test

The MTF of the two 70mm films exceeds 0.5 at all points, with the GSFC contact N-2 higher in MTF than the P-1 at all frequencies tested. This difference is caused by chemical edge enhancement in processing Kodak SO-467 film and probably disappears at frequencies slightly finer than those in Figure 4.

The curves made at Sioux Falls predict the observed limiting resolution of 9 to 13 lp/mm, while limiting resolution for the Kodak and GSFC prints at 18 to 25 lp/mm falls beyond the finest frequency in Figure 4. However, extrapolation of MTF curves for these prints leads to about the same threshold MTF (0.1 to 0.15) for 2.4:1 contrast resolution that was observed on the Sioux Falls prints.

Substantial improvement at Sioux Falls is shown by MTF curve 7A made after the Bessler enlarger was modified. This curve is now similar to those obtained at the other two laboratories. Adjustment of the Sioux Falls Bessler machine also removed a large difference (up to 0.3 in modulation) between the MTF curves measured on axis but perpendicular to each other. This effect is another indication of the need for critical and positive alignment between

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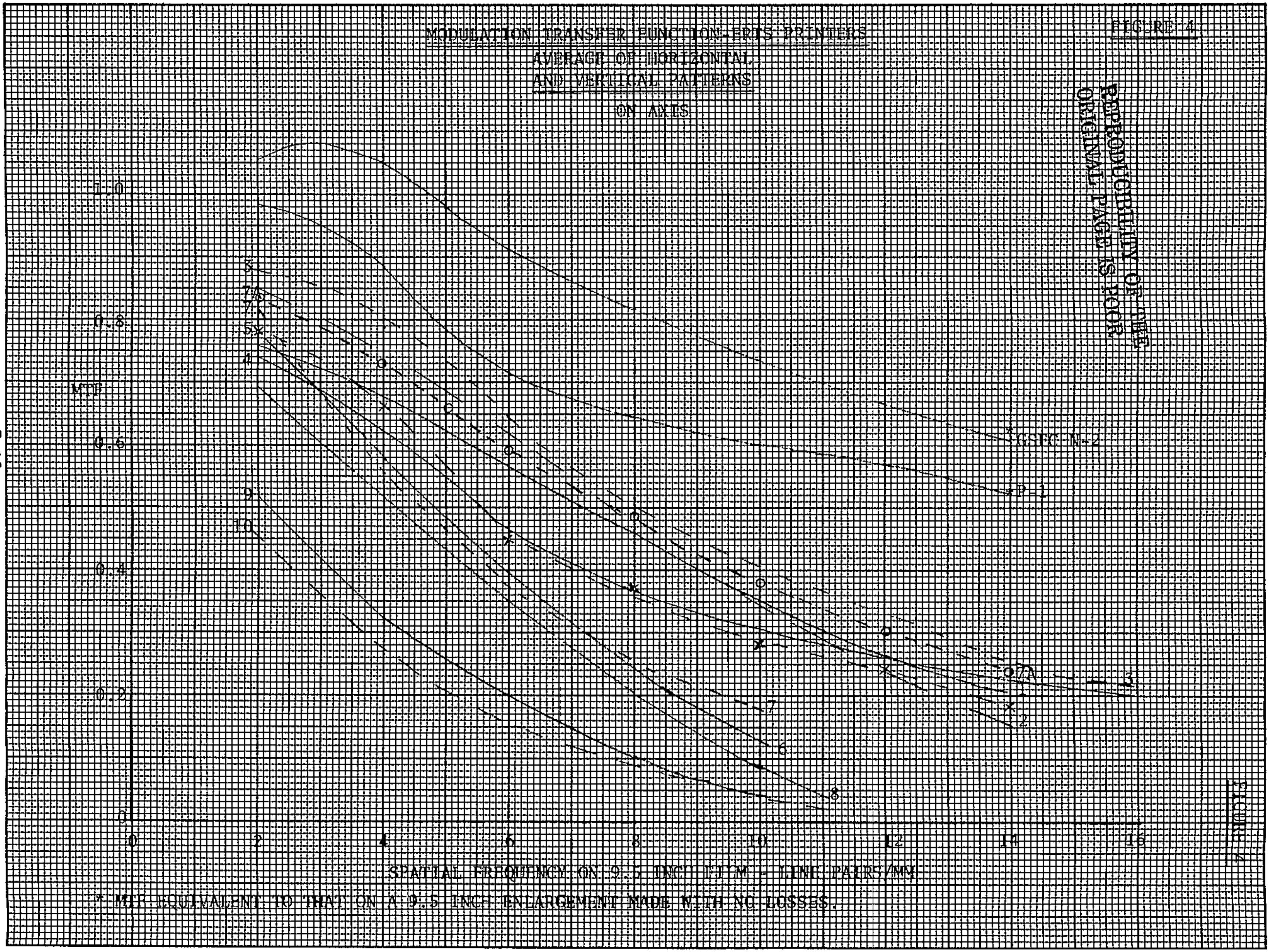


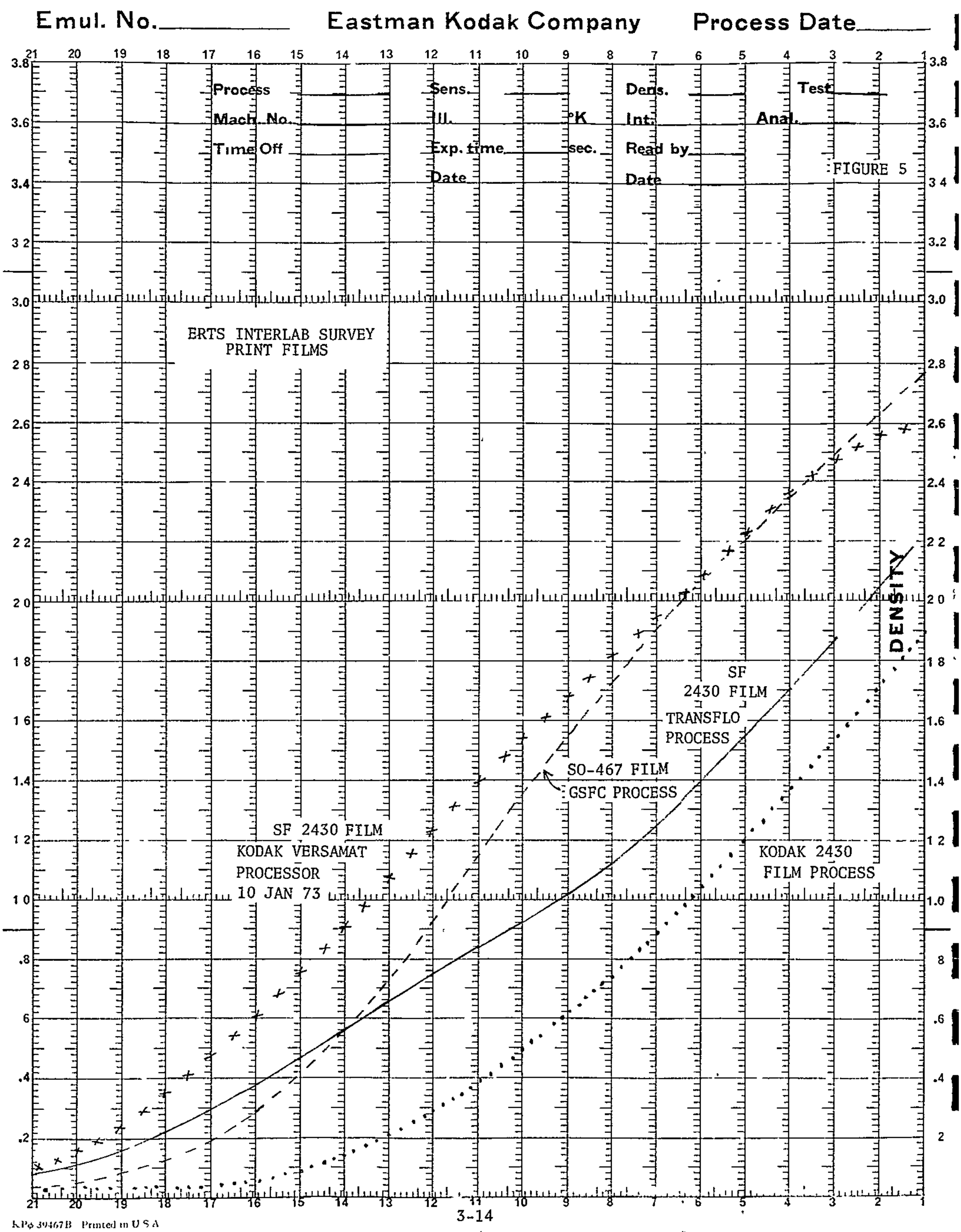
REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

enlarger lens and film planes in ERTS printing. Orthogonal MTF curves measured on Kodak and GSFC prints were nearly identical, indicating proper alignment of lens and film.

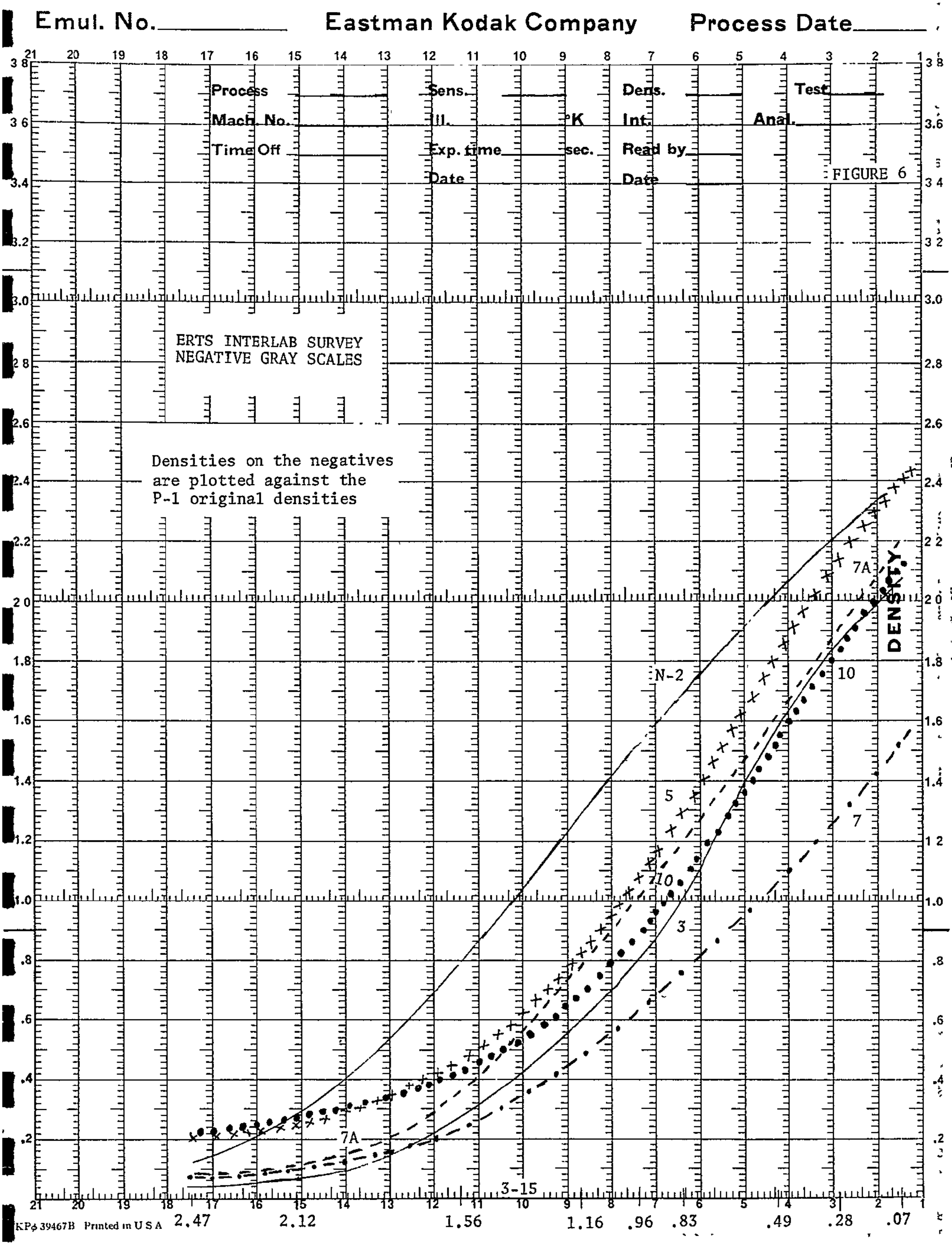
Tone Reproduction

Print film characteristics curves exposed on each laboratory sensitometer and processed with the prints are shown in Figure 5. Here, the speed relationships are not correct but the relative gamma and curve shape are significant. Figure 6 shows print-through negative gray scales made from the 9 center test areas of the P-1. The most uniform scale - the N-2 contact print - reproduces P-1 densities from 0.07 to 2.47 in a nearly linear manner covering densities from 0.12 to 2.40. All optical negatives show tone distortion, especially at low P-1 densities, with the Sioux Falls print (7) having 0.7 less density range than the better prints. However, by using the Transflo curve in Figure 5 it can be shown that prints from the Bessler (7) and K&E (10) enlargers at Sioux Falls would be similar if negative (7) had been printed using 0.45 log E more exposure. Both enlargers have considerably more flare than that shown in the Kodak print (3).

In the second test at Sioux Falls, a much better optical print (7A) was produced. This curve has a density range equal to that produced by Kodak and GSFC and shows very linear tone reproduction, though not as good as on the contact-printed N-2.



Emul. No.
Eastman Kodak Company
Process Date
Process
Sens.
Dens.
Test
Mach. No.
Ill.
°K
Int.
Anal.
Time Off
Exp. time
sec.
Read by
Date
Date
FIGURE 5
ERTS INTERLAB SURVEY
PRINT FILMS
SF
2430 FILM
TRANSFLO
PROCESS
SO-467 FILM
GSFC PROCESS
SF 2430 FILM
KODAK VERSAMAT
PROCESSOR
10 JAN 73
KODAK 2430
FILM PROCESS
DENSITY
KPφ 39467B Printed in U S A



Emul. No.
Eastman Kodak Company
Process Date
Process
Mach. No.
Time Off
Sens.
Ill.
°K
Exp. time
sec.
Date
Dens.
Int.
Read by
Date
Test
Anal.
FIGURE 6
ERTS INTERLAB SURVEY
NEGATIVE GRAY SCALES
Densities on the negatives
are plotted against the
P-1 original densities
N-2
5
10
3
7A
7
3-15
DENSITY
2.47
2.12
1.56
1.16
.96
.83
.49
.28
.07
KPϕ 39467B Printed in U S A

Since the Kodak and GSFC negatives have about the same contrast in Figure 6, the enlarger at GSFC must have slightly more flare because the curve for SO-467 film in Figure 5 has higher gamma than the one for Kodak 2430 film.

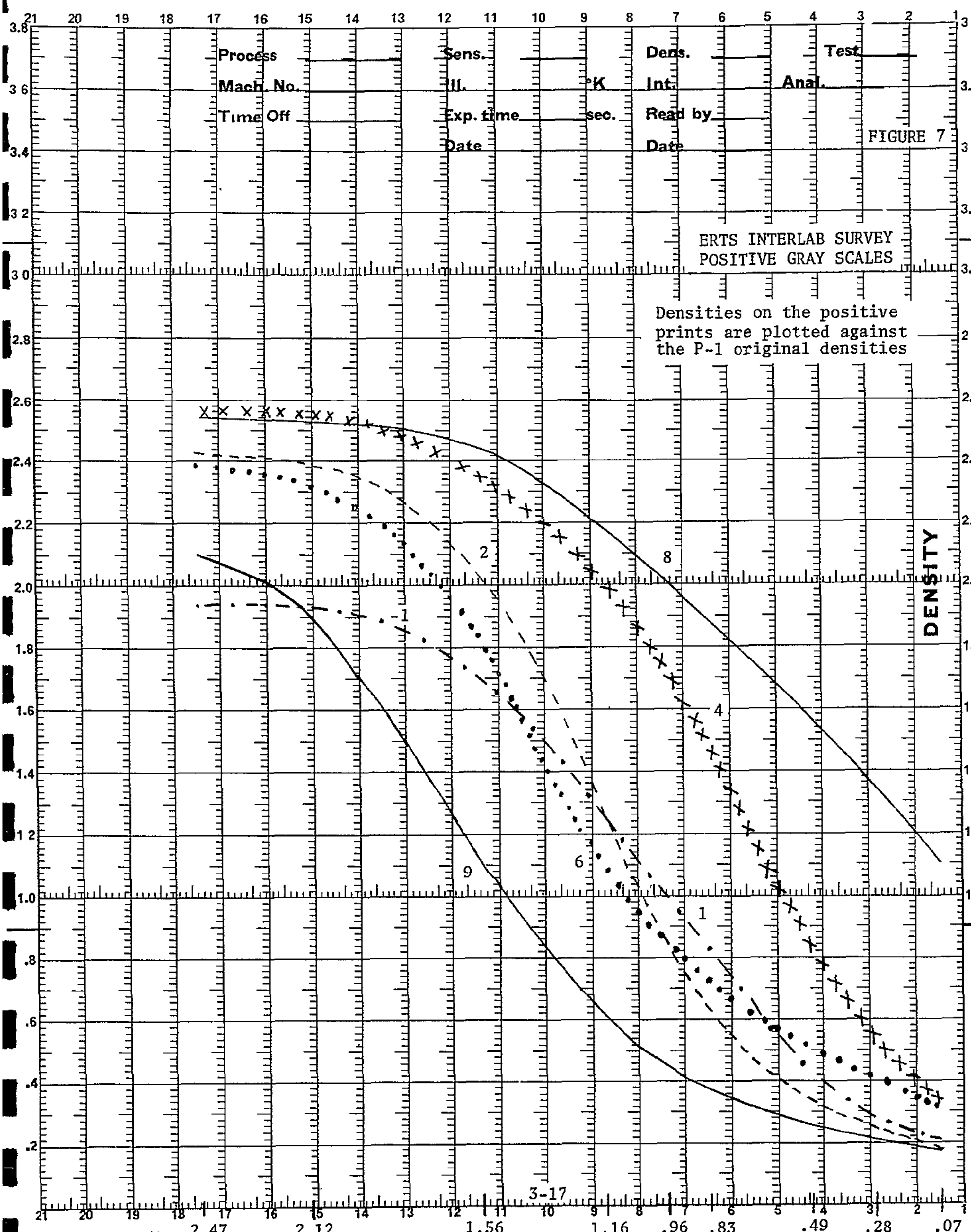
Figure 7 shows overall tone reproduction curves for positive prints made in this test. Prints (1), (4), and (8) reflect the characteristics of previously enlarged negatives, while prints (2), (6), and (9) are made from the GSFC contact N-2. Print (8) from the Sioux Falls Bessler shows the expected compressed tone scale, and prints (6) and (9) also exhibit the effects of flare in the Sioux Falls equipment. Non linearity in the Transflo processor curve for 2430 film in Figure 6 also contributes to tone distortion in the Sioux Falls prints.

Of particular interest is the difference in contrast on Kodak prints (1) and (2). Print (1) has a gamma of 1.24 and was contact printed from a negative that was enlarged from the P-1. Print (2) is enlarged from the 70mm N-2 made by GSFC on SO-467 film; it has a gamma of 2.14. Since the printers and print film are identical for both prints, it is evident that the enlarger is "viewing" the N-2 on SO-467 film at much higher gamma than the P-1 on SO-438 film. If the N-2 made by GSFC is to be a true copy of the P-1 it should appear to have the same contrast by either optical or contact printing. Further study of the requirements for MTF, granularity, and tone reproduction on the 70mm N-2 may be needed to optimize the usefulness of this record in all kinds of printers. Possibly a special 70mm N-2 of finer grain and lower gamma may be necessary for those users who will make enlargements from this record.

Emul. No.________ Eastman Kodak Company Process Date________

Process ________ Sens. ________ Dens. ________ Test ________
Mach. No. ________ Ill. ________ °K Int. ________ Anal. ________
Time Off ________ Exp. time ________ sec. Read by ________
Date ________ Date ________

FIGURE 7



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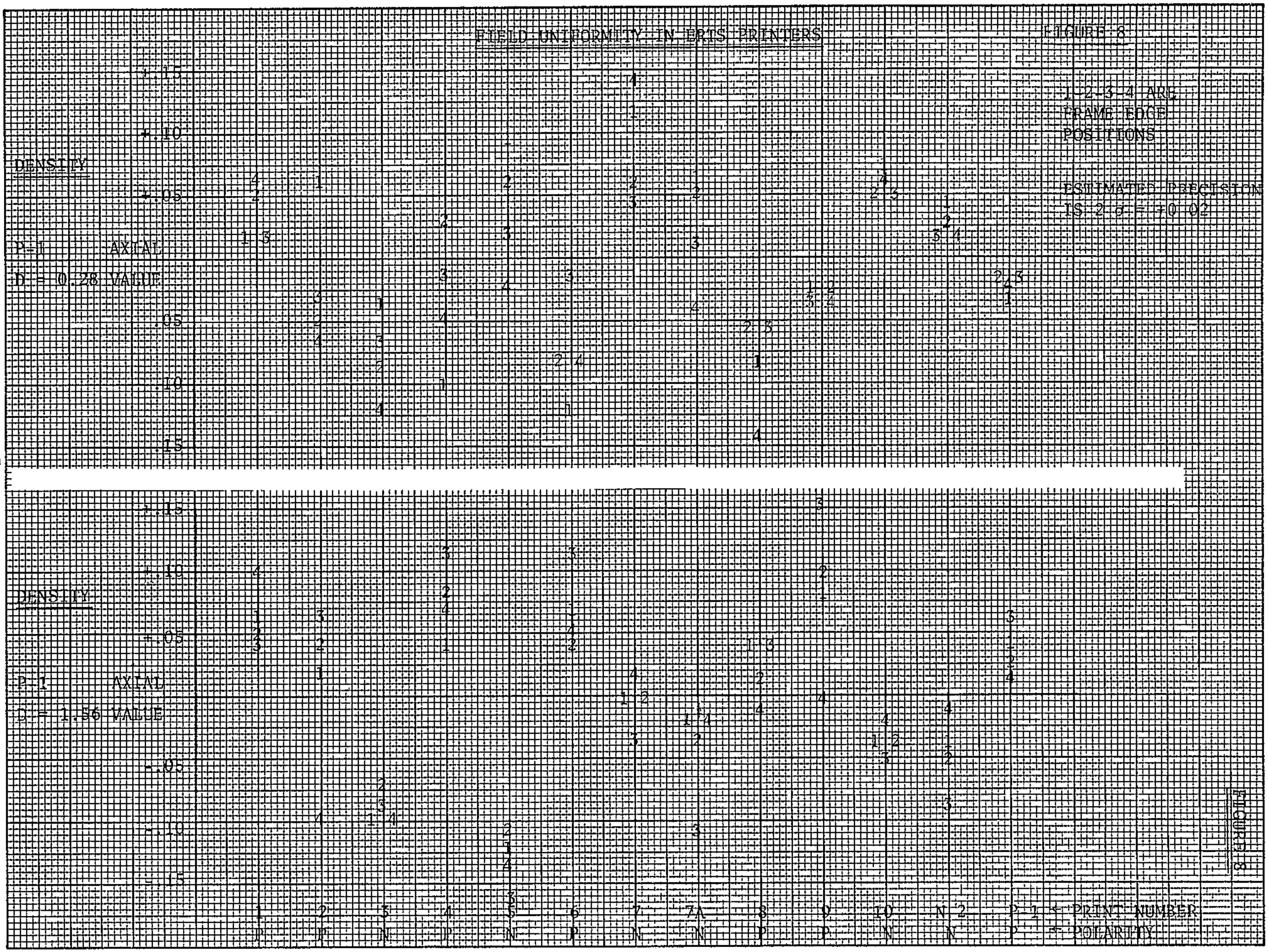
Another aspect of tone reproduction is the uniformity of tone rendition in all parts of the frame. This characteristic was checked by comparing the density of a light (D = 0.28) and a dark (D = 1.56) area near each edge of the P-1 test frame with the density of identical areas in the central gray scale. For both density levels, differences in the density between axis and edge are plotted in Figure 8. On this plot some edge areas deviate up to ±0.15 from the axial value, especially on prints (5), (7), and (9). Print (7A) shows some improvement in this respect over the first print (7) made on the Bessler enlarger at Sioux Falls.

Test areas at the edges and center of the original P-1 are uniform only to ±0.03 density, and this pattern is revealed and amplified in subsequent prints. Note that edge 3 at density 1.56 is high and remains that way on 5 of the 6 positive prints and is low on most negative prints. Also, at density 0.28 edge 1 is slightly low on the P-1 as it is on half of the positive prints; it is high on 5 out of 6 negative prints.

Absolute density values for the field areas are not shown in Figure 8 but are important. For instance, the apparent uniformity of print (9) at density 0.28 is caused in part by placement of the image near the toe of the characteristic curve; densities both on and off axis are compressed to a uniform value.

One point demonstrated by Figure 8 is the difficulty of precisely measuring apparent scene radiances by densitometry of a

[redacted] K+E [redacted] 10 X 10 TO THE ½ INCH [redacted] 359-1 [redacted]
KEUFFEL & ESSER CO MADE IN U S A



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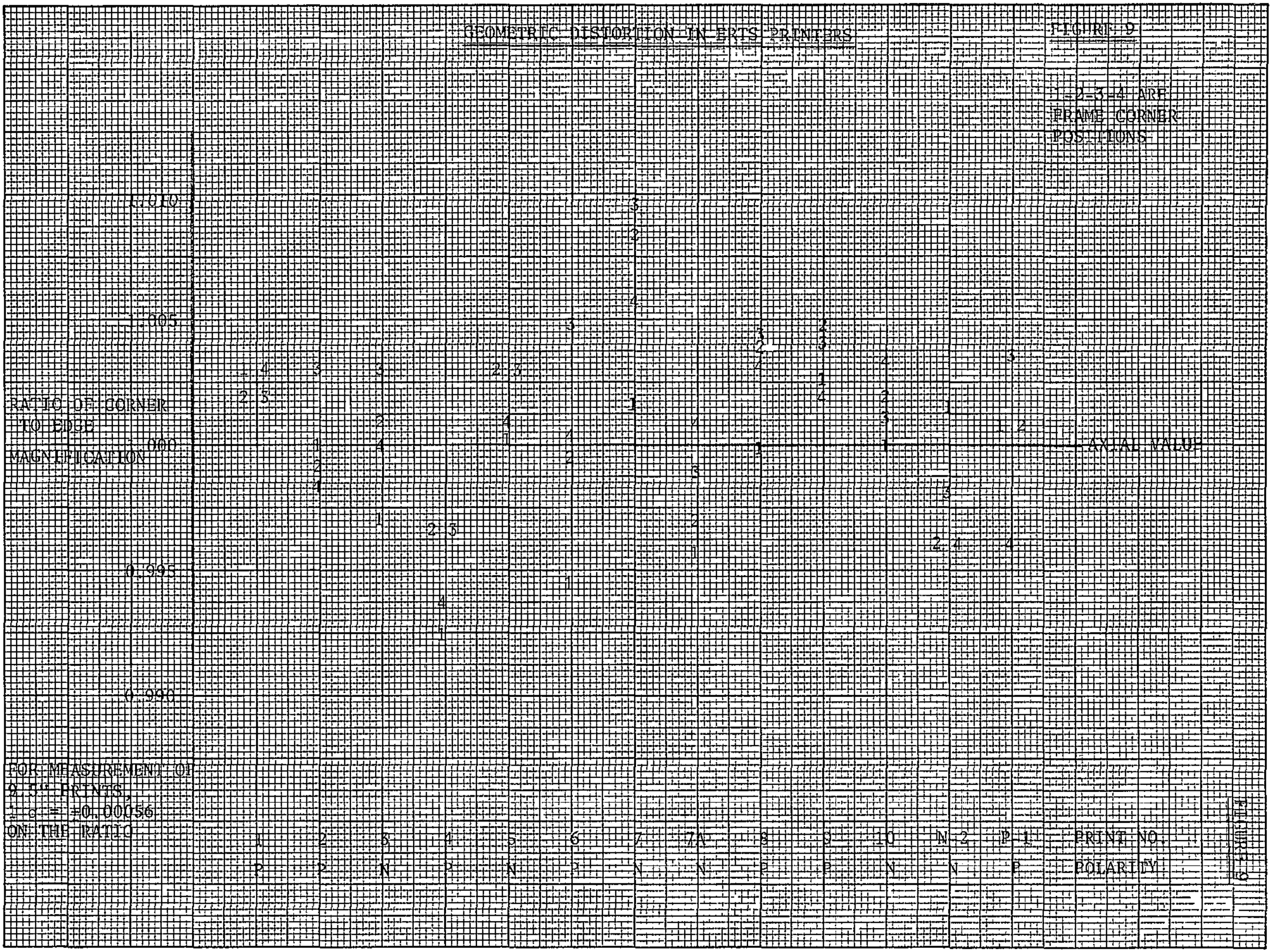
photographic print. To the expected errors in densitometry, processing and system parameters must be added the uncertainty from nonuniform printing revealed in Figure 8. At low densities, this last factor can introduce errors of up to ±50% in some prints.

Geometric Distortion

A measurement was made of the difference in magnification between each corner and the center of the frame. This ratio is plotted in Figure 9 for each enlargement and for the 70mm P-1 original and the N-2 made at GSFC. These data were obtained by measuring the length of the complete tribar array in each of the five positions. The length in each corner was then compared to that in the center to obtain the ratios plotted in Figure 9.

All areas on most of the prints show magnification ratios within ±0.005 of unity. The Bessler enlarger at Sioux Falls, print (7), showed up to 1% distortion, but this was reduced later (7A) by proper alignment of lens and film. It is not clear why print (4) made on the Kodak Colorado printer at GSFC should show poorer geometric properties than print (5) from which it was made. Distortion of prints made on the Colorado machine is usually ±0.03% or less. Properly designed and adjusted optical or contact printers probably do not show a serious amount of distortion compared to that caused by other parts of the ERTS imaging system.

K+E 10 X 10 TO THE 1/2 INCH 359-12
KEUFFEL & ESSER CO MADE IN U.S.A.

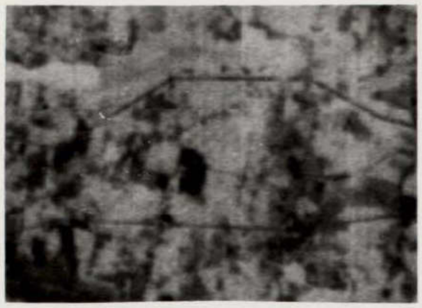


Picture Test

The enlargements in Figure 10 are made from part of the Seattle test frame (RBV No. 2) to illustrate the practical effect of the photographic and optical differences previously discussed. All are 5X enlargements from 9.5-inch prints except those labeled "GSF N-2" and "Original P-1" which are enlarged 16.8 times from the 70mm film. The six negative pictures at the top of Figure 10 were made by laboratories in this survey directly from the 70mm P-1 scene. Positive prints on the lower half of the page are made from 70mm or 9.5-inch N-2's and may be compared to the original P-1 image near the center of Figure 10. All scenes were enlarged onto KODAK Low Contrast Fine Grain Aerographic Duplicating Film (ESTAR Base) SO-355 which was then contact printed onto Kodabromide paper without dodging or other adjustment.

Individual EBR scan lines are reproduced in the GSFC contact N-2 and in enlargements (1), (3), (4), and (7A). Prints from the first test at Sioux Falls are soft and low in contrast, but a dramatic improvement is seen in the second test (7A). Careful comparison of prints (1) and (2) shows (1) to be sharper although much lower in contrast.

Prints made directly from the P-1 original [(3), (5), and (7A)] show more detail than those made from the GSFC N-2 [(2), (6), and (9)]. This difference is more pronounced in these scenes taken half way to the edge of the frame than it would be on axis, as the 3.369X optical printer at GSFC shows significant loss in resolution off axis.



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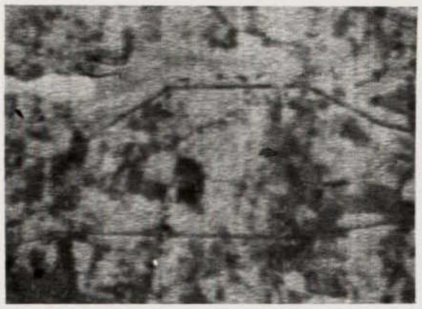
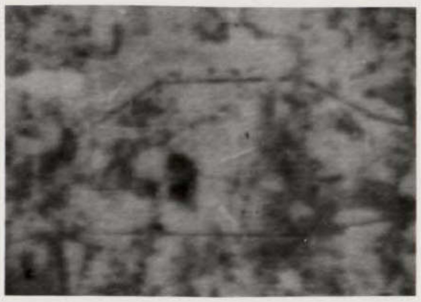


GSFC N-2

5



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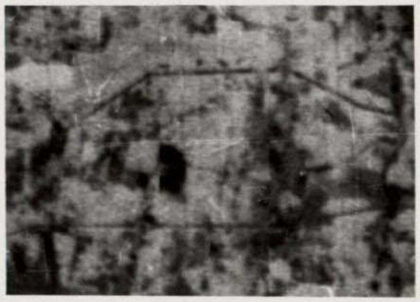
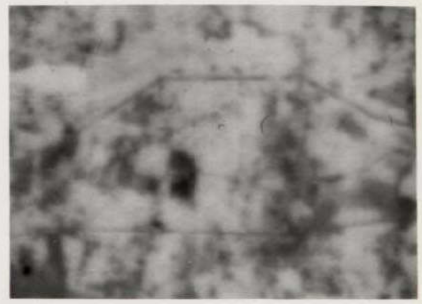


7A



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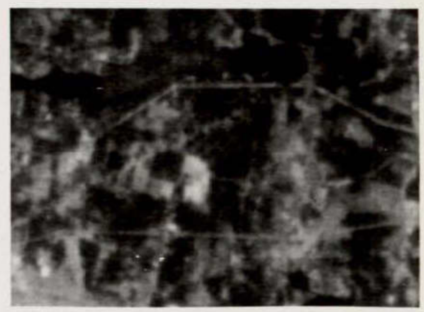
ORIGINAL P-1



1

6

4

FIGURE 10

ENLARGEMENTS FROM AREA IN SEATTLE TEST SCENE LOCATED HALF WAY TO EDGE OF FRAME. P-1 AND N-2 ENLARGED 16.8X; ALL 9.5 INCH PRINTS ENLARGED 5X. CONTRAST AND INTENSITY REPRODUCTION IS UNIFORM FOR ALL PRINTS.

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9

8

Processing of EBR Film

To insure proper radiometry and tone reproduction, NASA is striving for very low variability in the primary film record produced by the Electron Beam Recorder. This device exposes Eastman Electron Recording Film (ESTAR Base) SO-438 for subsequent treatment in the Kodak Versamat Processor Model 11. Kodak MX-641 Chemicals, diluted 1:1 are used in this processor to obtain the desired sensitometry in a reasonable development time.

The purpose of this work was to measure the variability of SO-438 film and processing in order to determine realistic operating tolerances for this recording system. Twelve rolls (70mm x 46 meters (150 feet)) of SO-438 film were obtained from stock similar to that used to fill orders for NASA-GSFC. Tests were made for film uniformity along and across the factory coated roll, for density variability during processing of 365 meters of film in 13 days, for densitometer variability, and for the effect of latent image keeping. Additional runs were made to learn the effect of changes in film travel speed and in developer temperature.

Figures 11 and 12 show that a change in development time (film travel speed) moves the D-log E curve very little while variations of 3°C in developer temperature have a significant effect. The dashed curve from the GSFC process is well matched

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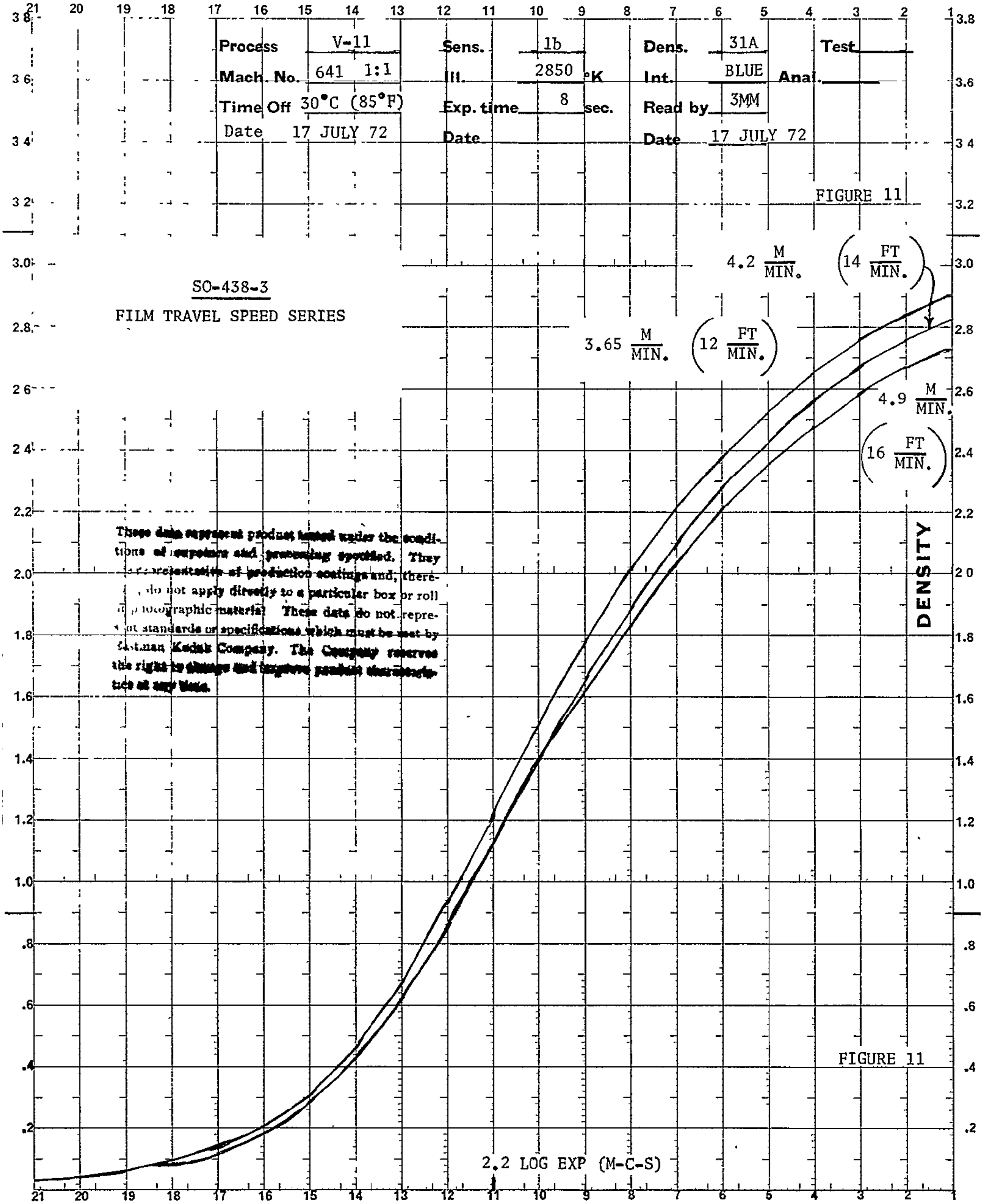

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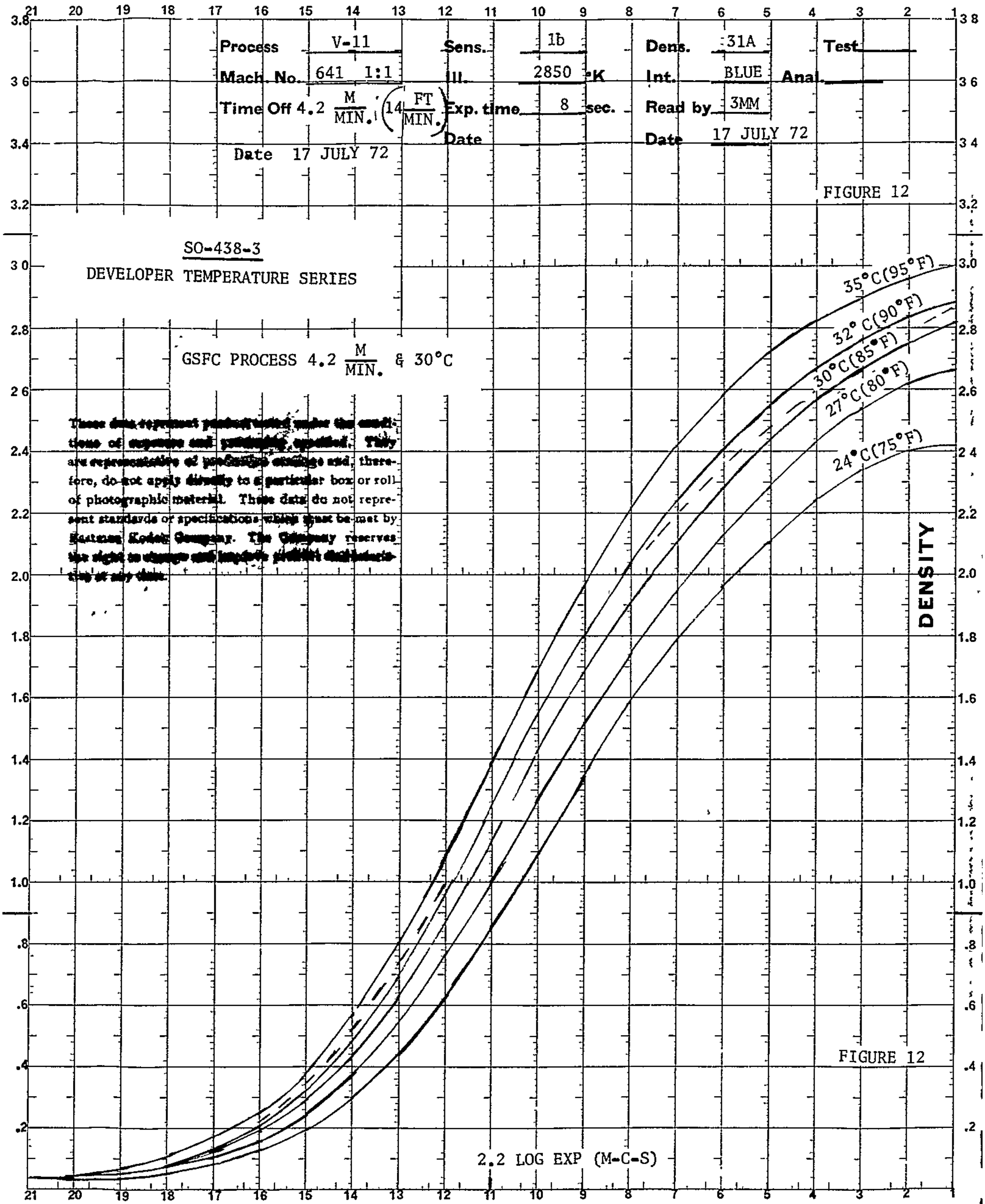

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by our run made under the same process settings. Exposure time is 8 seconds on the Kodak 1b sensitometer compared to 5 seconds on the GSFC Herrnfeld sensitometer.

Variability in the combination of SO-438 film and Kodak 1b sensitometer was measured by exposing two gray scales on strips from the head end of 11 rolls of film and similar scales at the middle and tail end of one 70mm roll. All strips were processed at one time and densities read on the Eastman Electronic Densitometer Model 31A using a 3mm aperture and a Kodak Status A blue filter. A density near 1.0 appears most sensitive to changes in film and processing and was selected for a statistical measure of film-sensitometer variability. The one sigma variation in density was ±0.03 along the roll and ±0.05 across the 11 rolls.

A similar one sigma value of ±0.006 was determined for the densitometer by reading the same gray scale 11 times in 10 days. Further tests revealed that sensitometry is not changed by processing gray scales with either the heavy or light exposure end first through the Kodak Versamat machine.

Extensive testing is required to properly study the overall variation in process control strips. Our tests were limited to processing 365 meters of 70mm film at two replenisher rates over a period of 13 days. Each roll of SO-438 film was flashed on a precision printer to a density of about 0.85 and was accompanied through the process by gray scales at the head and tail of the roll. All gray scale strips were cut from a single roll of film, randomized, exposed on the Kodak 1b sensitometer, and frozen prior to use.

Densities from four gray scale steps processed with the first 244 meters of film are shown in Figure 13. A developer replenishment rate of 70 mls/min. was used for all but the final run when no replenisher was used. Under replenishment is indicated in Figure 13 by a small loss in density with increasing footage (especially for Step 12, D = 0.95), but this effect is more apparent in Figure 14 which shows the loss in density on the flashed film.

The final three rolls of film were processed with a developer replenisher rate of 100 mls/min. and produced the nearly constant densities shown in Figure 15. Although these data are very limited evidence on which to base a replenisher rate or to determine process control limits, it does appear that 100 mls/min. is a useful replenisher rate. Statistical analysis of the density variation for Step 12 in both replenisher runs yields a one sigma value of ±0.02 after removal of the overall density loss at 70 mls/min.

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KEUFFEL & ESSER CO MADE IN U.S.A.

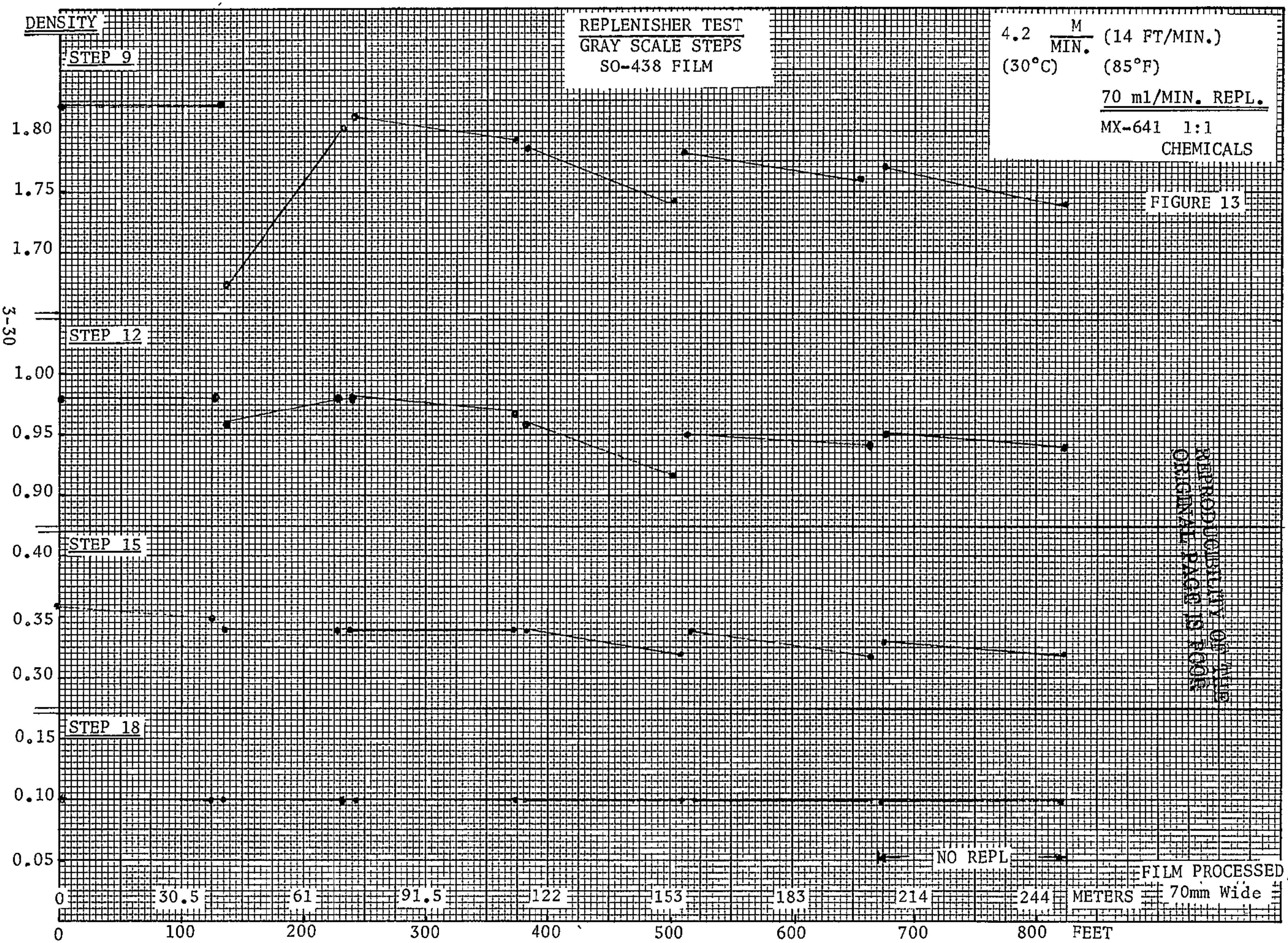

FIGURE 13

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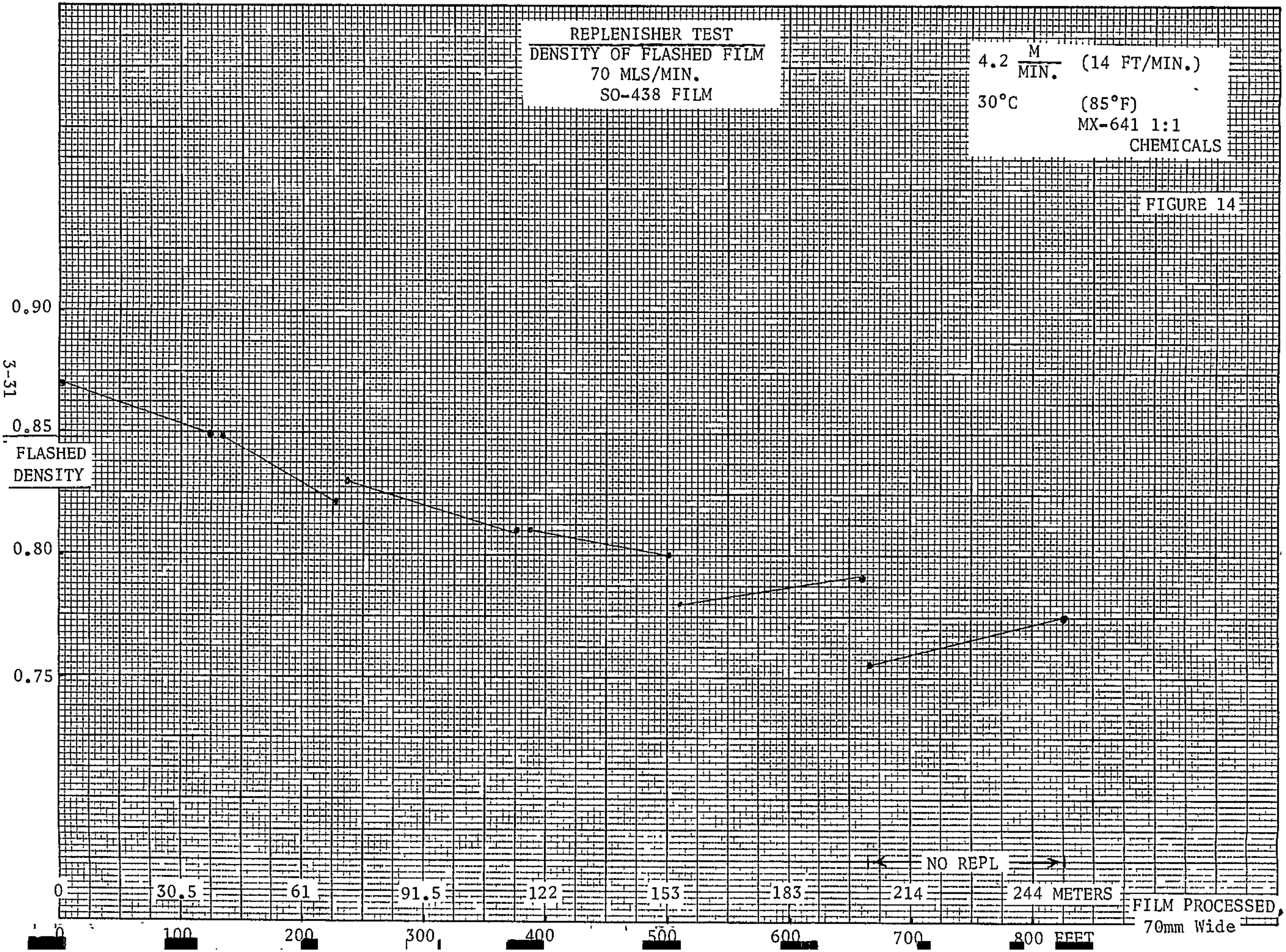

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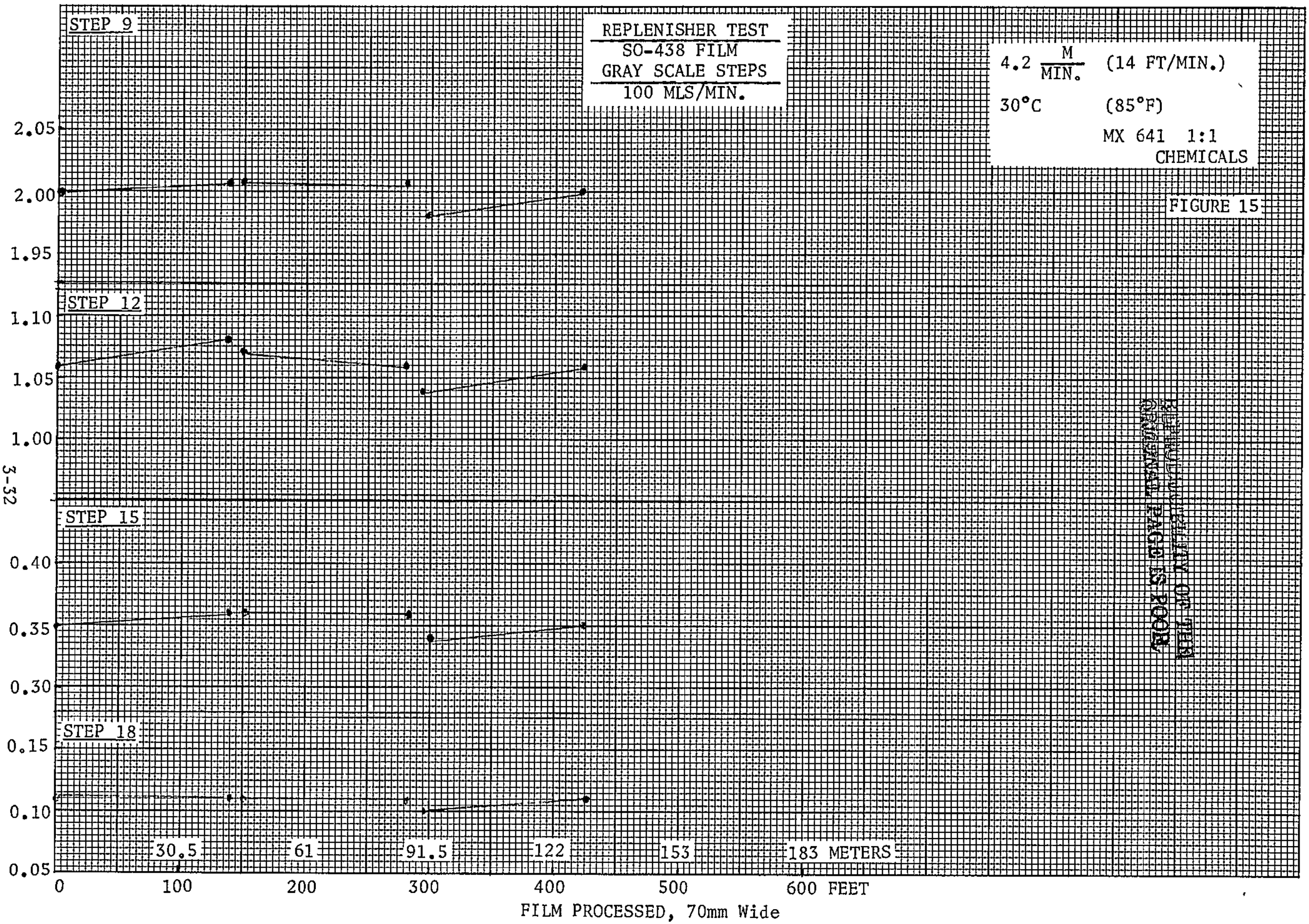

FIGURE 15

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The preceding variability factors are summarized in Table II where it appears the contribution from film plus sensitometer is 3 times greater than the overall variance. However, the process control value of ±0.02 will increase as the sample size increases, and may approach the ±0.05 for Across Roll variability as the number a gray scales becomes very large. An overall one sigma limit of ±0.04 at density 1.0 seems reasonable for a series of control strips cut from one roll. This value agrees fairly well with experience on the process at GSFC.

Table II also describes the 0.10 loss in density (at D = 1.0) caused by latent image keeping for 1 to 2 days at 23°C. In this test three gray scales were exposed for each condition on randomized strips of SO-438 film using the Kodak Model 60 Sensitometer. Strips were stored at either -18° or 23°C for 6 to 48 hours after exposure, then were all processed together in the Kodak Versamat processor at 30°C and 4.2 meters/minute.

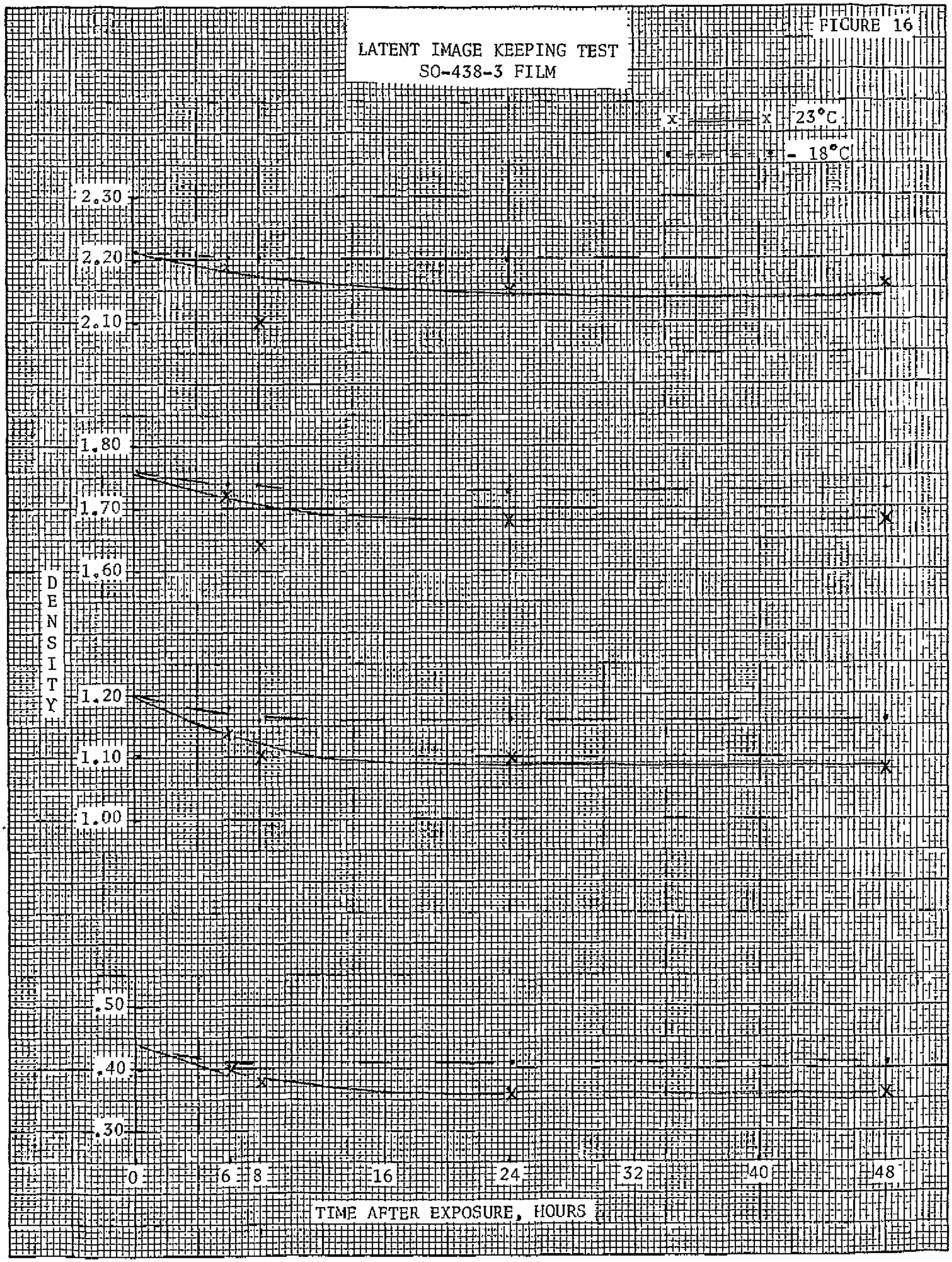
Densities from the 3 strips were averaged for each test condition and are plotted in Figure 16 for 4 of the gray scale steps. Even at -18°C some of the image is lost 8 hours after exposure, but the effect is 3 times greater at 23°C. Since latent images losses at room temperature seem to level out after 24 hours, it is suggested that control strips be kept at 20°C for 1 or 2 days after exposure and prior to freezing to allow this aging effect to occur.

Table II

Variability Tests on Kodak SO-438 Film

	±1 Sigma at Density $\cong$ 1.0
Kodak 1b Sensitometer + SO-438 Film - Along Roll	0.03
- Across Roll	0.05
Kodak 31A Densitometer	0.006
Head First or Tail First on Kodak Versamat Processor	0.00
Overall Process Control	0.02
18 samples 365 meters (1200 feet) 1b control strips cut from single roll	

Effect of latent image keeping 1 to 2 days at 23°C (73°F)	Density loss = 0.10



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Measurement of Distortion on the Colorado Printer

As an aid in locating sources of geometric distortion in ERTS photographs, we evaluated the distortion caused by printing an original SO-438 film onto KODAK Aerial Duplicating Film (ESTAR Base) SO-467 using the GSFC Colorado printer. Distortion is determined by measuring the moiré pattern formed when an original and the print are compared to a glass plate master for a repetitive pattern image.

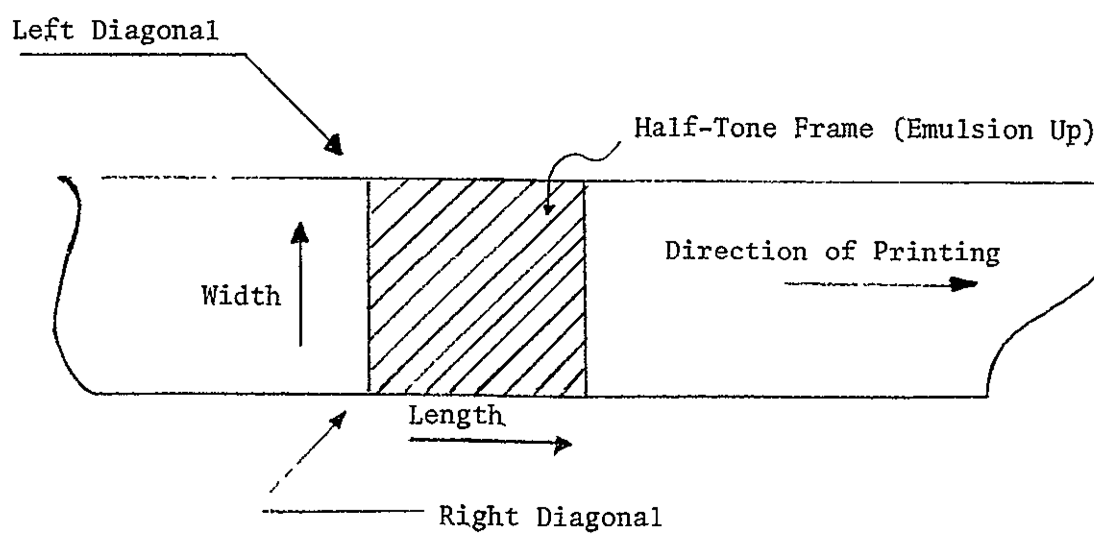
A half tone screen of 40 lines/mm was carefully printed onto 70mm SO-438 film in five 70mm square areas spaced at equal intervals in a roll of 36.5 meters. After tests run in Rochester to verify the quality of this original film pattern, the roll was printed onto SO-467 film using the Kodak Colorado printer at the ERTS Photographic Laboratory. Both the original SO-468 film and the SO-467 print film are superimposed on a second glass master having a line frequency that is slightly different from that on the original glass screen. The line patterns on the glass master and the film image interact to produce a moiré pattern that is measured for frequency and uniformity. Comparison of the patterns made by the original film and the print film yields a measure of the distortion caused by exposing and processing the print film.

The results of this test are summarized below where Test Area #1 was printed first on the roll. All film was on standard 5.4 cm diameter "A" cores.

Distortion Expressed as Percent Change in Size

Test Area	Length	Width	L Diag.	R Diag.
1	-0.028	+0.017	0.014	-0.072
2	-0.037	+0.017	0.007	-0.017
3	-0.035	+0.012	0.013	-0.034
4	-0.031	+0.016	0.011	-0.021
5	-0.031	+0.015	0.009	-0.024

The orientation of the above four directions is depicted by the following diagram.



The Colorado Printer reduces the length of the frame while slightly increasing the width. The length reduction is caused by the wrapping the original over the duplicating film which in turn is wrapped over a drum. For every revolution of the drum, slightly less duplicating film than original material will pass the printing aperture.

The difference in diagonal distortion values indicates that square frames take on a parallelogram shape. This change is caused by rollers that are not in perfect alignment with the film.

While the negative values for length distortion could be decreased by increasing tension in the original strand, this would tend to accentuate the diagonal distortion differences.

It is concluded that the best tension balance for distortion occurs at or near the recommended tension settings for the film combinations tested. The tensions for this test were measured and appear below:

FILM TENSION ON KODAK
COLORADO PRINTER

<u>Supply Spindles</u>

Tension Setting	Tension Range
45	2.3 - 3.8 kgms (5.12 - 8.35 lb.)

<u>Take-Up Spindles</u>

Tension Setting	Tension Range
65	0.4 - 1.2 kgms (1.62 - 2.68 lb.)

The variation in tension is caused by changes in spool diameters as the material passes from the supply to the take-up spindles. This variation does not significantly affect the distortion values from the test film materials.

Filter Curves

During our work on the Colorado Printer, personnel at the NDPF requested transmission curves for the filters in this machine. These data are given in Figure 17.

Microdensitometer Service

Early in our association with the ERTS program, Mr. A. Shulman requested that we read on a Kodak microdensitometer a number of test patterns generated in the ERTS printing cycles. This request stemmed from the need to improve on the speed of such service received when previous material had been sent to a laboratory at Los Alamos, N. M. Data were needed on granularity, modulation transfer function, and edge sharpness for several printing stages. Multiple film samples for each stage were exposed and measured to increase confidence in the data.

On 16 June J. Polger of the General Electric Co. staff at GSFC delivered to Kodak in Rochester processed film samples containing uniform gray patches for granularity measurement and sine wave images for determination of MTF. The sequence of laboratory operations used to generate the MTF test material is outlined in Table III.

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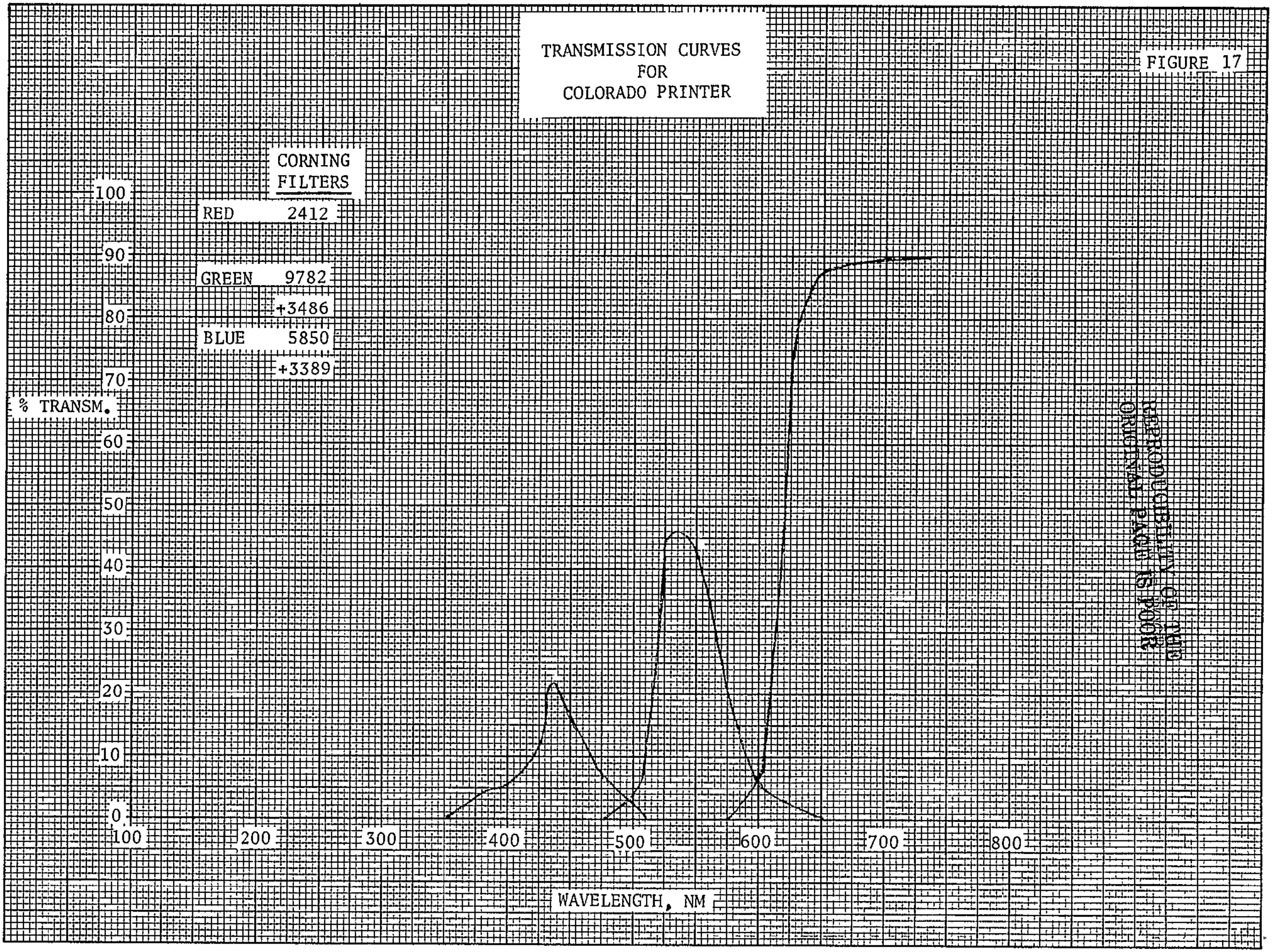

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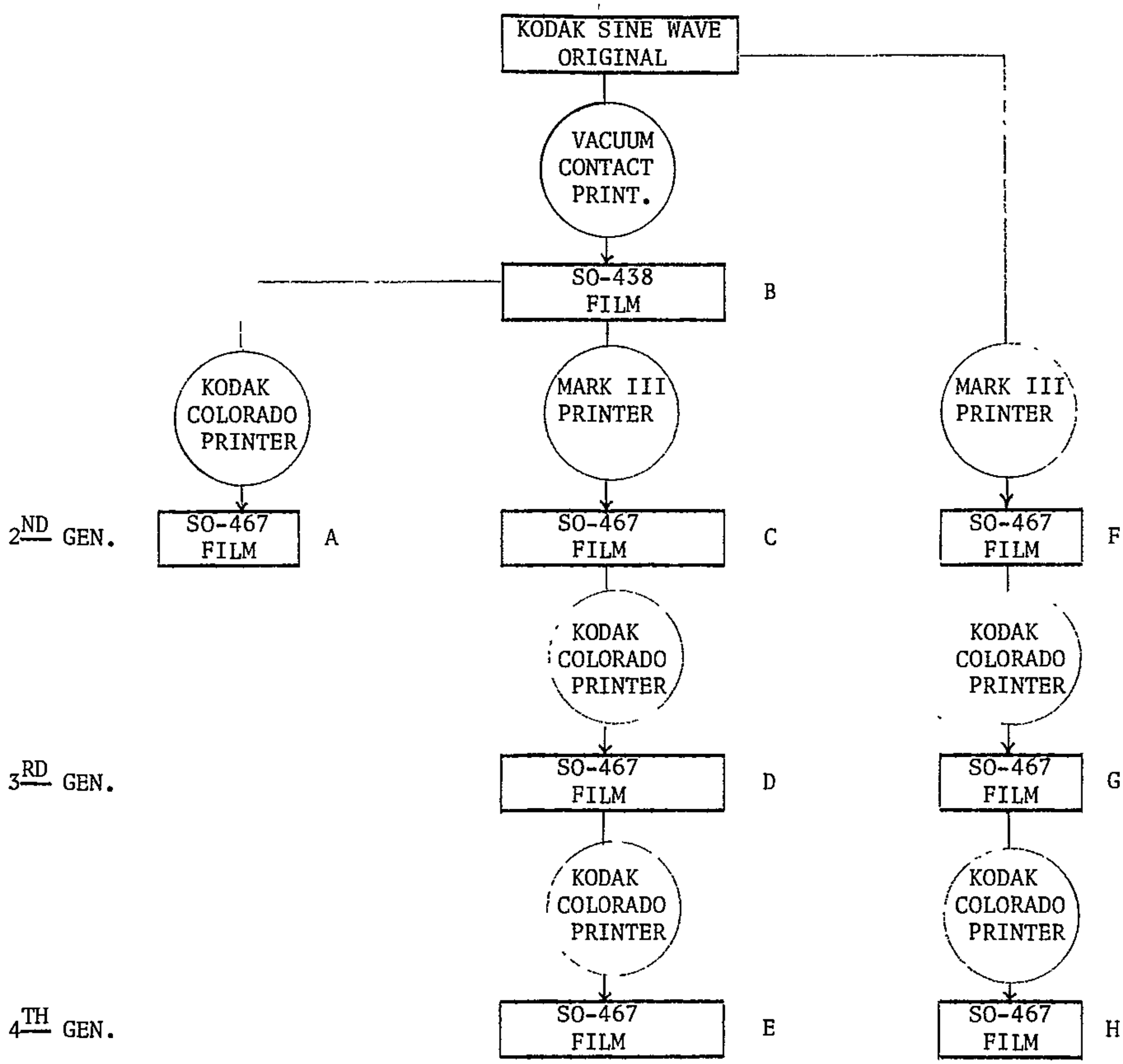
TABLE III

LABORATORY OPERATIONS FOR GENERATION OF MTF TEST MATERIAL



LETTERS A TO H DESIGNATE THE PRINTING STAGES DURING MICRODENSITOMETRY OF THE SAMPLES AT KODAK.

Evaluation of the MTF for items A and C compares the image quality from the LogE Mark III and Kodak Colorado printers, while item E shows the frequency response after the full four stages of duplication. Film H is a similar multi-stage test but without the contribution from the SO-438 EBR recording film.

On three samples at each stage, sine wave images were evaluated at frequencies of 1.5, 3, 6, 12, 18, 24, 30, 36 and 42 cycles/mm. A slit width of 2 x 275 micrometers was used in scanning the film which had been given standard processing in the NDPF machines.

The MTF results shown in Figures 18, 19 and 20 were delivered to Mr. Polger on 20 June 1972. These data are averages of three determinations at each printing stage. Although lines connect each data point, a smooth curve through the points might be equally valid, since the 1-sigma tolerance on any one of these points is ±0.10 for the SO-438 film (B) and ±0.03 for all other stages.

Figure 18 shows that frequencies to 42 cycles/mm are transferred slightly better via the Kodak Colorado printer (A) than through the LogE Mark III printer (C). Also, there might be some enhancement of frequencies near 30 cycles/mm by reproduction on SO-438 film.

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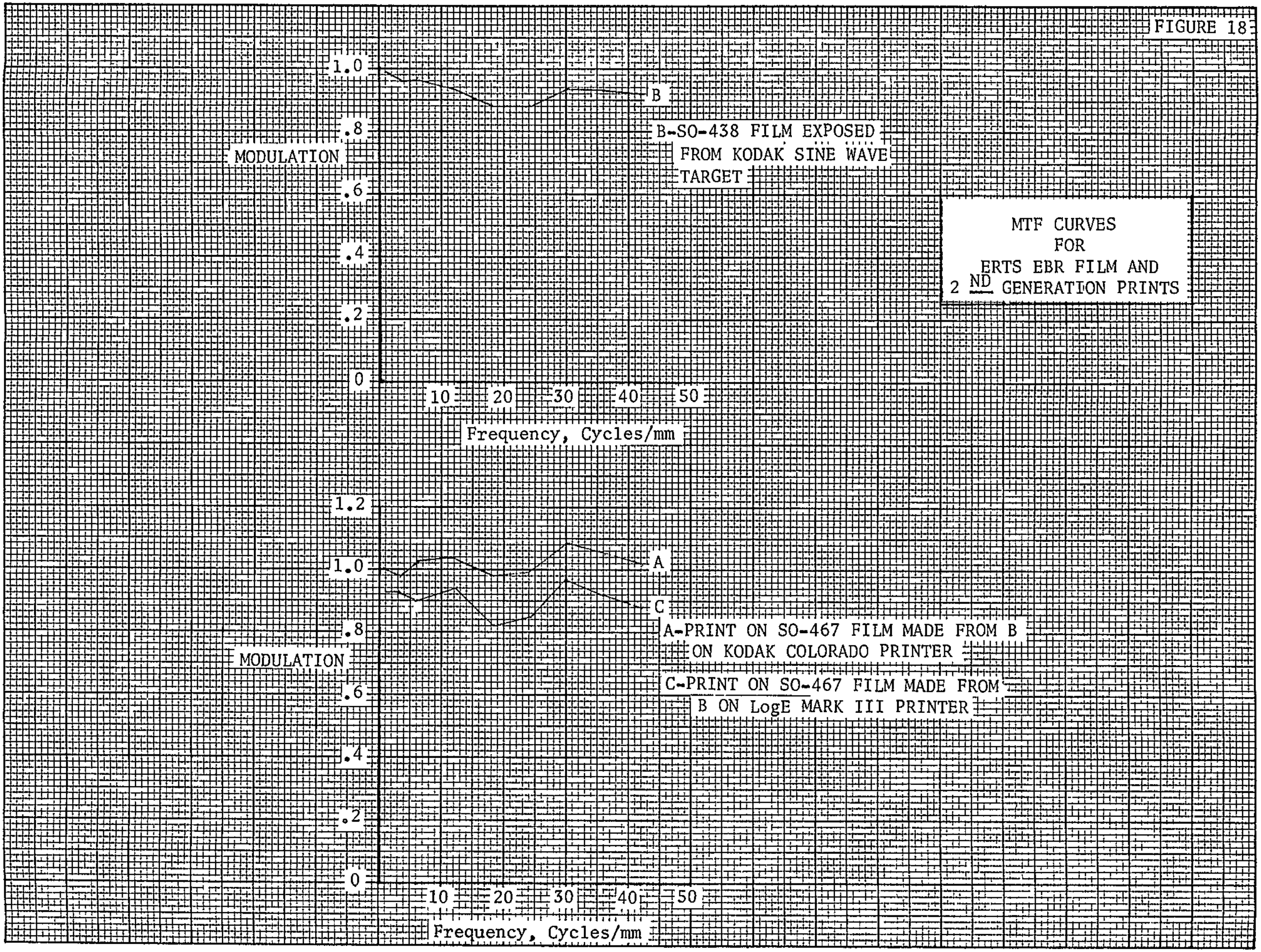
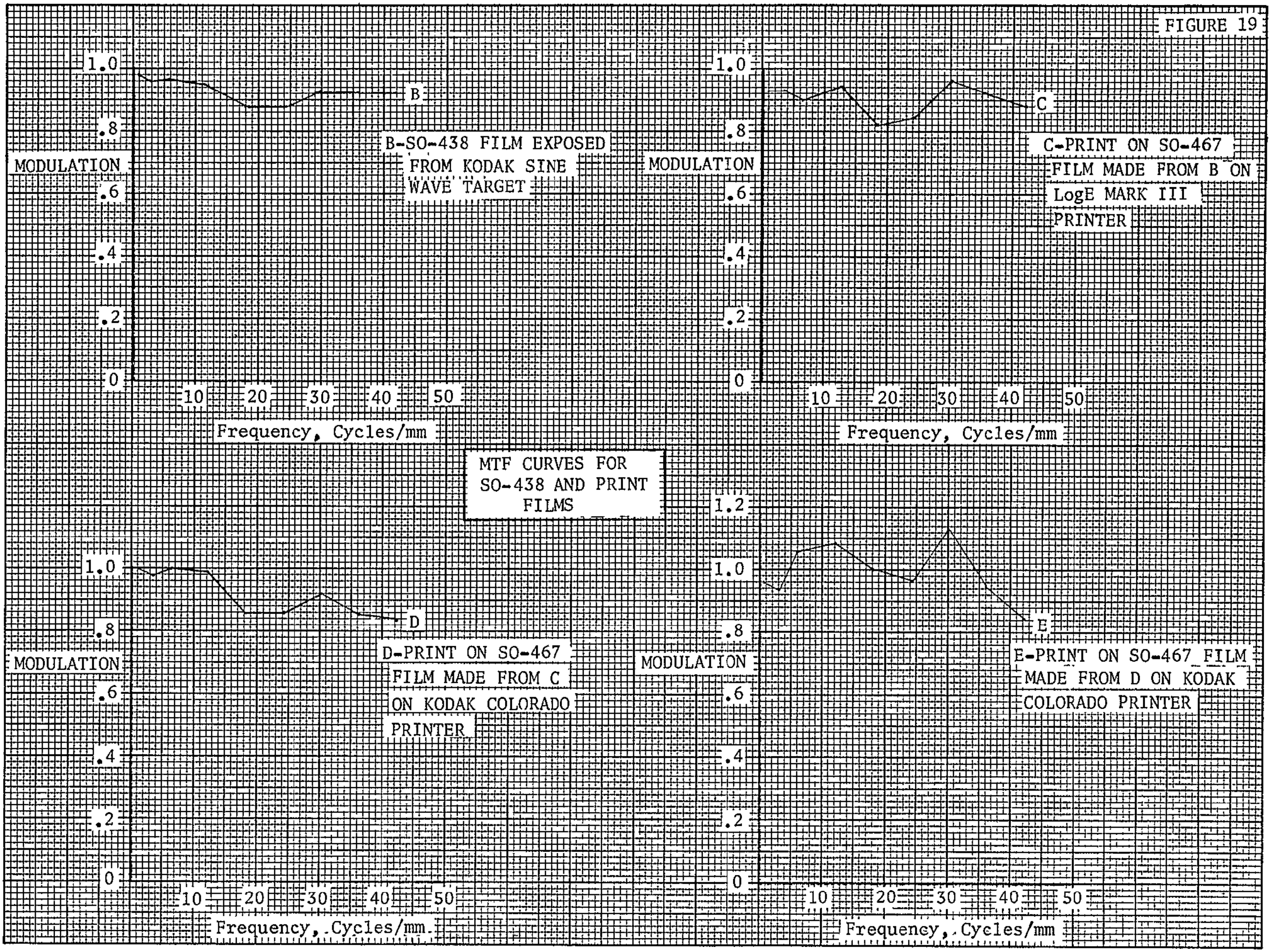


K+E 10 X 10 TO THE 1/2 INCH 359-12
KEUFFEL & ESSER CO. MADE IN U.S.A.



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KEUFFEL & ESSER CO

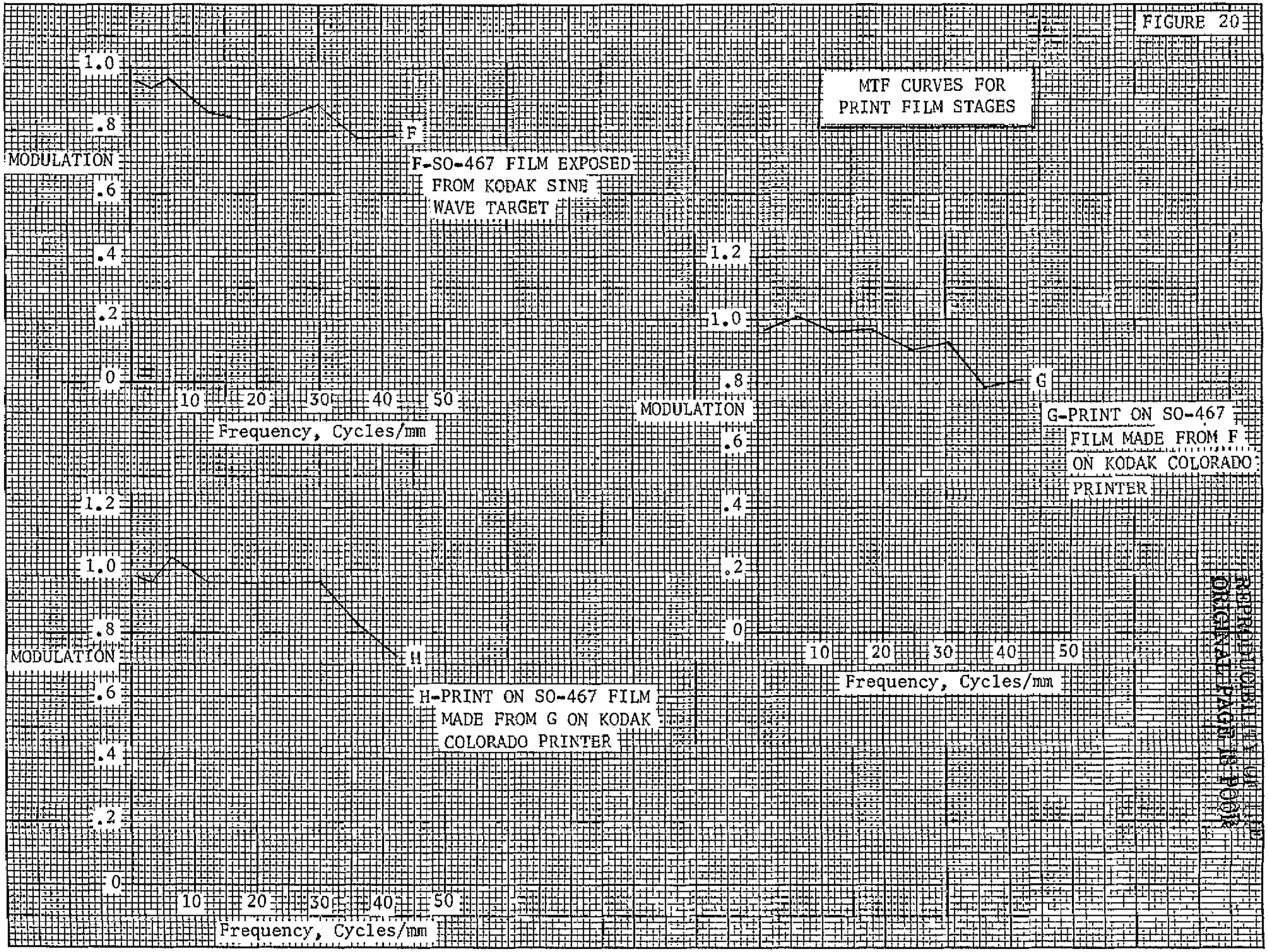

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Figure 19 presents the MTF obtained in the usual duplication cycle at the NDPF. Modulation averages 0.9 over all frequencies and printing stages, but may be dropping in the 4th generation (E) at the highest frequencies. Again, same enhancement is found at 30 cycles/mm.

Only SO-467 print film stages are shown in Figure 20. These MTF curves are very similar to those in Figure 19 that include SO-438 film. However, the loss in modulation at 36 and 42 cycles/mm is more severe on Figure 20 where the SO-438 film is omitted.

Granularity

NASA furnished eight to twelve film samples with uniform densities ranging from 0.09 to 2.50 for measurement of the granularity produced at each stage of printing. These films were read on a Kodak microdensitometer using apertures of 12.7 and 24. micrometers. A circular trace of 6mm diameter yields an analog RMS reading on the output meter. Single samples at each density were read and are plotted in Figures 21 and 22 after substraction of the instrument RMS value when no sample is in the beam.

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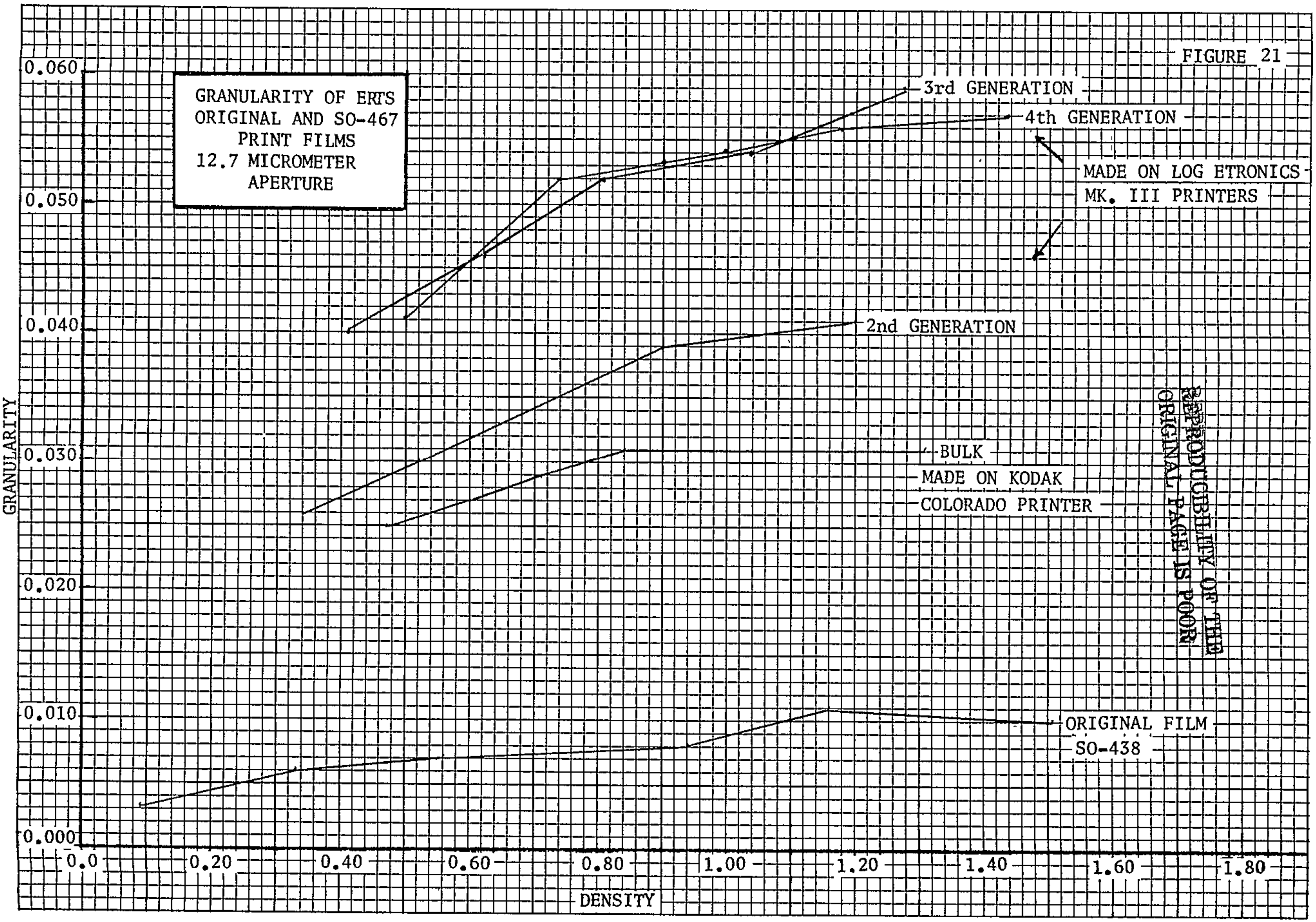

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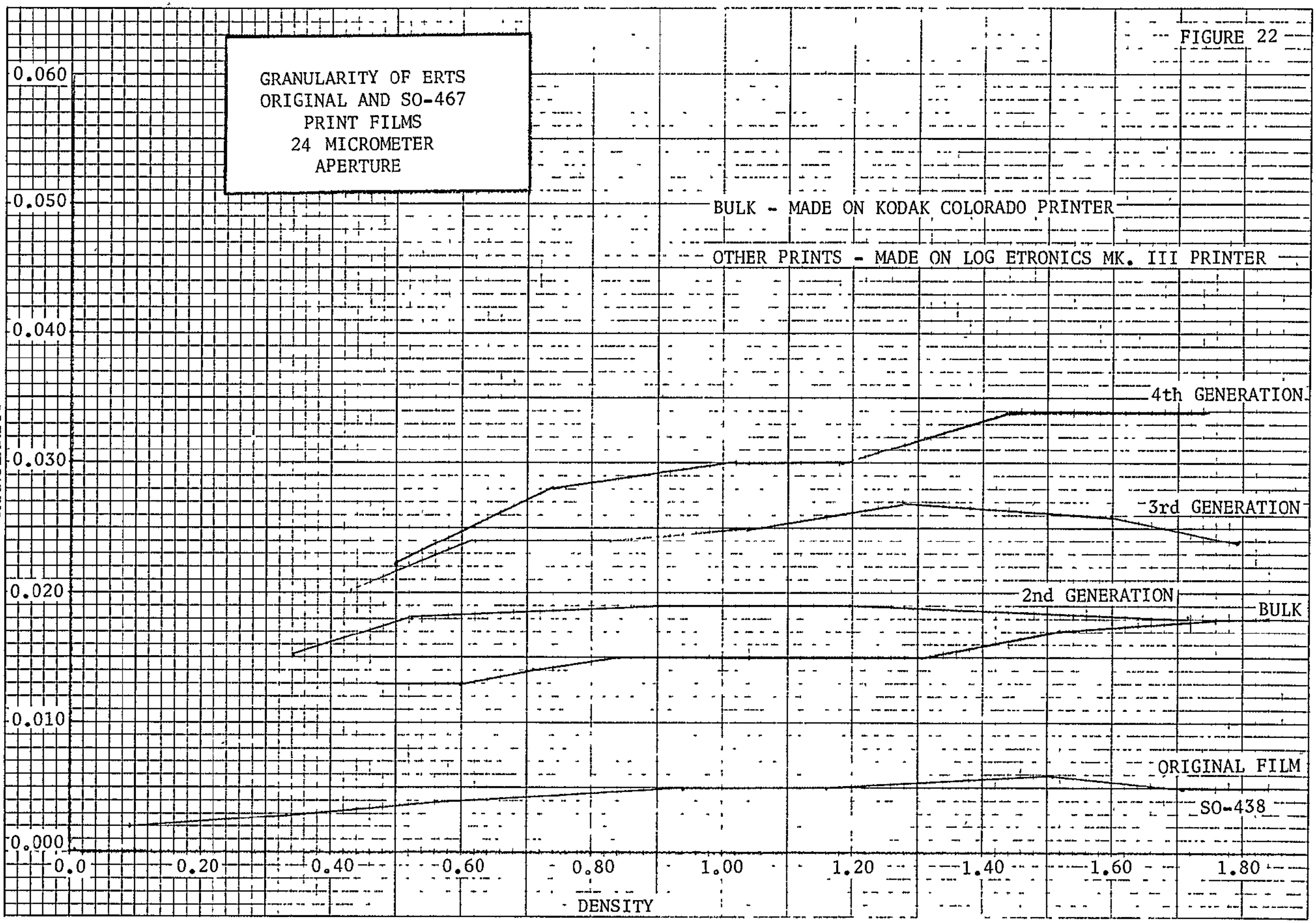

As expected, granularity is about twice as large when measured with the smaller aperture, and increases slightly at higher densities. Note that the granularity is the same for third and fourth generation prints measured with an aperture of 12.7 micrometers. This effect is absent in Figure 22 and is caused by production of a grain pattern that in the 3rd generation print is about 12 but less than 24 micrometers in size. When measured with the larger aperture, granularity continues to increase for each printing stage but differences in grain between stages are less pronounced. Grain for the second generation bulk prints is slightly less than for the edited second generation prints, probably because of differences in specularity and contact between the two printers.

Edge Patterns

High contrast edges arranged in an L pattern were read but not analyzed by Kodak. Sixty four traces were made on the Kodak microdensitometer using a slit of 2 x 275 micrometers. These traces showed some chemical edge effects, especially on the SO-438 film. Analysis of the chart traces was to be done by engineers at the NDPF.

Sensitometry and Edge Sharpness of Color Films

On several occasions we discussed with NDPF personnel the reproduction of ERTS pictures on color materials. While neither of the ERTS sensors produce a color rendition that shows the scene as it would appear to the eye, it is reasonable to strive for linear tone reproduction in the record for each wavelength band. Furthermore, the gamma and shape of each color record should be the same unless agreement is reached on a desirable deviation from matched records.

An area of concern in obtaining proper sensitometry with color films is the correct matching of densitometer filters and dye spectral densities. Engineers at the NDPF have noted low blue and high red gamma on prints from KODAK Aerocolor Negative Film 2445 (ESTAR Base). This condition can arise if matched gammas are obtained on 2445 film by process adjustments and the gray scale is read using Status AA filters. Note in Figure 23 that densitometry through Status AA filters yields higher blue and lower red gammas than are found if Status MM filters are used.

The reason for this difference is shown in Figures 24 and 25 in which the pass bands of the densitometer filters can be compared to the spectral dye densities of 2445 film. The Status AA

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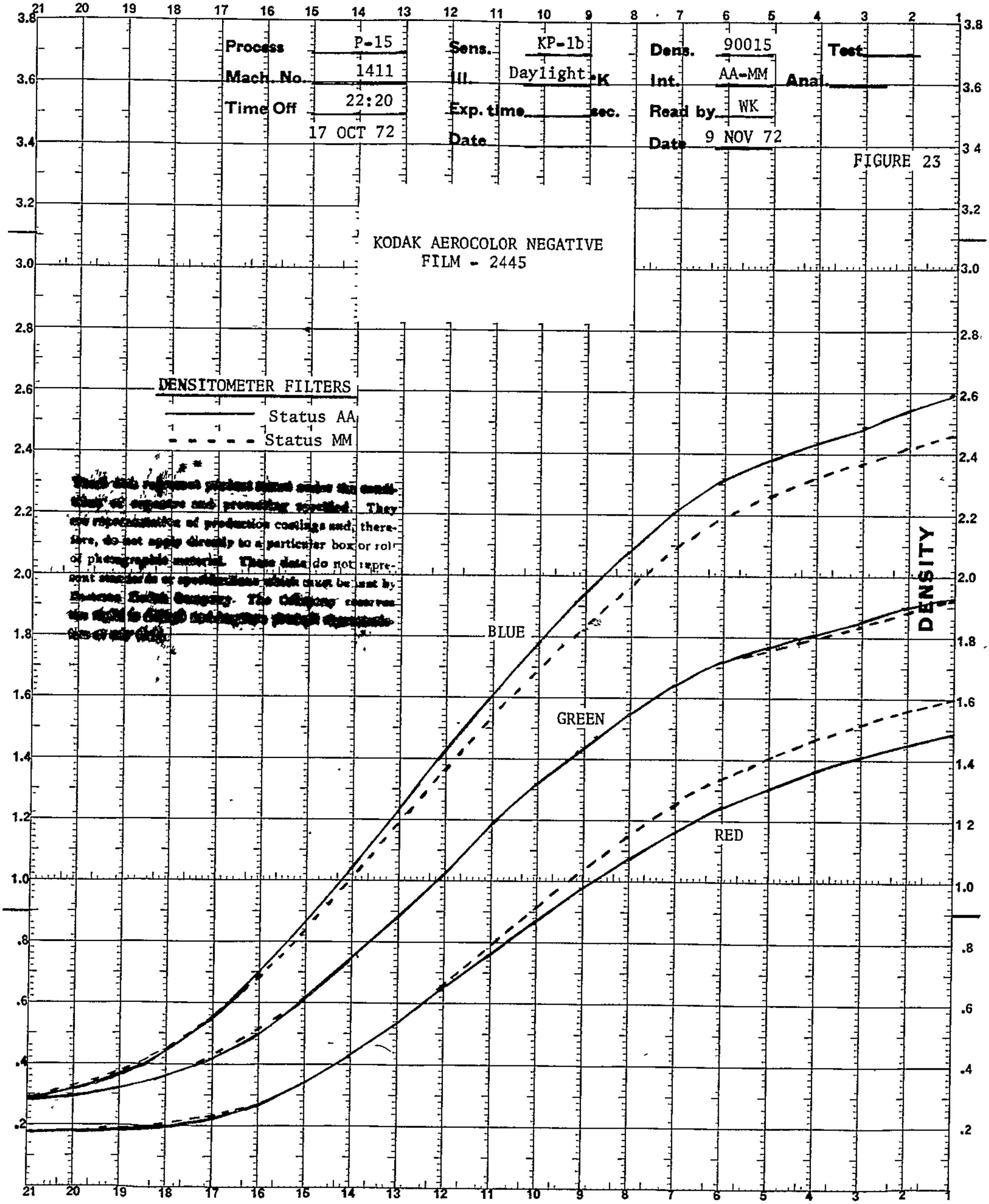

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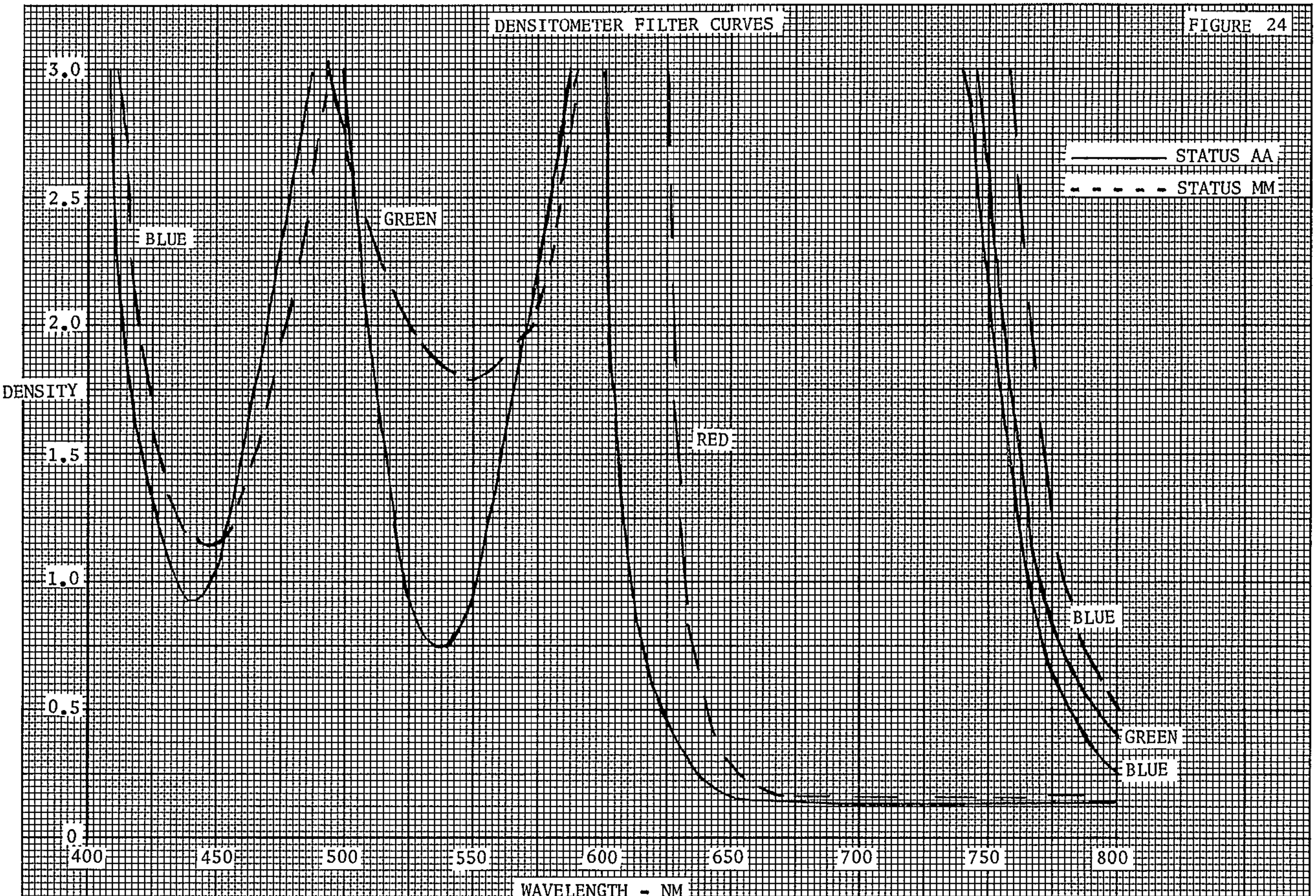

FIGURE 24

DENSITOMETER FILTER CURVES

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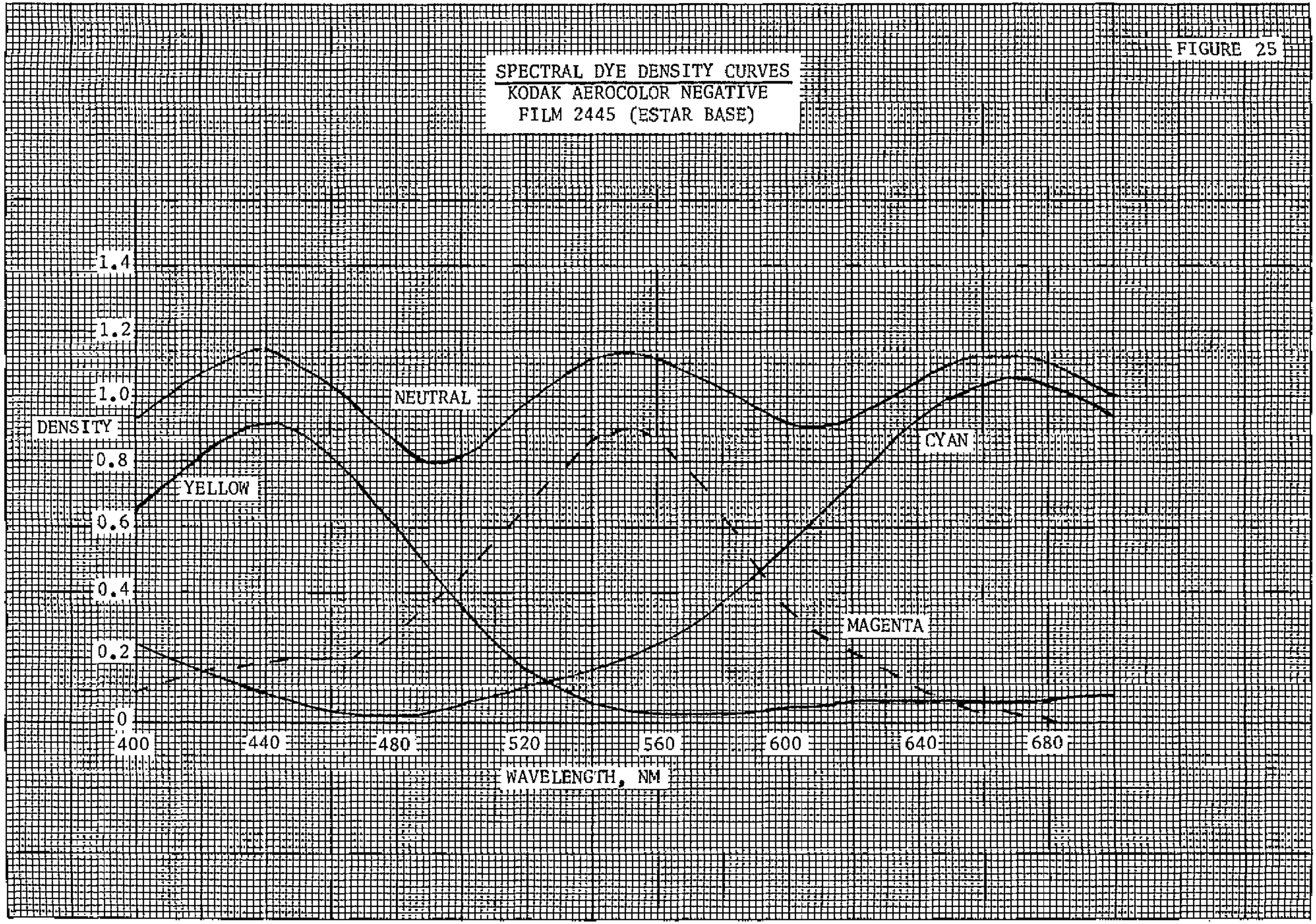

blue filter reads nearer the peak density of the yellow dye record, while the Status MM red filter is nearer the peak of the cyan dye density curve. Density readings taken near the peak absorption of a dye yield the maximum gamma for that record. Status MM filters have been designed to give printing densities, i. e., they produce curves showing the approximate relationship of the dye records as seen by the print film. If gray scales read from 2445 film with Status MM filters show mismatched gammas, this condition should be corrected without making a compensating change in the characteristic curve for the print film.

The three color records for KODAK Ektacolor Print Film 4109 (ESTAR Thick Base) are fairly well matched for gamma in the typical characteristic curves shown in Figure 26. This product is normally read using Status AA filters which are designed to "see" color film images with approximately the response of the human eye. Gray scales made on 2445 and 4109 films should be examined for matched printing and visual gammas by carefully exposing and measuring the characteristic curves of the actual emulsions used in the NDPF laboratory. Standard Kodak test strips serve very well for process control, but investigation of tone reproduction for a color film requires sensitometry exposed in the laboratory on the operational equipment and films.

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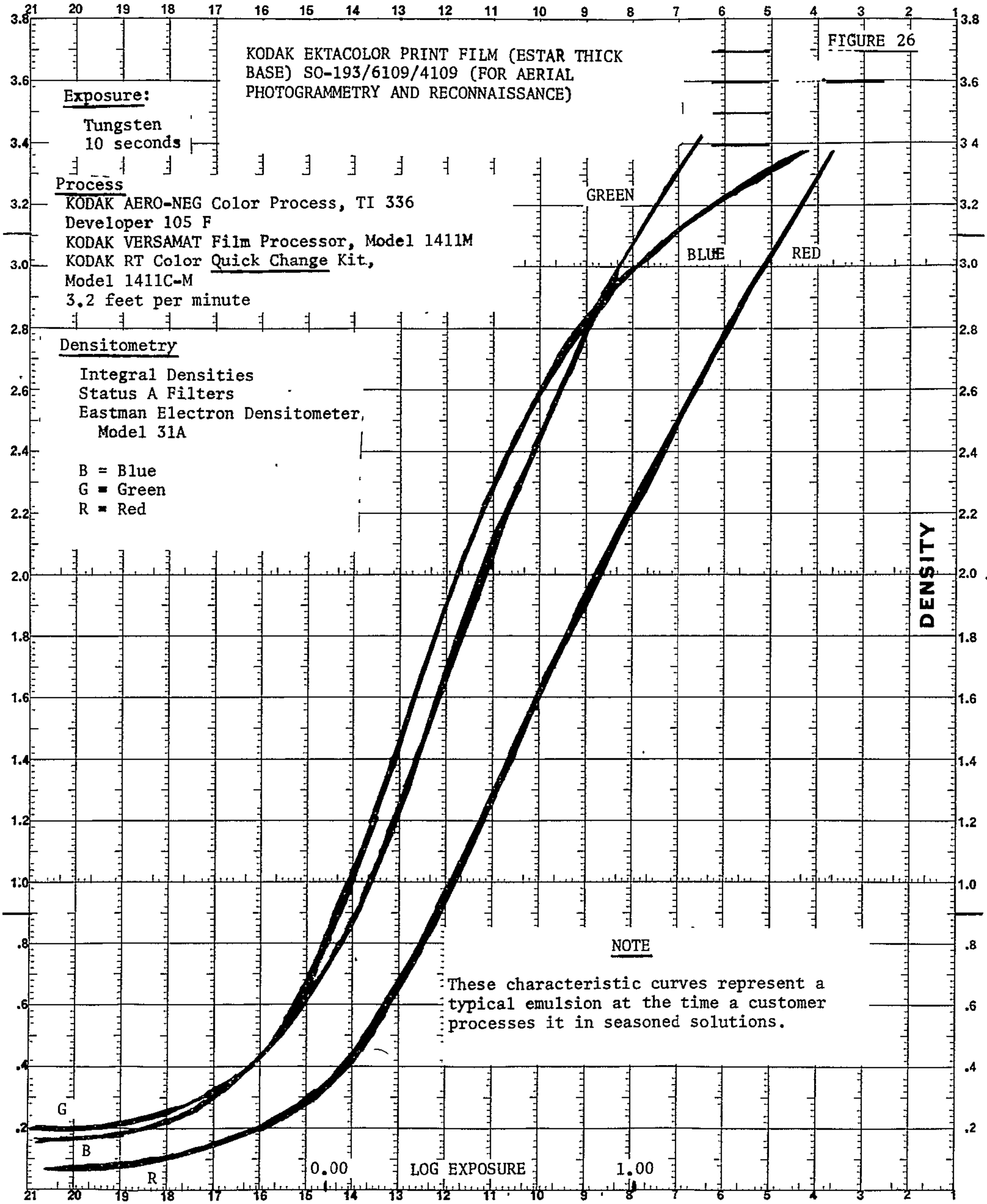

Effect of Atmosphere

A color print system with an overall gamma of 1.0 would reproduce the scene exactly as it appears from the satellite vehicle. This rendition, however, would not show matched gammas for a neutral gray scale on the ground because of the spectrally selective effect of the Earth's atmosphere. Darker areas of the scene are affected by haze to the greatest extent and frequently appear bluish in reproductions of photography exposed from high altitude.

Figures 27 and 28 describe correction curves for the effects of the atmosphere for each of the ERTS sensors. These plots show for average atmospheric and lighting conditions the difference in gamma correction factors between each wavelength band of the sensors. The plots are derived by the Kodak Research Laboratories using a proprietary computer program and data from considerable high altitude photography. It is assumed that a ground object of 10% reflectance is imaged to the equivalent of a film density of 1.00 at which point all the correction curves are equal. For the short wavelength records, brighter objects need less gamma correction while darker objects require more correction.

Edge Sharpness

Mr. A. Shulman at GSFC questioned the contribution to color fringing at edges that is caused by light scattering and

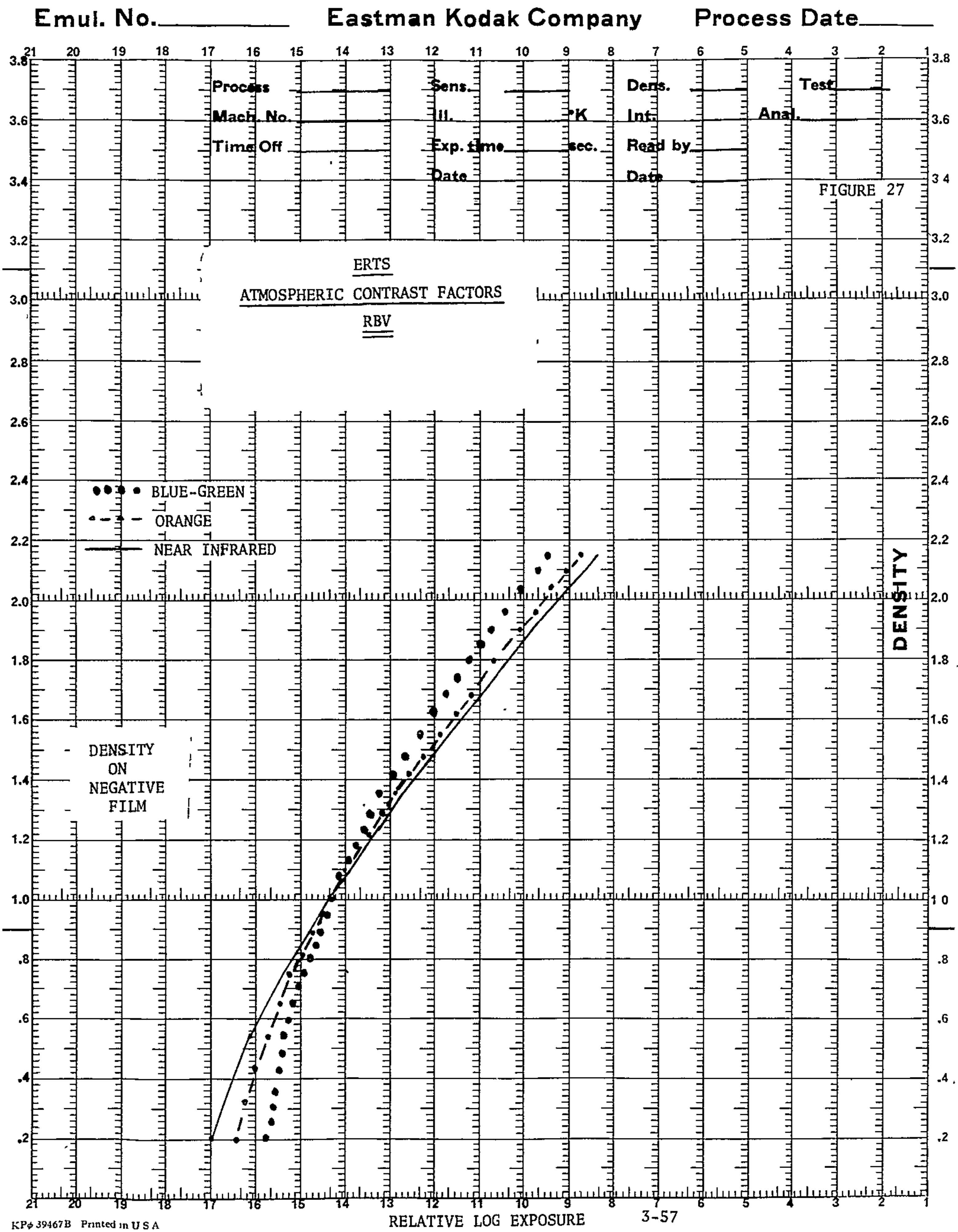

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FIGURE 27
ERTS
ATMOSPHERIC CONTRAST FACTORS
RBV
BLUE-GREEN
ORANGE
NEAR INFRARED
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RELATIVE LOG EXPOSURE
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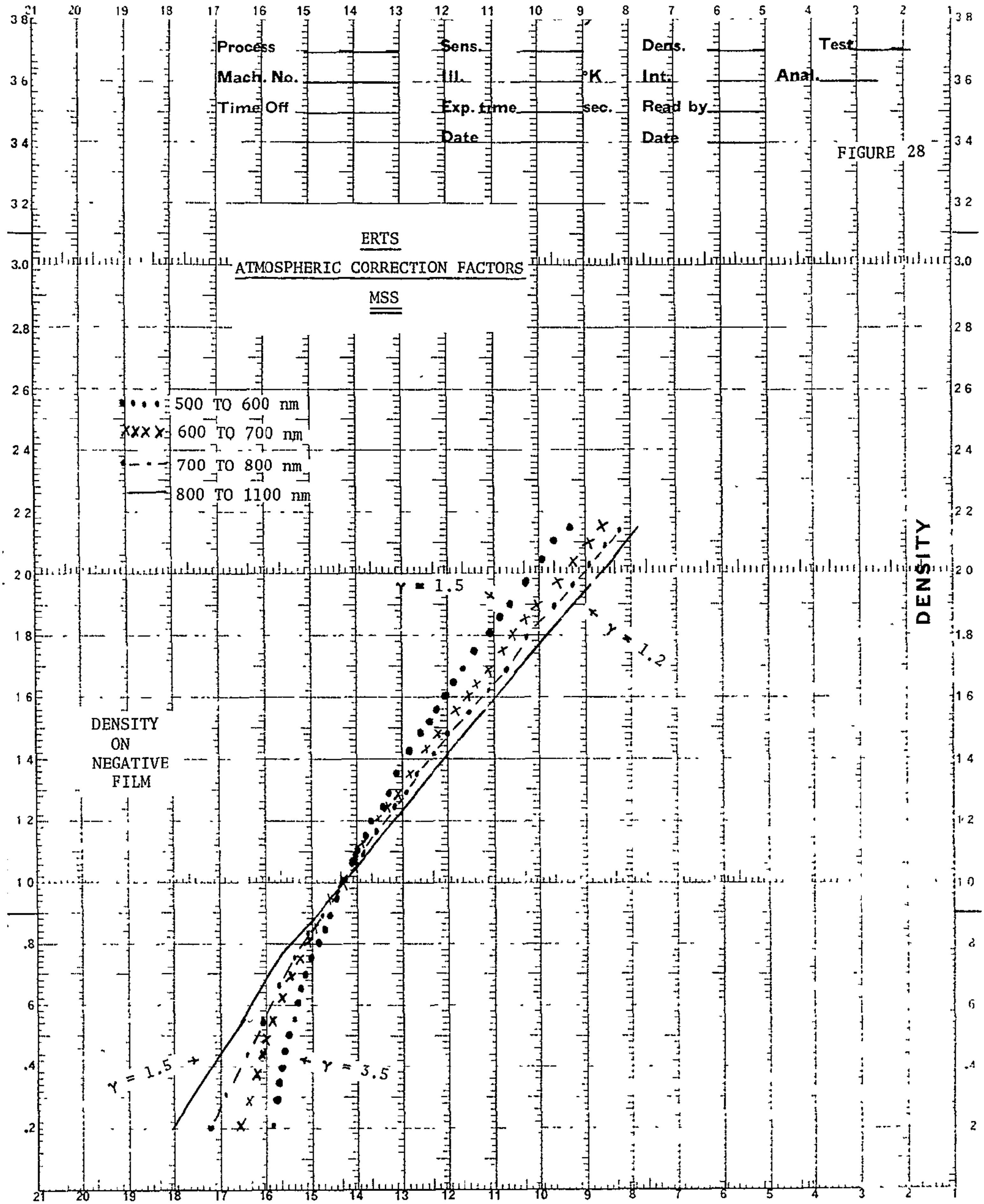

developmental effects in the 2445-4109 color film system. The color fringing observed in prints on Kodak 4109 film often exceeds the error tolerance of 22 micrometers.

To study this effect, exposures were made on 2445 and 4109 film of a series of neutral sharp edges of high contrast. Inspection of film cross sections at 100X and 200X showed a red fringe of 10μ width on 4109 film and, on 2445 film, fringes of 5μ to 15μ in the magenta and cyan layers, respectively. When the processed edge images on 2445 film were printed onto 4109 film in the Kodak Colorado Printer, a near-neutral fringe of about 5μ was produced. Apparently, the arrangement of dye layers and interaction of factors contributing to image fringing yield some cancellation of edge fringing in this color film system. The observed 5μ fringe is a small factor compared to registration errors or image distortion that occurs in producing the prints.

SECOND COMPARISON OF PRINTING FACILITIES FOR EARTH RESOURCES PHOTOGRAPHY

This study is part of
Work Order #6 under
Contract NASW-2317

Submitted to
National Aeronautics and Space Administration
Earth Observation Programs
Washington, D. C. 20546

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Approved by

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30 April 1974

Introduction and Summary

Important characteristics of ERTS printers at Goddard Space Flight Center and at the EROS Data Center were summarized in a report to NASA Headquarters under Work Order No. 5 on 7 February 1973. Since then, improvements in equipment have been made and new procedures instituted. As a consequence, a second survey that also includes tests run at the Johnson Space Center was undertaken. JSC is experiencing increasing demands for high quality printing in reproducing films from the Skylab missions.

The survey includes tests run for reference on Kodak equipment in Rochester. The purpose of the survey is to measure the characteristics of individual printers at each laboratory; however, there is less emphasis than previously on the reproduction of image quality through several printing stages in a laboratory. These measurements reveal printer quality at one moment and do not necessarily represent average quality over a long period. The test frames were carefully made, but they did not simulate the output of the ERTS Electron Beam Recorder.

The survey reveals improved performance from the EDC 3.37X film enlarger, but adjustments or new optics are indicated for the Sickles and Texas printers at JSC and for the ECP-70 and 13X paper printers at EROS Data Center. There has been no improvement in the poor off-axis image quality from the 3.37X enlargers at GSFC.

Another survey will probably be made late in 1974.

Procedure

Two test frames were printed at each laboratory. One is clear with a black stripe for testing flare in enlargers, while the other includes patterns for measuring resolution, modulation transfer function, and the fidelity of tone reproduction, illumination and magnification. The format for the multi-element test frame is shown in Figure 1.

Uniformity of illumination was measured in the background region between the light and dark circular areas, as these patches were too near maximum and minimum luminance to be adequately sensitive to variations in exposure. Tribar patterns are of 2:1 contrast covering the range from 8 to 120 line pairs/mm. Geometrical distortion was calculated from the ratio of the length of this tribar pattern in each corner to that on axis.

Two groups of bars covering frequencies from 8 to 80 cycles/mm and 15 to 150 cycles/mm form a log periodic test pattern. A microdensitometer slit of 1 x 96 microns produces a tracking of these patterns on which amplitude is measured at each frequency and the modulation transfer function calculated using a proprietary program. This technique is described by Granger and Cupery in "Photographic Science and Engineering", Vol. 16, No. 3, May 1972.

The flare test was made in accordance with MIL-STD-150A. In this procedure a clear field with a black stripe having a density of at least 2.0 and subtending 1 degree as seen from the enlarging

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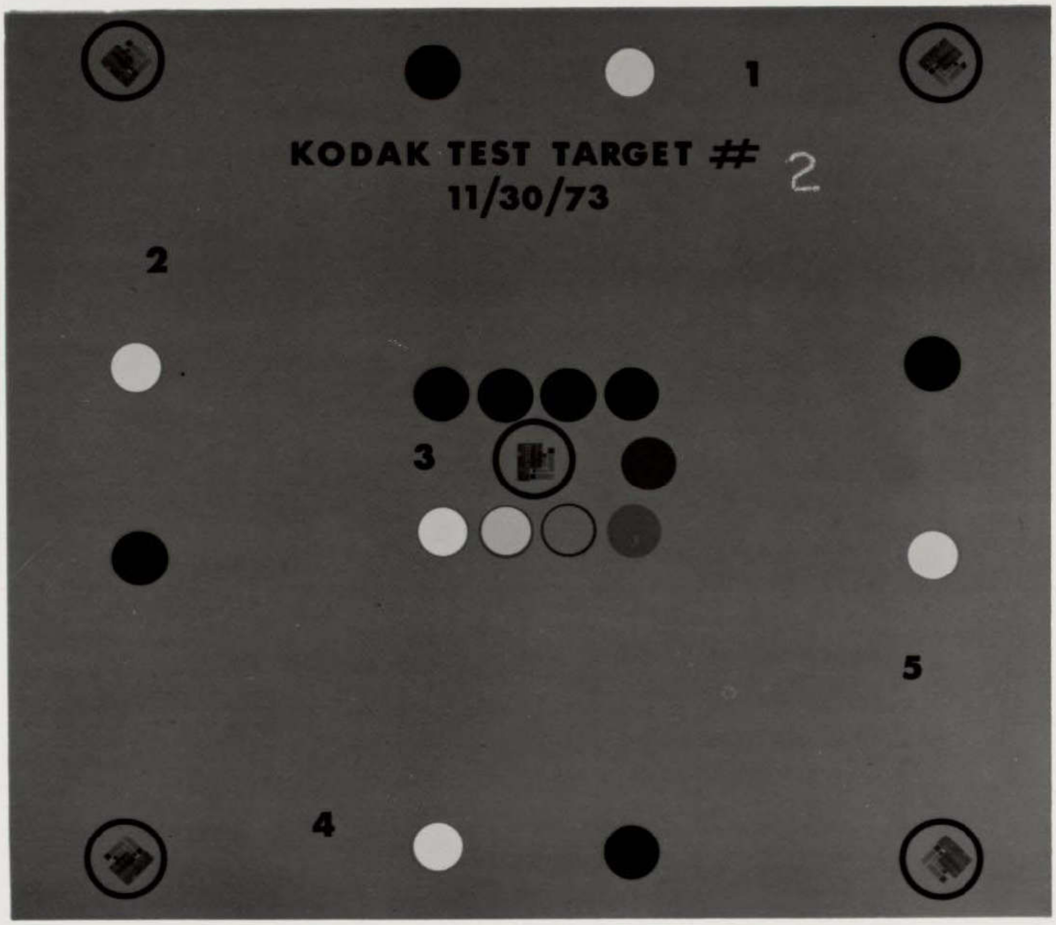

FIGURE 1

TEST FRAME FOR INTERLABORATORY PRINTER SURVEY. THE 5-INCH AND 70MM TARGETS HAVE IDENTICAL PATTERNS SPACED TO COVER THE FULL FRAME AREA. TRIBARS OF 2:1 CONTRAST RANGE FROM 8 TO 120 LINE PAIRS/MM.

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ORIGINAL PAGE IS POOR

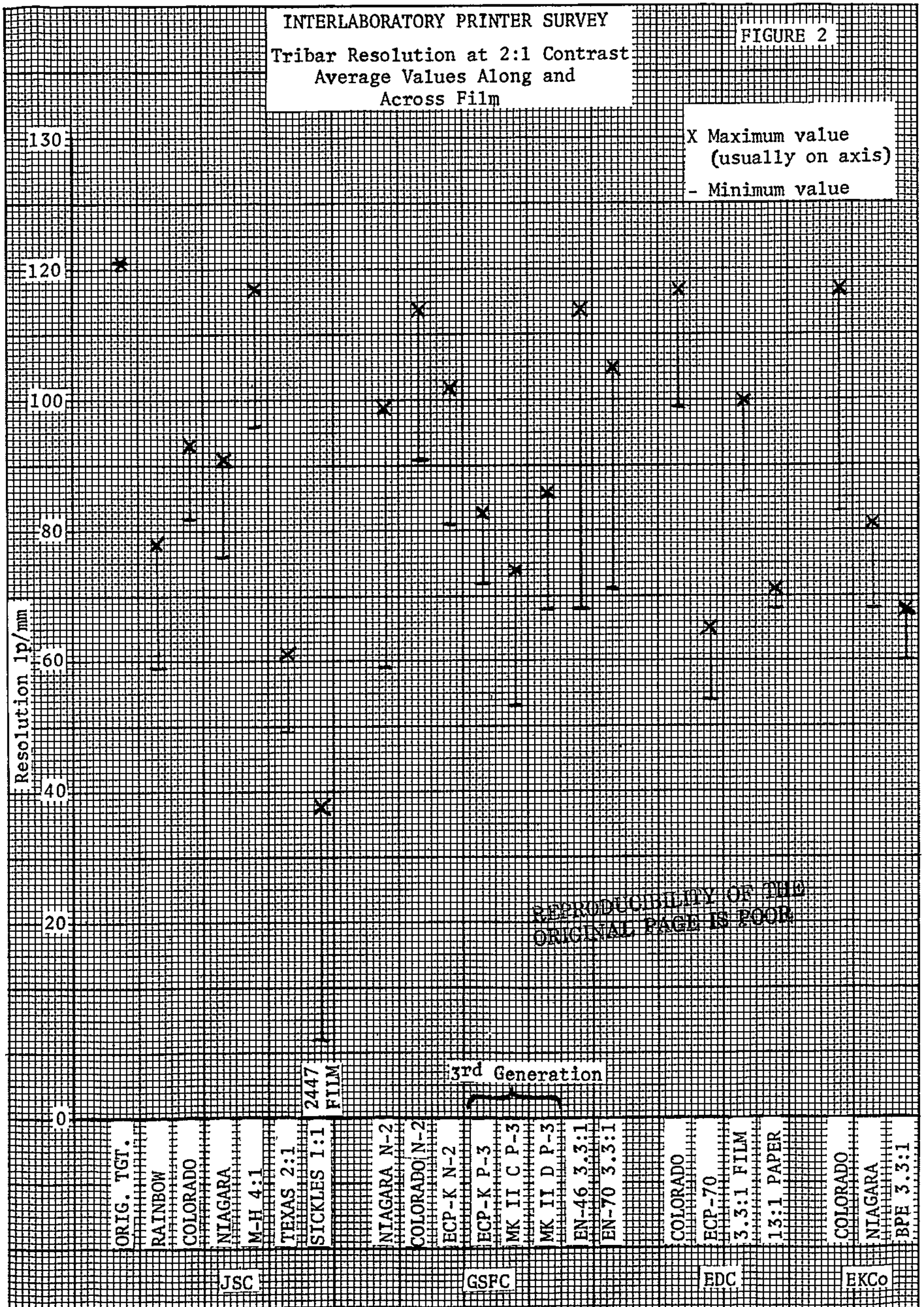
Geometric fidelity was assessed to ± 0.003mm by measurement of a 4mm interval located on axis and in each corner.

Results

Tribar Resolution

Low contrast tribar resolution provides a realistic evaluation of printer performance on aerial or satellite scenes. In this survey the original target carried frequencies at 2:1 contrast to 120 line pairs/mm.

Figure 2 shows that resolution at 70mm scale on prints from this target averaged about 90 lp/mm but with some printers yielding less than 50 lp/mm. The plotted values are averages of resolution along and across the film with the axial value usually higher than that in the corners. The Texas optical printer at JSC and the EN-70 at GSFC showed orthogonal resolution differing by a factor of 2 at several points in the field. Most printers were more uniform in this respect, but quality was generally lower from the Rainbow at JSC, the Niagara at Rochester, the Niagara at GSFC, and the ECP-70 and 13X paper printers at EDC. As in the first survey, the 3.3X optical printers at GSFC show substantial losses in sharpness off axis - a condition that will be corrected after receipt of new Tropel lenses. At JSC the Sickle 1:1 optical printer produces substandard imagery and should be improved by a new lens and focusing arrangement.



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The improvement in resolution from the 3.3X film printer at EDC is noteworthy; previously its performance was less than that from the Kodak Beacon Precision Enlarger. At 65 lp/mm the f/17 BPE lens is operating near the diffraction limit, while the EDC lens is working less perfectly but at a relative aperture of f/5.6.

After substantial modification at GSFC, the ECP-K (N-2) is performing well while a similar machine, the ECP-70 at EDC, gives very poor resolution. One change made at GSFC is installation of a more specular light source; this modification and probably others are needed at EDC.

Performance of the 13X paper enlarger at EDC is low, partly because the lens is used at a slow relative aperture in order to obtain uniform field illumination. The spatial frequency response of the paper at 5 lp/mm does not limit these results.

The Niagara printer at GSFC gave low resolution at one corner, and a similar machine in Rochester was below standard. These printers should perform as well as the Colorado printer when web tensions and rollers are properly adjusted. Probably these results simply illustrate the difficulty of measuring printer quality from a single film test, although the Niagara test in Rochester was repeated with similar results.

Modulation Transfer Function

Unlike limiting tribar resolution the MTF curve contains information regarding image quality at all frequencies. The curves in Figures 3-6 are on-axis MTF's for the overall printing system including the effects of the original target, printer and print film. However, in Figure 6 losses from two stages of printing are combined to yield curves that are somewhat lower in MTF than those for most single-stage prints.

Curves for the contact prints in Figure 3 generally parallel the original target curve and lie approximately in the order expected from the axial values for low contrast tribar resolution. Only the Niagara printer at JSC shows a curve with appreciable nonlinearity, and this effect may be caused by under-exposure of this print. As noted from the tribar data, the Rainbow printer at JSC needs adjustment to improve performance at all frequencies.

Optical printers at JSC show the widely different MTF curves plotted in Figure 4. Most MTF curves in Figures 3-6 are averages of curves measured on axis in two orthogonal directions; MTF data for the Texas printer at JSC differed enough in each direction to prohibit averaging. This difference is concealed in the graph for tribar resolution but is well shown in Figure 4. Apparently image sharpness in the direction of film travel in this continuous enlarger is significantly reduced by uncompensated image motion.

Excellent MTF at higher frequencies is shown by the Miller-Holzworth 4X enlarger. However, response at 50 cycles/mm is only 0.34 compared to 0.56 from a well-adjusted Colorado printer.

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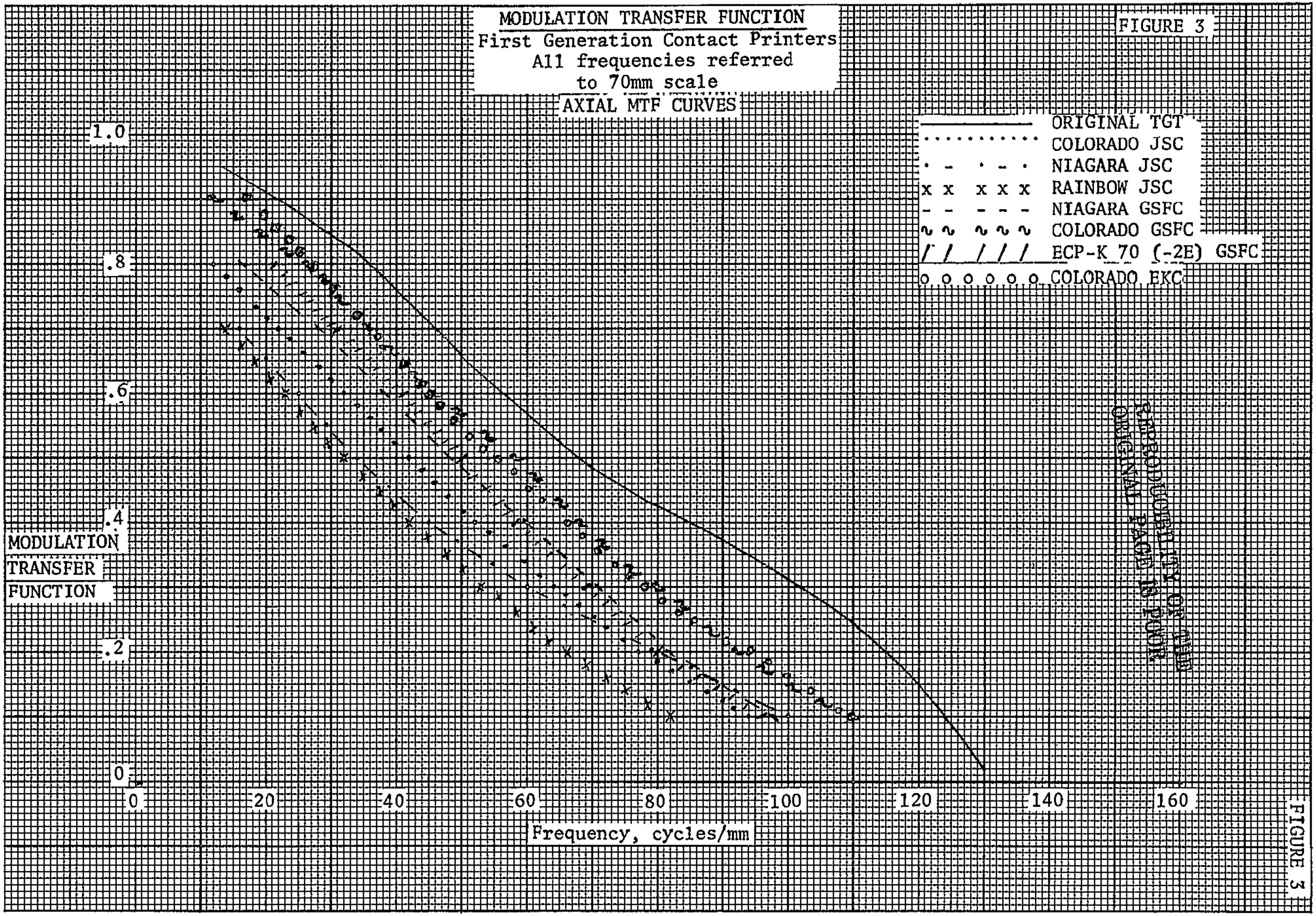

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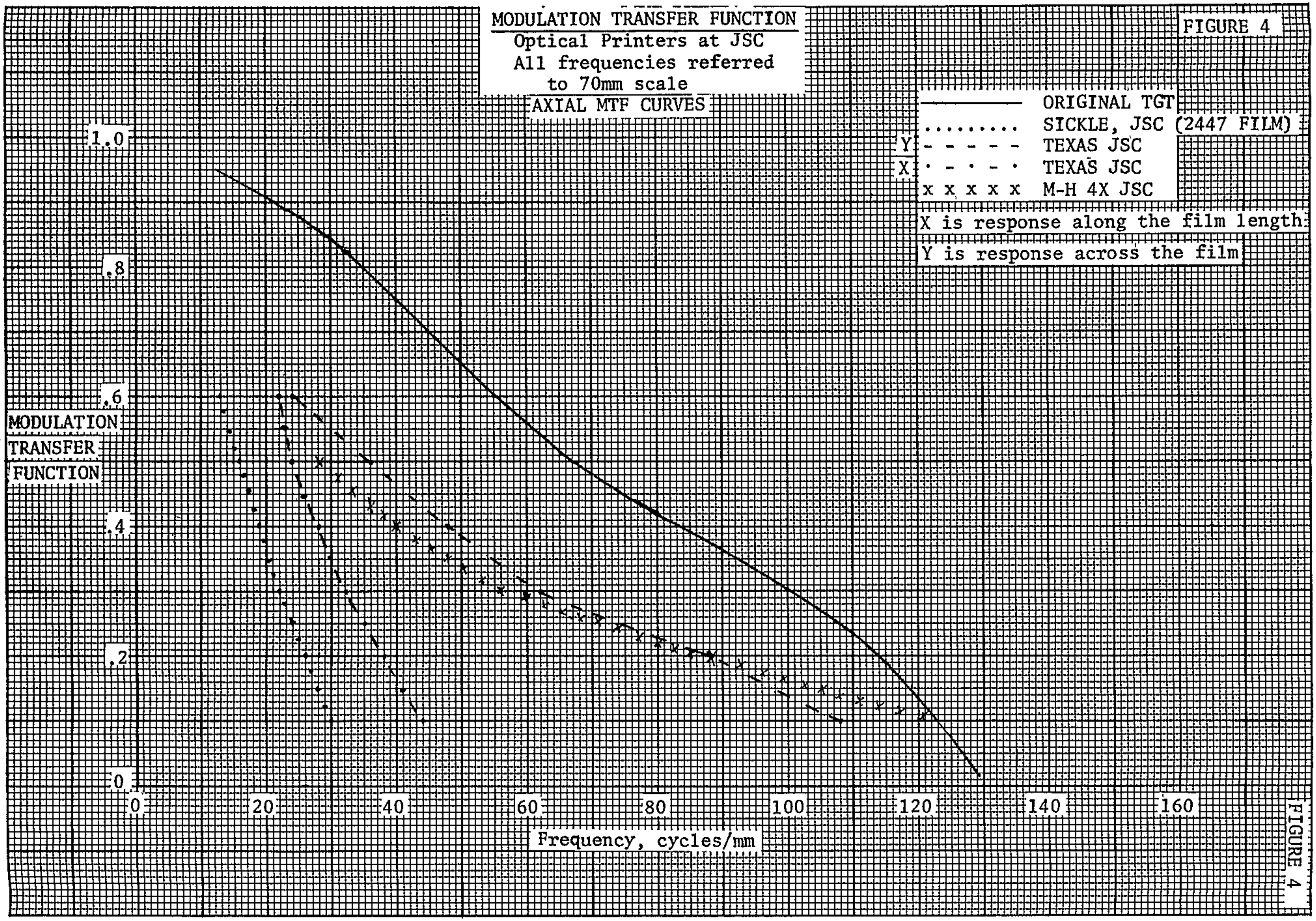

FIGURE 4

Prints from the 4X enlarger will retain nearly all the fine detail in Skylab original films but coarse frequencies will show some loss in sharpness. Note that this test was done in blue light on SO-467 film. However, tribar resolution on 2447 color film exposed in this printer was still 77 to 111 line pairs/mm instead of the 96 to 117 line pairs/mm shown in Figure 1 for the test on SO-467 film.

MTF from the Sickle printer is very low in this on-axis test on 2447 film. Performance in several corners was such that resolution was worse than the coarsest frequency (12 lp/mm) in the test pattern. This printer uses a Zeiss Planar f/3.5 lens of 135mm focal length. Since the lens is corrected for use in an aerial camera, its poor performance at 1:1 conjugates is not surprising. In addition, the lens is loosely mounted in a threaded focusing cell that is often moved by the printer operator. A better arrangement would use solid mounting sleeves with locked adjustments for the 1:1 and 2:1 imaging positions. A new lens designed for 1:1 conjugates would be rather expensive, but the present image quality could be improved by carefully mounting two lenses of 270 ~~135~~mm focal length face-to-face.

For optical printers charted in Figure 5, the EN70 3.37X enlarger at EDC shows a very good MTF curve. Resolution on-axis is 100 lp/mm and the response at 50 cycles/mm is 0.48, only 17% below the performance of the best contact printers. This machine

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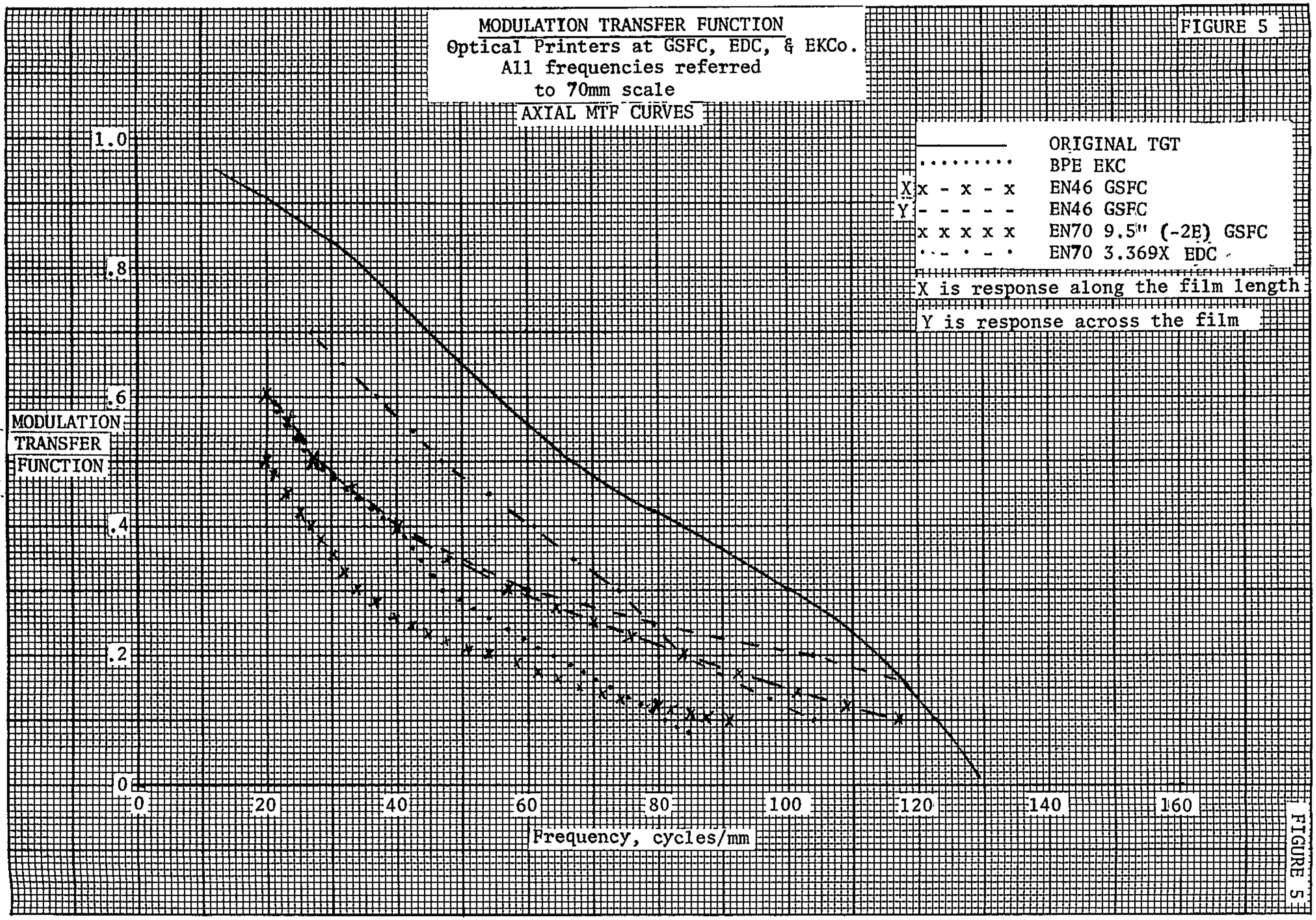

4-12

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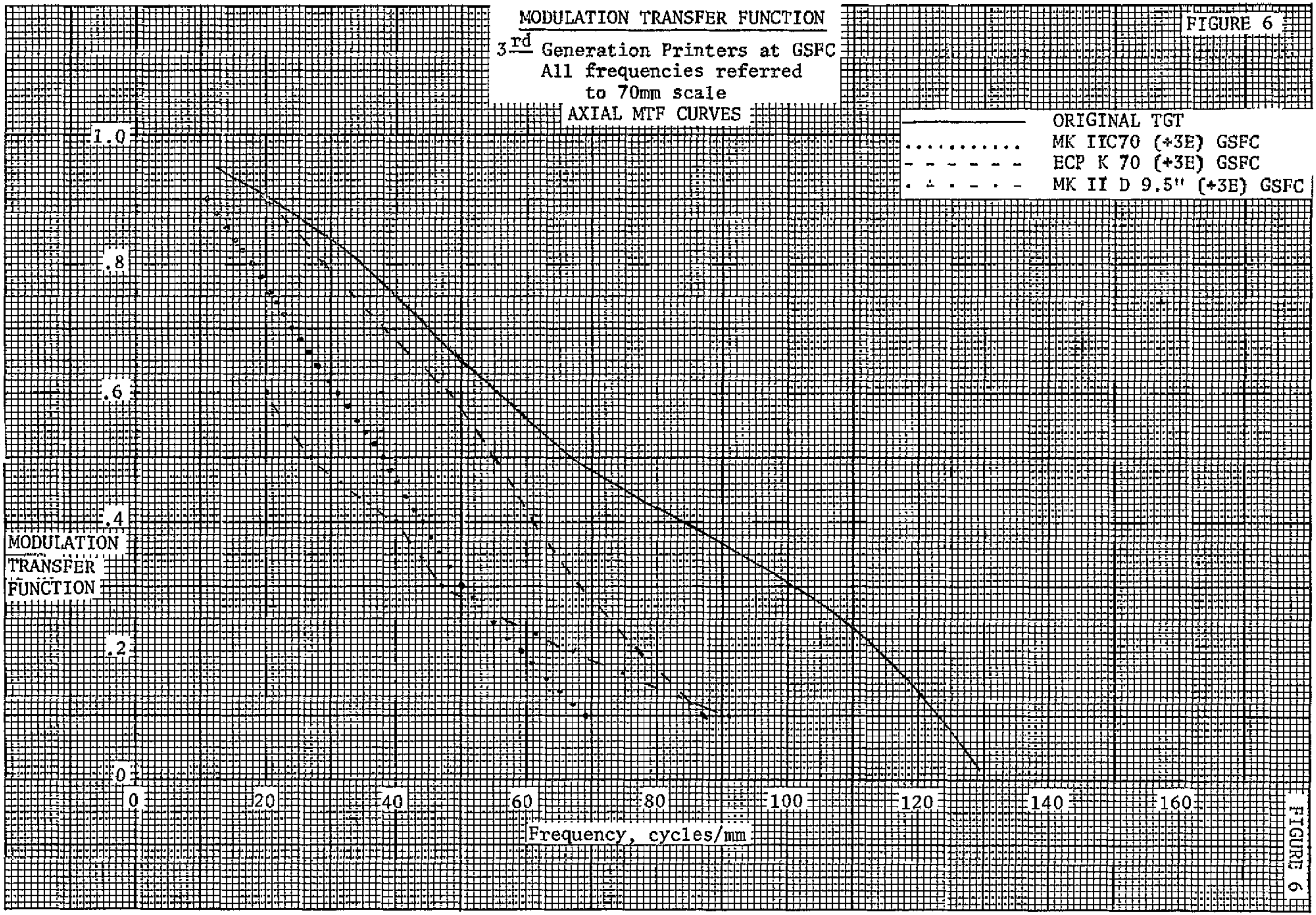
[redacted]



enlarges ERTS negatives in which fine detail is limited by the scan-line pattern to 42 cycles/mm. Despite this greatly improved performance even better results, especially off-axis, may be anticipated when the Tropel f/3.5 lens is received at EDC.

Both the EN46 and the EN70 at GSFC are substantially poorer at coarse frequencies and off-axis than they are on-axis. This condition is similar to that found in the previous survey, and it will be corrected by use of new Tropel lenses. Axial MTF beyond 60 cycles/mm differed enough in X and Y directions to require a separate plot for the EN46 data.

As noted previously, MTF curves for the Kodak BPE in Figure 5 are nearly diffraction limited at f/17. Performance at 3.37X can be improved only by increasing the lens diameter at the relatively fixed conjugates used on this enlarger.

Third generation MTF curves in Figure 6 show more response at low frequencies than the 2nd generation curves in Figures 3 and 5. This gain is caused by chemical edge effects introduced by processing the SO-467 film.

Tone Reproduction

Figures 7-10 show 9-step tone reproduction curves generated by printers at each laboratory. In all cases these are overall tone curves in which densities on each print are plotted against a scale of relative log exposure formed by the

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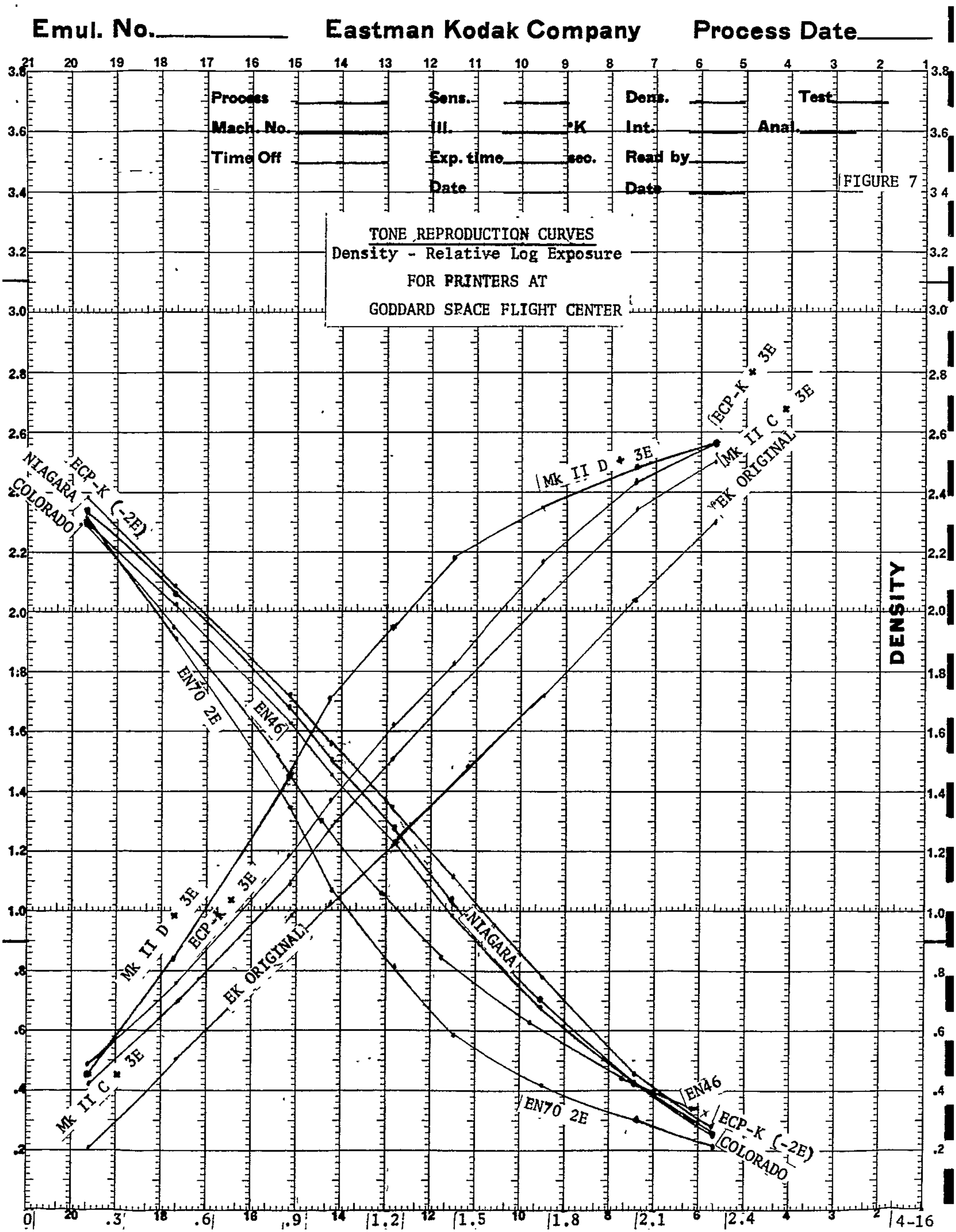
nine densities on the original target. As in the previous survey, curves in Figure 7 from printers at GSFC are very linear except for the effects of substantial flare in the EN70 and EN46 enlargers. This condition has persisted since the beginning of the ERTS program and is apparently caused by poor construction and baffling in the lens and illumination system. Note that upper densities of negatives made on these enlargers show a gamma about 40% higher than that on contact prints. High film-process gamma permits similar overall density ranges on contact and optical prints despite flare in the enlargers. Curve shape from the contact print made on the Mk II D (+ 3E) simply reflects the effect of flare in the EN70 used to make the negative.

Tone curves from printers at JSC are shown in Figure 8. While some effect of flare is evident, much of the curvature at lower densities is caused by underexposure. The Niagara print is especially thin while the print made on the Colorado is overexposed. As at GSFC, both contact prints are lower in contrast than the three optical prints. This effect - a result of scattering in the original target - is present to some extent in the Kodak curves shown in Figure 9, but flare is very low in the Kodak BPE.

Curves from the EDC printers in Figure 10 differ considerably in density level but are similar in gamma. The unusual shape of the tone curve from the 3.37X enlarger may indicate some fog on this test frame.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Eastman Kodak Company
Process Date
Process
Mach. No.
Time Off
Sens.
Ill.
°K
Exp. time
sec.
Date
Dens.
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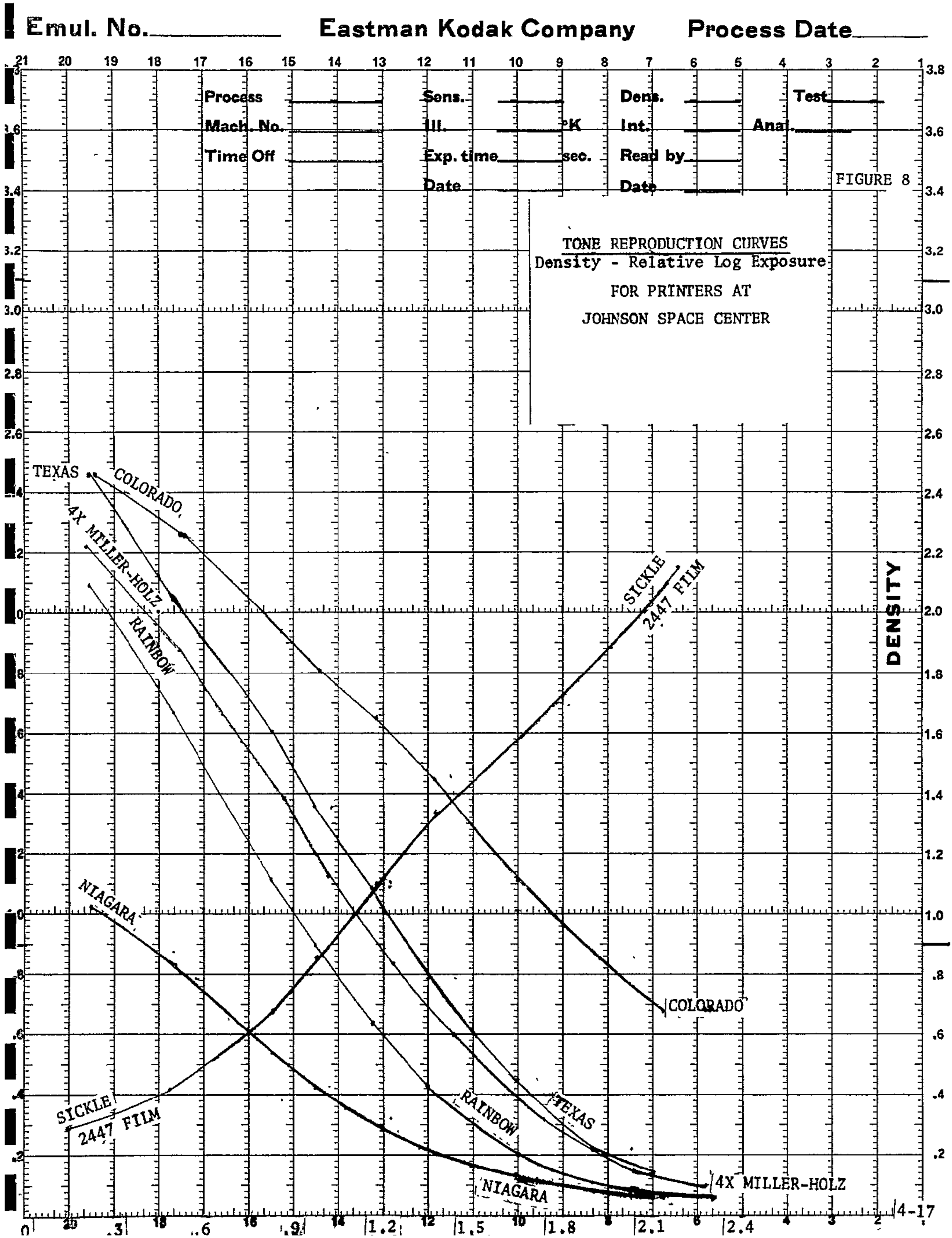
Read by
Date
Test
Anal.
FIGURE 7
TONE REPRODUCTION CURVES
Density - Relative Log Exposure
FOR PRINTERS AT
GODDARD SPACE FLIGHT CENTER
DENSITY
NIAGARA
ECP-K (-2E)
COLORADO
EN70 2E
EN46
Mk II D + 3E
ECP-K + 3E
Mk II C + 3E
EK ORIGINAL
0
.3
.6
.9
1.2
1.5
1.8
2.1
2.4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Eastman Kodak Company
Process Date
Process
Mach. No.
Time Off
Sens.
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Exp. time
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Date
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Date
Test
Anal.
FIGURE 8
TONE REPRODUCTION CURVES
Density - Relative Log Exposure
FOR PRINTERS AT
JOHNSON SPACE CENTER
TEXAS
COLORADO
4X MILLER-HOLZ
RAINBOW
NIAGARA
SICKLE
2447 FILM
DENSITY
4-17

Emul. No.__________ Eastman Kodak Company Process Date______

Process ______ Sens. ______ Dens. ______ Test______

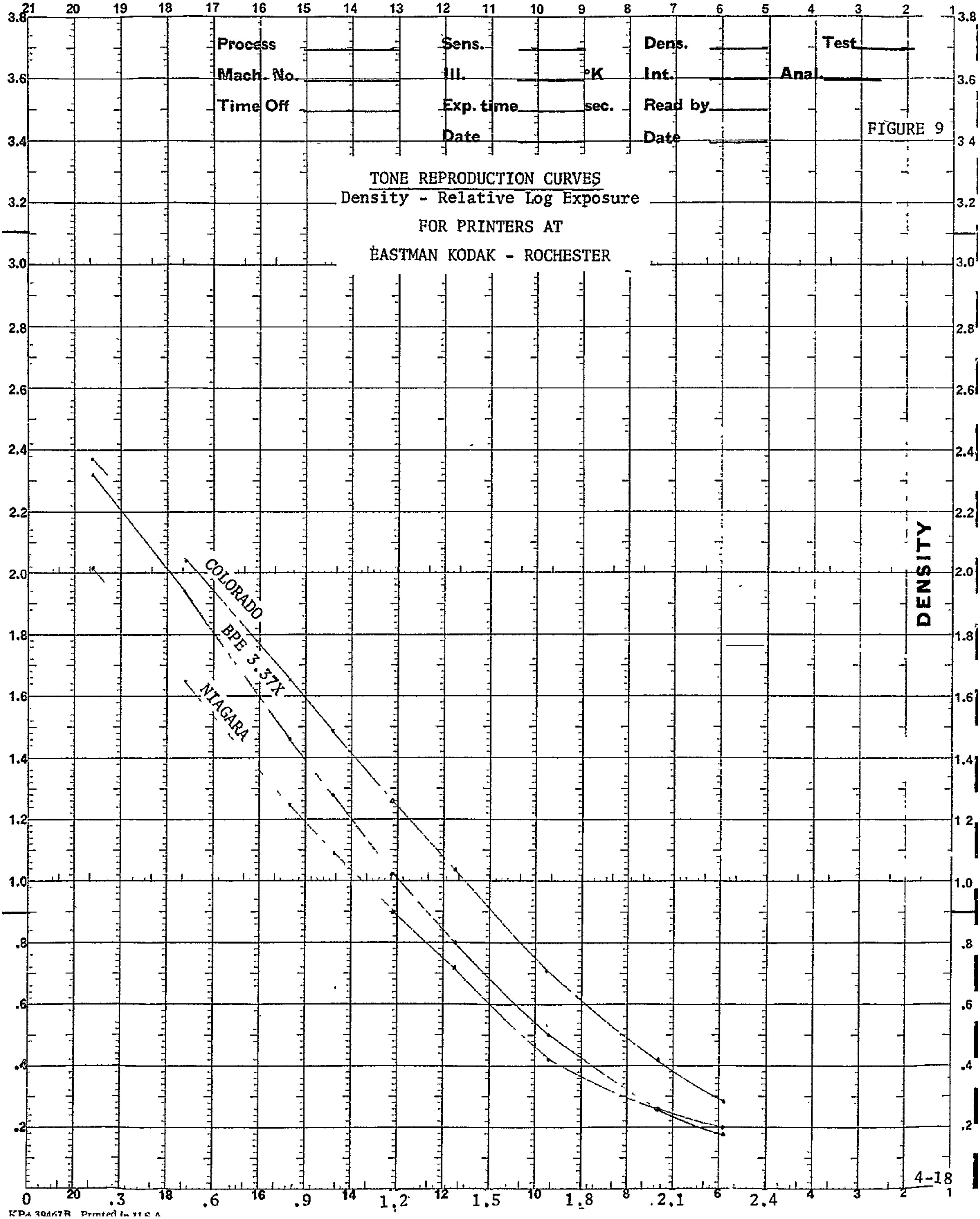
Mach. No. ______ Ill. ______ °K Int. ______ Anal.______

Time Off ______ Exp. time______ sec. Read by______

Date ______ Date ______

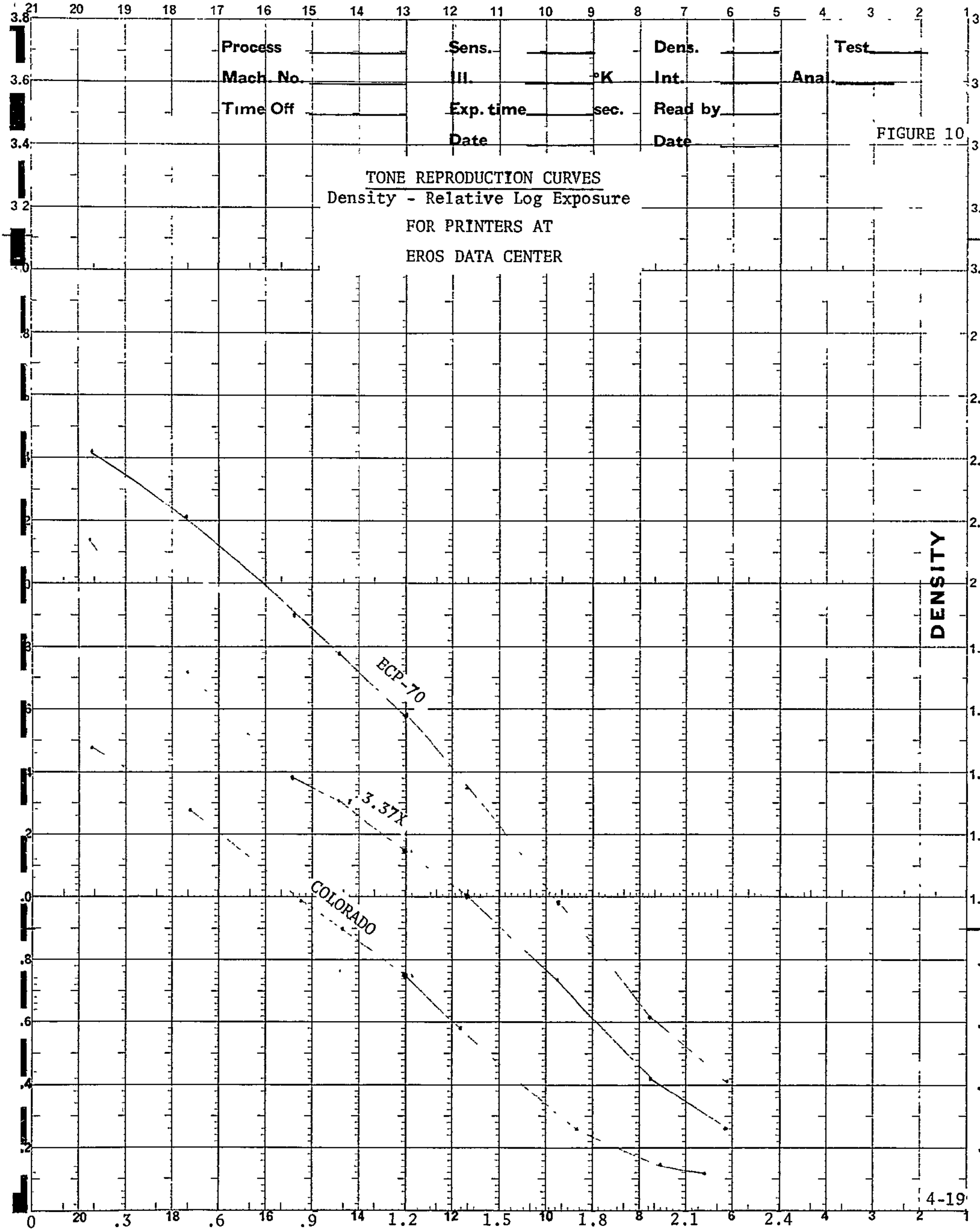
FIGURE 9

TONE REPRODUCTION CURVES
Density - Relative Log Exposure
FOR PRINTERS AT
EASTMAN KODAK - ROCHESTER



KP4 39467B Printed in U.S.A.

Emul. No.________ Eastman Kodak Company Process Date____



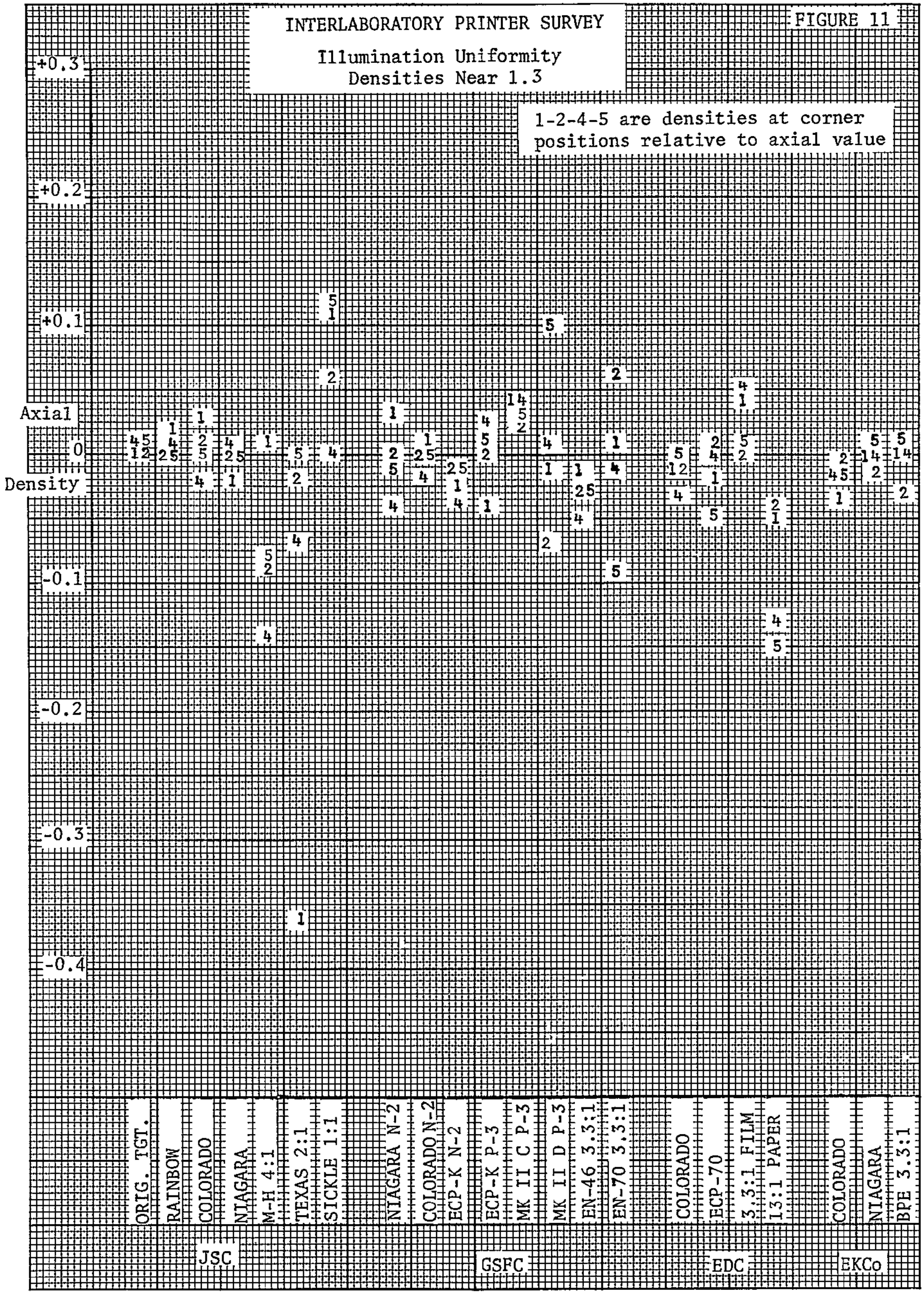
KP4 39467B Printed in U.S.A.

In addition to producing a linear tone scale, earth resources printers should have uniform illumination intensity over the frame. To show this characteristic, background densities at the four corners of the frame are plotted in Figure 11 relative to the density produced on axis. Although a few prints are excessively light or dark, most background densities are near 1.3 and form a sensitive test for exposure uniformity at a gamma of about 1.0.

Contact printers at all laboratories give uniform exposure to ±0.05 density, but many enlargers are nonuniform. The Texas, Miller-Holzworth and Sickles printers at JSC show the largest deviations, while the 13X paper enlarger at EDC also needs adjustment. Nonuniformity in the third generation print made on the Mk II D at GSFC reproduces the nonuniform field of the EN70 enlarger used to make the 3.37X negative.

Geometric Distortion

One measure of geometric distortion in a printer is the uniformity of magnification across the image format. In Figure 12 the magnification at four corners is plotted relative to that on axis for the original target and for each printer. Data for all contact printers are within ±0.2% at all points in the frame, but several enlargers show as much as 0.7% error. Corners 4 and 5 in



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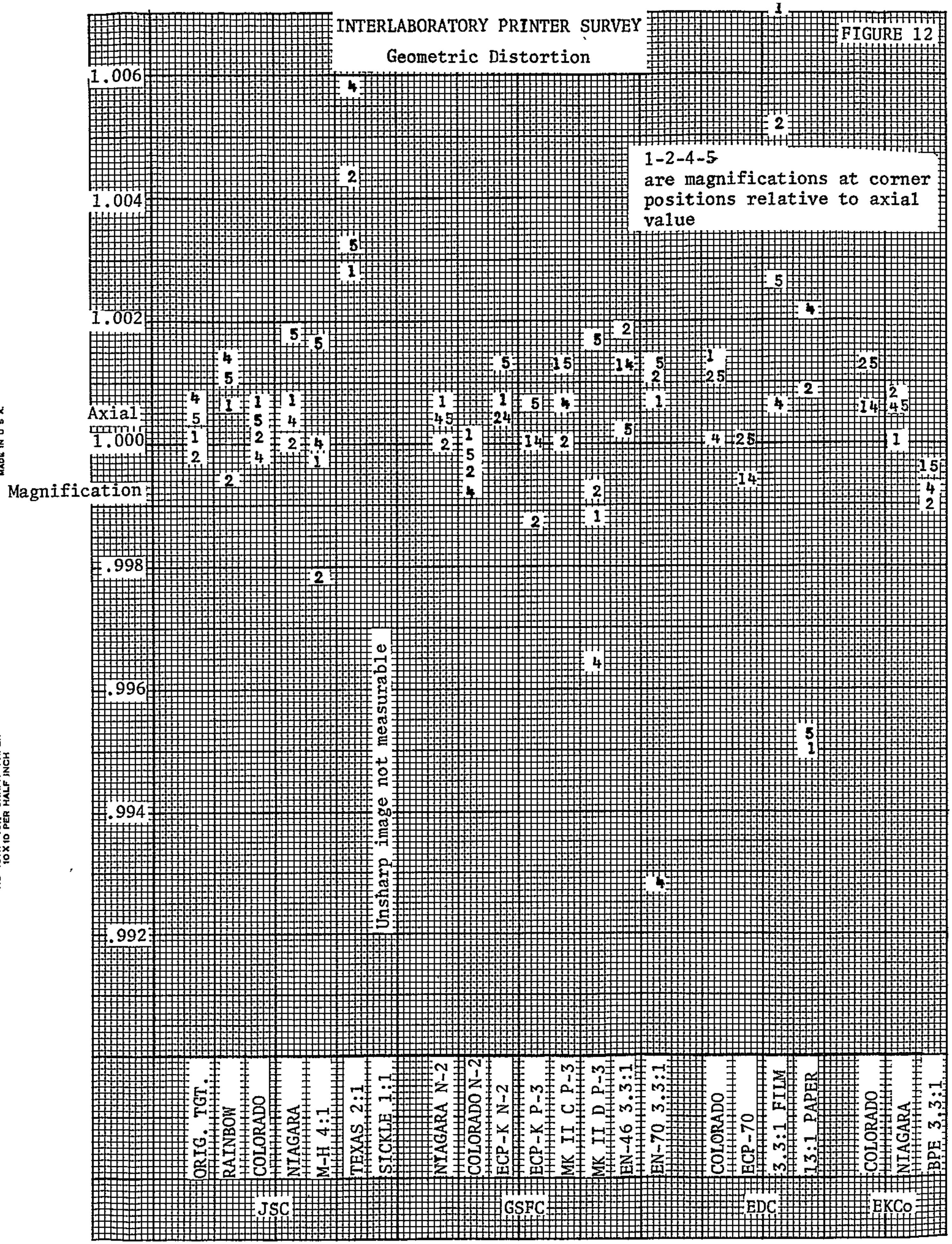
INTERLABORATORY PRINTER SURVEY
Geometric Distortion
FIGURE 12
1-2-4-5
are magnifications at corner positions relative to axial value
Axial
Magnification
1.006
1.004
1.002
1.000
.998
.996
.994
.992
Unsharp image not measurable
ORIG. TGT.
RAINBOW
COLORADO
NIAGARA
M-H 4:1
TEXAS 2:1
SICKLE 1:1
NIAGARA N-2
COLORADO N-2
ECP-K N-2
ECP-K P-3
MK II C P-3
MK II D P-3
EN-46 3.3:1
EN-70 3.3:1
COLORADO
ECP-70
3.3:1 FILM
13:1 PAPER
COLORADO
NIAGARA
BPE 3.3:1
JSC
GSFC
EDC
EKCo

the original target have a slight positive error that is reproduced well by most contact printers. Values from the Texas and EN70 enlargers were checked by repeated measurements; these data yield a precision of ±0.0004 for the points plotted in Figure 12.

Flare

The flare test described in MIL-STD-150A produced the percent flare information listed in Table I. In enlargers having significant flare, this defect is usually largest on-axis where it appears as a "hot-spot". The two machines at GSFC show excessive flare, while all others are below 2%, an arbitrary maximum value for high quality work. Use of Tropel f/3.5 lenses should reduce flare.

Even when flare is between 1% and 2% it may be profitable to further reduce flare light by darkening adjacent walls, operator clothing, and all surfaces along the optical path that can be "seen" by the print material. The enlarging lens must be very clean and have an antireflection coating that is effective at the exposing wavelengths. The edges of the lens elements should be beveled and blackened to reduce reflections into the lens.

Tribar Enlargements

To illustrate the variation in image quality obtained in this survey, the enlargements in Figure 13 were prepared. These images were made using a diffraction limited f/4 lens on KODAK

TABLE I

FLARE IN ENLARGERS

Used for

EARTH RESOURCES PHOTOGRAPHY

	Percent Flare Across Frame				
	Edge	1/2	Center	1/2	Edge
GSFC					
EN-70 3.3:1	3.4		8.4		3.3
EN-46 3.3:1	2.3	5.8	11.2	5.9	2.3
JSC					
Miller-Holzworth 4:1	0.5	1.0	0.7	0.6	0.7
Texas 2:1	0.6	0.6	0.6	0.6	0.6
EDC					
3.37X Film	0.6	1.0	1.5	1.3	0.7
13X Paper	1.2	1.4	1.9	1.6	1.5
EKCo.					
BPE 3.37X	0.4	0.7	0.9	0.7	0.6

ENLARGEMENTS
OF AXIAL TRIBAR IMAGES
50X FROM ORIGINAL SCALE

FIGURE 13

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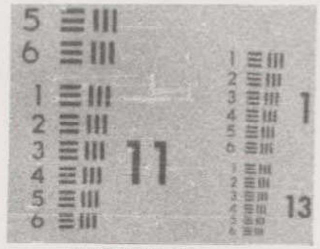


ORIGINAL
TARGET

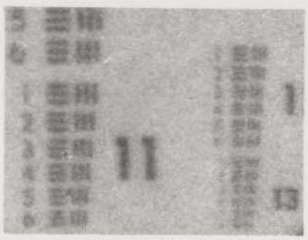
COLORADO
70 N2 GSFC

NIAGARA
70 N2 GSFC

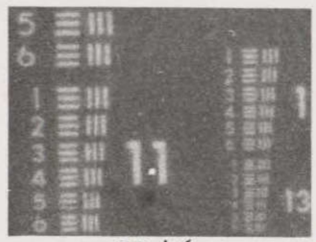
ECP K
70 2E GSFC

ECP K
70 3E GSFC

MK II C
70 3E GSFC



MK II D
9.5 3E GSFC



EN 46
GSFC

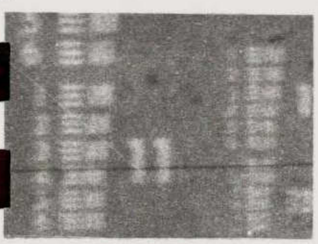
EN 70
GSFC

COLORADO
JSC

NIAGARA
JSC

RAINBOW
JSC

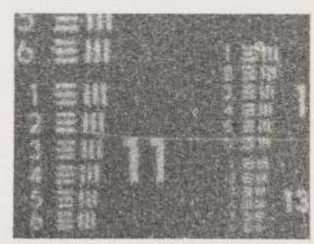
SICKLES
JSC



TEXAS 2:1
JSC

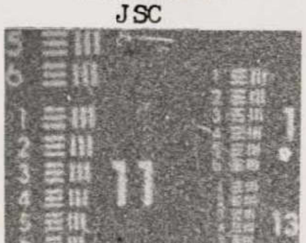
MILLER-
HOLZWORTH
JSC

3.369 X
EDC



COLORADO
EDC

ECP 70
EDC



KODAK
COLORADO

KODAK
NIAGARA

KODAK
BPE

4. Additional tests should be run on the Niagara printers at GSFC and in Rochester to improve resolution at all points across the field.

5. Resolution from the Kodak BPE at 3.37X is not equal to that obtained from several other enlargers. However, both resolution and illumination are very uniform on the BPE enlarger.

6. The Sickles and Texas optical printers at JSC give unsatisfactory resolution and show geometric and radiometric nonuniformity. Adjustment of the Texas film drive may improve resolution along the film length.

   Replacement of the Sickles lens with two lenses of proper focal length placed face-to-face should improve 1:1 image quality. Focus adjustments on this machine should be more positive and must be locked in place at the operating position.

7. While the M-H 4X enlarger at JSC is giving excellent quality the Rainbow contact printer gives low resolution and image contrast and should be adjusted.

COMPARISON OF
ERTS PHOTOGRAPHS
FROM THREE LABORATORIES

This study is part of
Work Order #5 under
Contract NASW-2317

Submitted to
National Aeronautics and Space Administration
Earth Observation Programs
Washington, D. C. 20546

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Approved by,

George L. Pearce

23 August 1974

Introduction and Summary

Image quality of ERTS pictures may be evaluated using routine ERTS photographs or special test targets, as was done quantitatively in two previous surveys made under this contract. In this case an unbiased assessment of ERTS quality was obtained by ordering 9 inch transparencies of identical frames from the EROS Data Center, Goddard Space Flight Center, and USDA Western Laboratory in Salt Lake City. On these prints physical defects and image sharpness were noted and discussed with laboratory personnel. Following this appraisal reprints were made that in each case showed improved sharpness and cleanliness.

The GSFC print is darker by 1.2 density units than the print from USDA, and shows significantly better resolution on axis than at the edges. Under-exposure and substantial physical damage marred the USDA contact print, but both factors were greatly improved in a reprint at that laboratory. The USDA optical print was soft and low in contrast because of flare. The best tone reproduction and image quality were produced by EDC, but dirt and scratches also were prominent in this work.

Improvements are planned at all three laboratories. EDC will have Tropel lenses in their new K&E enlargers and have made considerable headway in reducing damage to negatives. GSFC has similar lenses on order for their 3.37X printers. Extensive modifications and expansion of facilities are planned at USDA; application of experiences at the other two sites should lead to substantial improvement in ERTS imagery from USDA.

This kind of survey should be repeated later in 1974 using recent ERTS frames.

Procedure

In previous surveys of printers in earth resources laboratories, quality evaluations were made from images of a special test target. Because the target is obviously a test pattern, there is some question as to its unbiased treatment by laboratory personnel. Accordingly another survey was planned in which the quality of a single ERTS frame was measured on 9.5 inch transparencies made at Goddard Space Flight Center, EROS Data Center, and the USDA Western Laboratory in Salt Lake City.

ERTS photography in Band 5 (red light) was obtained in February, 1974 from GSFC after perusal of a computer listing of useful frames for Sacramento, Calif., Kansas City, Mo., and Rochester, N. Y. Similar photography was ordered from the EROS laboratory on 25 July 1973 and received on 24 March 1974. Both sets of pictures were obtained without identification of Eastman Kodak as the recipient.

After preliminary analysis of this photography, two of the frames were ordered in February, 1974 on Kodak letterhead from the USDA Western Laboratory at Salt Lake City. While several pictures from each laboratory were similar in area and seasonal coverage, only one frame was identical in all three cases. ERTS picture 1398-16273 exposed in Band 5 (red) on 25 August 1973 over Kansas City, Mo. was used for most of the enlargements and quality analyses.

These 9.5-inch transparencies were inspected at 7X magnification for image quality and physical defects. Enlargements were made of selected areas to demonstrate certain quality features. The edge gray scale was read in blue light (31A-Status A) as were the maximum and minimum scene densities using an aperture of 0.75 mm. In the course of discussing these results with laboratory personnel reprints of the test scene were made and evaluated.

Test Results

Table I lists observations of physical and photographic quality while similar comments are noted in Table II for the reprints. Two outstanding differences in the original prints are immediately evident: the USDA and GSFC prints differ in density by 1.2, and the prints from EDC and USDA show much greater physical damage than the GSFC print. The severe underexposure of the USDA print undoubtedly contributes to its lower sharpness, but it also suffers from poor contact and image transfer in the LogE MkII-10 printer. Furthermore, it is a 5th generation positive made from a 9.5-inch N-4 produced at GSFC. It is unsharp in the corners partly because of the poor off-axis performance of the GSFC EN-70 enlarger.

Differences in image quality are apparent in the 7.5X enlargements displayed in Figure 1 for off-axis and near-axial areas in prints from the three laboratories. The print made at EROS Data Center shows the finest details in both central and edge areas.

Table I

PHYSICAL & IMAGE QUALITY OF ERTS FRAMES

Frame	ERTS Date	Separation of N-S Fiducials on W side, mm	Image Quality	Physical Quality
GSFC				
1398-16273	25 Aug 73	202.5	Scan lines sharpest at W edge. Corners poor, center fair. Step tablet Dmin vignetted. Very high density print.	3 white dirt/cm^2; 2 white scratches/cm along film
1309-18181	28 May 73	-	Scan lines visible only on W edge.	5 white dirt/cm^2; very few scratches
1381-18165	8 Aug 73	-	Scan lines visible only on W edge.	3 white dirt/cm^2; very few scratches
EDC				
1398-16273	25 Aug 73	201.5	SE and SW corners show sharp scan lines. Center and NW corner fair. NE corner very soft.	24 black dirt/cm^2; 5 white dirt/cm^2 1 large white scratch/cm along film. White specks in sharply imaged areas.
1309-18181	28 May 73	-	Film fogged for 4 inch width. Similar to above except SE corner also soft.	20 black and white dirt/cm^2 5 white scratches/cm along film
1381-18165	8 Aug 73	201.3	Flare around edge data and final 2 gray scale steps Sharpness similar to 25 Aug 73.	20 black dirt/cm^2; 10 white dirt/cm^2 3 major scratches/cm along film
USDA				
1398-16273	25 Aug 73	202.5	Print very thin. Non uniform exposure of edge data. Scan lines in center, 2X poorer at edges, 4X poorer in corners. West edge nearly equal to axis.	8 very fine white scratches/cm along film 7 white fibers, hairs, or dirt/gray scale step
1291-18175	10 May 73	-	Worse overall than 25 Aug 73. Scan lines barely visible. Darker than 25 Aug 73 but still too thin.	Dirt as for 25 Aug 73. Some dirt marks are identical in both frames.

Table II

PHYSICAL & IMAGE QUALITY OF ERTS REPRINTS

Frame	Date REPRINTED	Separation of N-S Fiducials on W Side, mm	Image Quality	Physical Quality
GSFC				
1398-16273	26 June 74	201.8	Better overall than 1^{st} print West edge still sharper than others.	Very clean
EDC				
1381-18165	12 June 74	201.8	Better than 1^{st} print, scan lines visible on axis. Lines sharpest on N. edge, good on E & W edges, none on S edge.	Matte particles very sharply imaged by enlarger, show as white specks on print.
USDA				
1398-16273 Contact Reprint	11 July 74	202.5	Much darker than 1^{st} print. Probably better sharpness, but corners still poor quality	Much cleaner than 1^{st} print. New scratches along E & W edges. Newton Rings obvious. Some scratches gone, although identical N-4 was used.
1398-16273 Optical Print	11 July 74	201.0	Lower contrast, dull highlights compared to contact print. On-axis sharpness 2X poorer than contact print. Equal to contact print in corners.	Clean print. Very few scratches or dirt. Enlarger lens flare evident on black dirt along title edge and on gray scale Dmax. Flare at SW edge from print film easel.

FIGURE 1

ERTS PRINT COMPARISON
SCALE 1:133,000

25mm OFF AXIS

95mm OFF AXIS

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The falloff in sharpness at GSFC is fairly symmetrical around the lens axis, while the EDC print is best along the south side for two of the three frames. Despite the advantage of enlargement directly from the 70 mm P-1, the GSFC print does not show Electron Beam Recorder scan lines clearly except along the west edge. These lines seem to be enhanced in some areas of the USDA print, probably by virtue of selective improvement in the rendition of certain frequencies by the multiple printing stages. However, fine details of the scene are in every case poorer in the USDA print than in the print made at EDC. Improved image quality is evident at all three laboratories in the enlarged reprints shown in Figure 2.

Image contrast is reduced in the GSFC print because of lens flare in the 3.37X enlarger. Other aspects of tone reproduction in the three prints are shown in Figure 3 where densities on the 9.5-inch P-3 are plotted against densities on the original P-1. The shouldering of high densities on the GSFC print is caused by slight non-linearity in the toe of Kodak Aerial Duplicating Film (ESTAR Base) SO-467 film and primarily by lens flare in making the 9.5-inch N-2. Curvature at lower densities on GSFC print #1 is the result of non-uniform illumination in the EN-70 printer. This problem now has been corrected on this printer and on the EN-46 used for GSFC print #2.

Because of underexposure of the P-5 transparency, low densities on the USDA prints are greatly compressed. USDA print #2 is heavier and has improved tone scale, but both prints are very non-linear. Note that the ERTS gray scale is a poor record of scene tone rendition in USDA prints

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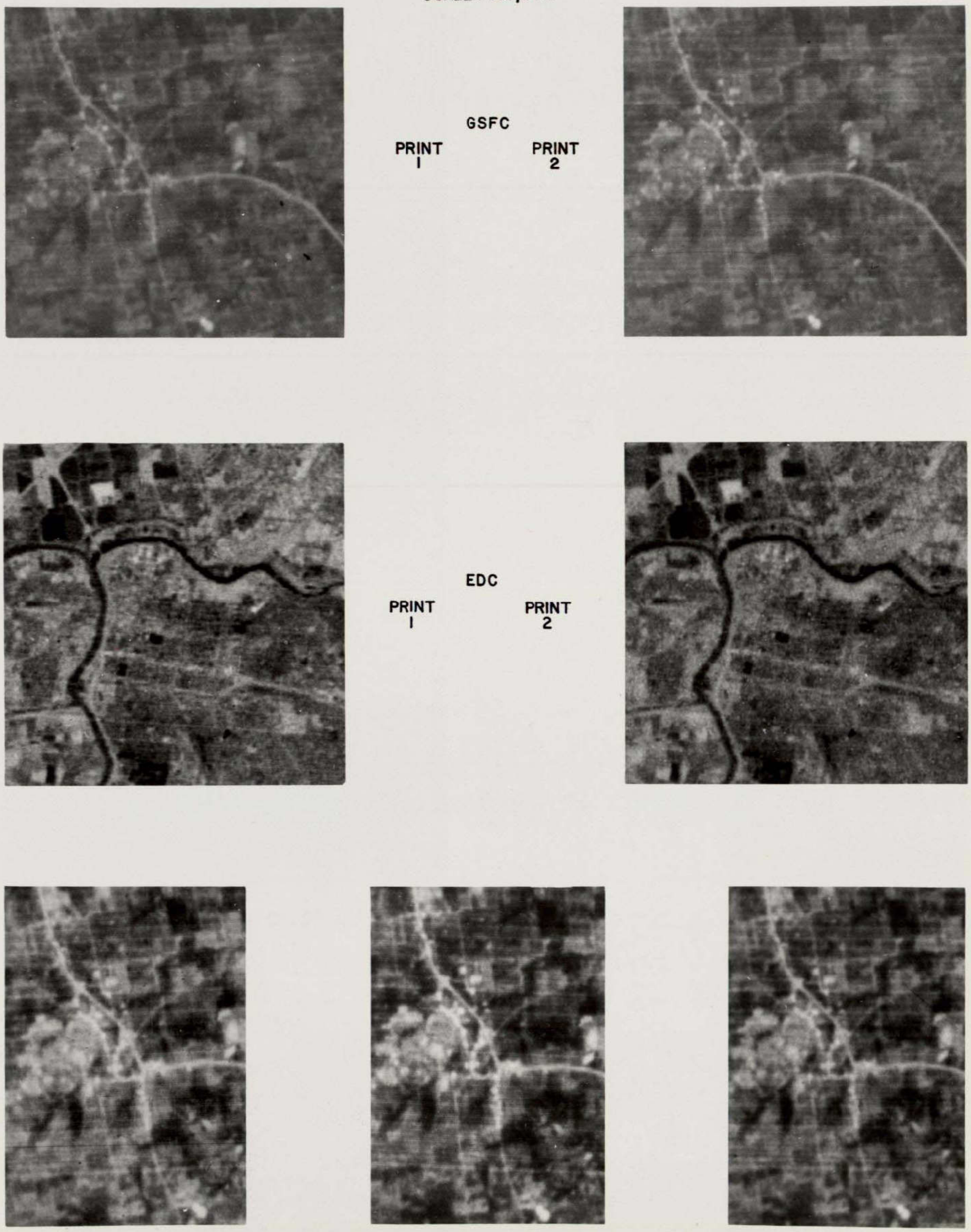
FIGURE 2

ERTS PRINT COMPARISON
SCALE 1:133,000



USDA CONTACT PRINT 1

USDA CONTACT PRINT 2

USDA OPTICAL PRINT

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as the gray scale is disproportionately compressed by the dodging action of the Logetronics contact printer. The second USDA prints in Figure 2 show strong midscale contrast and a good black level, as apparently rather high process gamma is used for SO-467 film to offset the effects of low sharpness and a non-linear tone scale.

At the Salt Lake City Laboratory a 3.37X enlargement was made from the GSFC 70mm N-2 using a 135mm Schneider Componon lens. This print appears clean but haslowercontrast than the contact print and does not show fine image details; perhaps both physical defects and image structure are subdued by flare and poor optical quality.

The reprints from all three laboratories are better in physical and photographic quality than the original prints, although this difference is small at EDC. Because of slightly better focus, print #2 from EDC (Figure 2) shows small white specks that are only faintly visible in print #1. These are matte particles coated by Kodak on the emulsion side of SO-467 film to minimize the formation of Newton Rings in printing. They are invisible in contact prints but are seen in specular enlargements of an SO-467 image, a print made fairly rarely. Possibly the 70mm N-2 images for EDC and other agencies should be made at GSFC on another film material that has finer grain and no or smaller matte particles in the overcoat; KODAK Fine Grain Aerial Duplicating Film 2430 (ESTAR Base) might be suitable as it has no matte coating.

Dirt and scratches are a prominent problem on these enlargements, especially at EDC and USDA. The level of physical damage on EDC N-2 images probably depends on the "popularity" of particular frames, as damage undoubtedly increases every time a negative is handled to fill an order. In addition, these prints are from fairly old negatives that were probably handled in the temporary EROS laboratory where equipment and procedures were of marginal quality. Current production at EDC is given better treatment, although there is certainly room for further improvement, particularly in enlarging equipment and cleaning techniques. Eventually, automation of the two new K&E 3.37X printers should greatly reduce film damage at EDC.

While the first prints from USDA were very dirty, the reprints demonstrate a capability for much cleaner work. This laboratory is planning extensive modifications and additional facilities which should produce sharper prints that show fewer scratches and dirt marks. For substantial gains to be made, vigorous laboratory cleanliness procedures are needed along with special air filtering and film handling techniques. The experience in this area at GSFC and EDC should be made available to USDA personnel.

Conclusions and Recommendations

1. Image sharpness and tone reproduction in ERTS prints made at EROS Data Center are superior to that in prints made at GSFC and the USDA Western Laboratory.
2. Density of GSFC prints is fairly high while the USDA print is definitely underexposed.
3. Marks from dirt and scratches are prominent on enlargements made by EDC and USDA.

4. In all cases reprints of the survey frames were cleaner and sharper than the first prints.

5. The survey should be repeated to monitor changes in quality at these facilities.

6. A new 3.37X lens is needed at GSFC to reduce flare and improve off axis image quality.

7. The USDA laboratory requires substantial improvements in both optical and contact printers for ERTS frames.

EVALUATION OF FLARE IN

PRINTING ERTS SCENES

This study is part of
Work Order #6 under
Contract NASW-2317

Submitted to
National Aeronatuics and Space Administration
Earth Observation Programs
Washington, D. C. 20546

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George T. Keene

25 October 1974

Summary

Edges in contact prints and enlargements from an ERTS P-1 frame were measured for flare at three printing stages. Contact prints show some reduction in edge gradient caused by halation in the print film but the loss of edge sharpness is much greater in enlargements. In particular the lens used for enlargements at the EROS Data Center shows narrow-angle flare from off-axis lens aberrations that lowers the gradient of high contrast edges and scatters light into adjacent low density areas. EDC will receive two new K and E enlargers in December with Tropel optics that should greatly reduce this problem.

Contact prints made using ultraviolet illumination on KODAK Aerial Duplicating Film (ESTAR Base) SO-467 show much sharper edges on high contrast detail than do white light prints. Ultraviolet filters are now being used in the KODAK Colorado Printers at EDC and GSFC. Similar filtration probably will not improve overall image quality in ERTS enlargements.

Introduction

For some time users of ERTS photography have been concerned about flare or halation surrounding strongly exposed areas. This defect is especially prominent around lakes in infrared pictures and at the final black step of the ERTS scene gray scale. Of course, it is more noticeable in positive enlargements and sometimes has been severe in 3.37X prints made by the EROS Data Center from 70mm N-2 scenes.

This investigation studied sources and remedies for this problem in a series of contact and optical prints made in Rochester and at EDC. All tests were made on KODAK Aerial Duplicating Film (ESTAR Base) SO-467 as this material is used extensively for contact and optical prints at EDC and GSFC.

Procedure

A 70mm ERTS frame on Eastman Electron Recording Film (ESTAR Base) SO-438 was used as a test object along with a Kodak step tablet scale. This material was contact printed onto KODAK Aerial Duplicating Film (ESTAR Base) SO-467 in a specularly illuminated glass printing frame. Two 70mm N-2 images were made, one on a black platen and one using a white platen. After evaluation, the N-2 made on a black platen was contact printed to make P-3 images on both black and white platens. In addition the N-2 was enlarged 3.37X to make a 9.5 inch P-3 on SO-467 film. The Durst condenser enlarger is equipped with a Schneider Comparon f/4.5 lens of 135mm focal length. All prints were made with unfiltered tungsten light.

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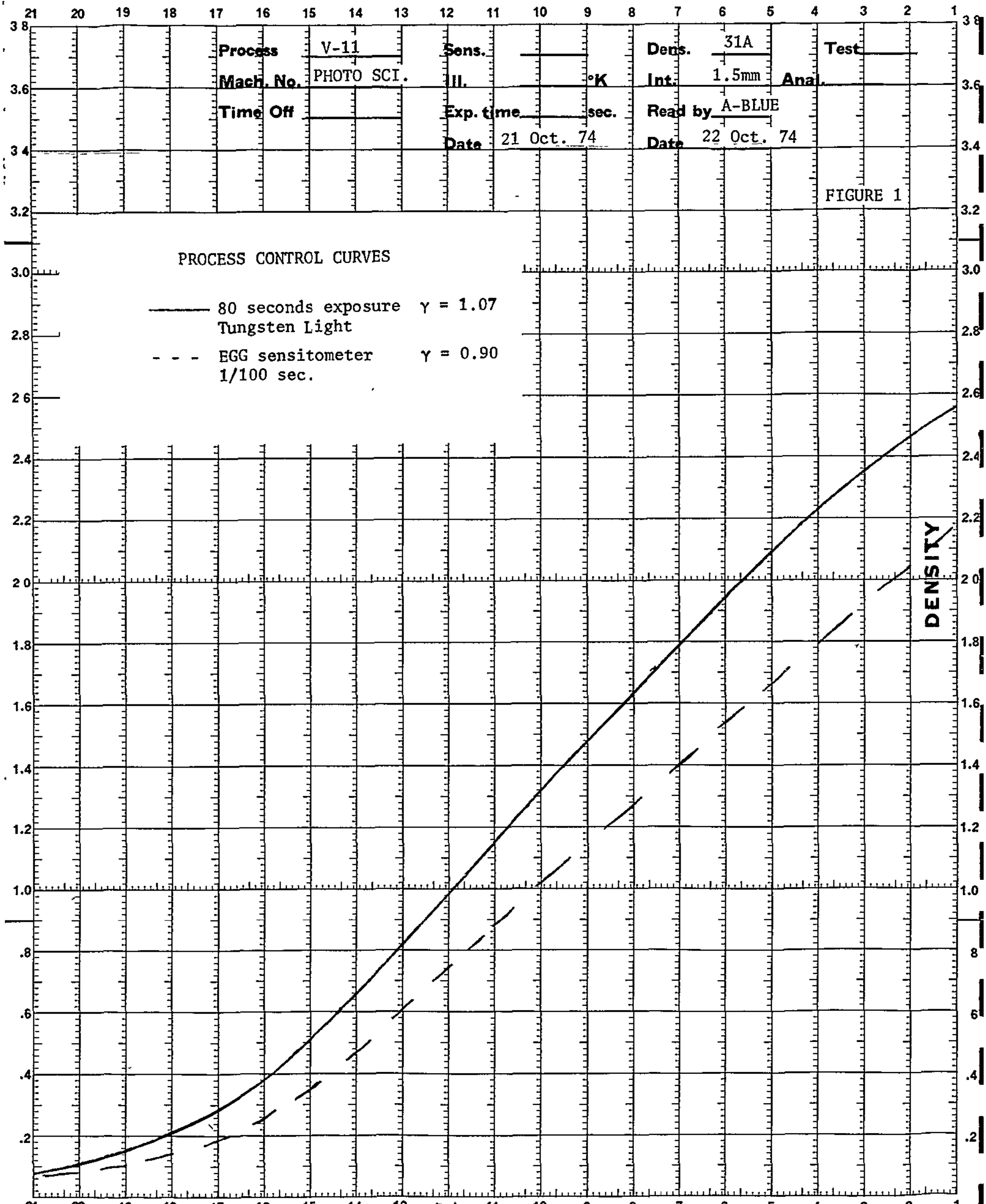
In every case an exposure series was made to insure correct placement of the ERTS gray scale on the control curve shown in Figure 1. All processing was done in a KODAK Versamat Processor Model 1411 using MX-641 chemicals to produce a gamma near 1.0. Note in Figure 1 that the EGG sensitometer at 0.01 second makes a curve of lower gamma than is obtained with the typical 80 seconds printing exposure.

Print through curves in Figure 2 demonstrate the linearity of the N-2 stage and show the difference in contrast between optical and contact printing from an image on SO-467 film. For these test conditions, SO-467 film has a Q factor of 1.3, but the effect of higher contrast in optical printing is partially offset by enlarger flare that increases lower densities on the P-3.

Only a small change in exposure was caused by using black or white paper platens behind the SO-467 raw stock. Density increases of 0.02 to 0.04 were measured in gray scales made on a white platen, and there was only a small loss in edge sharpness or increase in halation. However, a black platen is recommended for all printers.

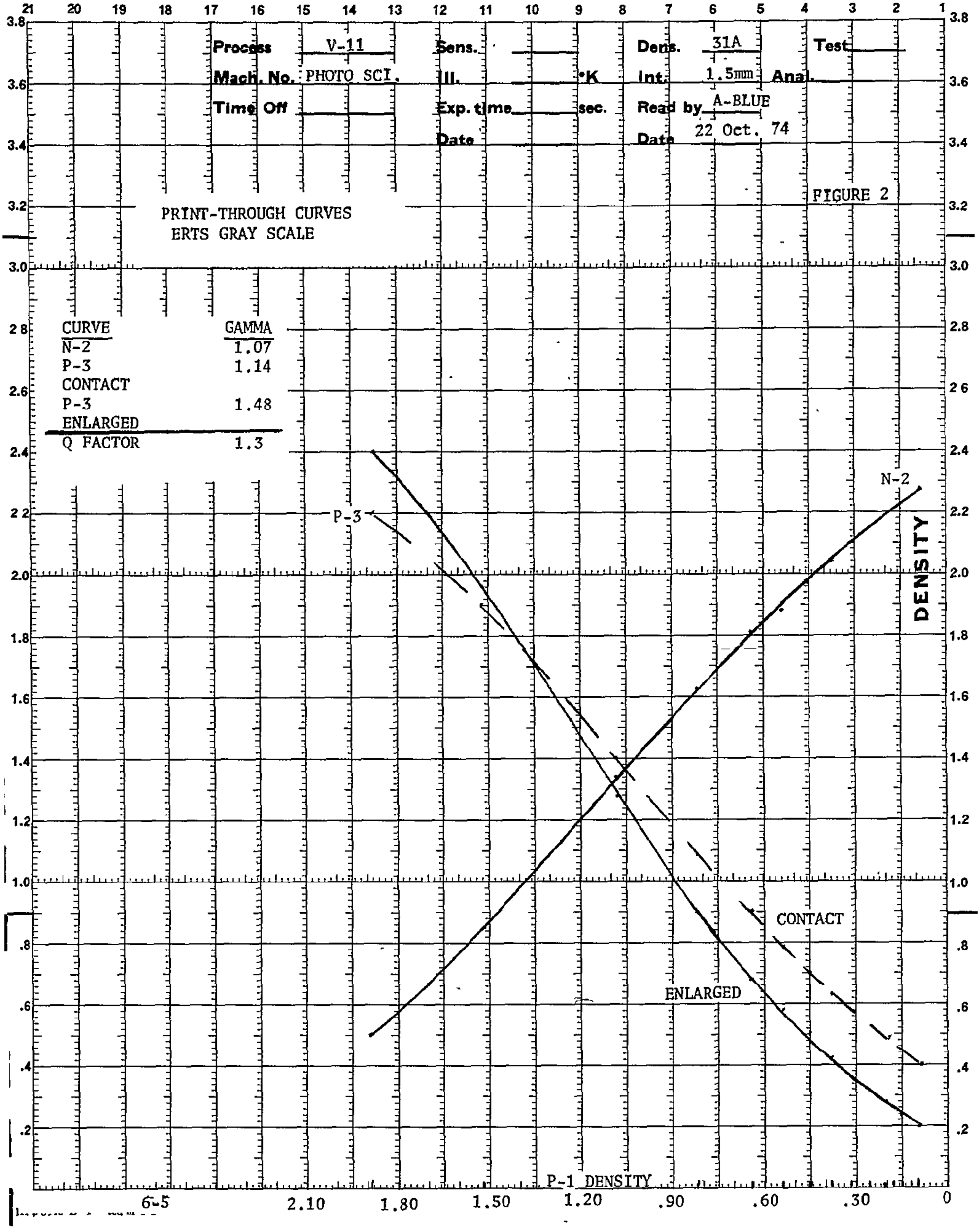
The 15-step ERTS gray scales were measured on an Eastman Electronic Densitometer Mod. 31A using an aperture of 1.5mm and a Status A blue filter. In addition, microdensitometer traces in white light were made with a 5 x 96 micron aperture across the side of ERTS step 15 and a step of similar density on the Kodak tablet. Since both areas seemed to give the same information, all plotted data and analyses are for the ERTS scale.

Emul. No. SO-467 **Eastman Kodak Company** **Process Date** 21 Oct. 74



KPφ 39467B Printed in U S A

Emul. No. SO-467 Eastman Kodak Company Process Date 21 Oct 74



While these tests were underway Mr. R. Shaffer compared the use of ultraviolet and blue light in exposing 70mm P-3 prints on the KODAK Colorado Printer at EDC. Measurements from these images are included in this report.

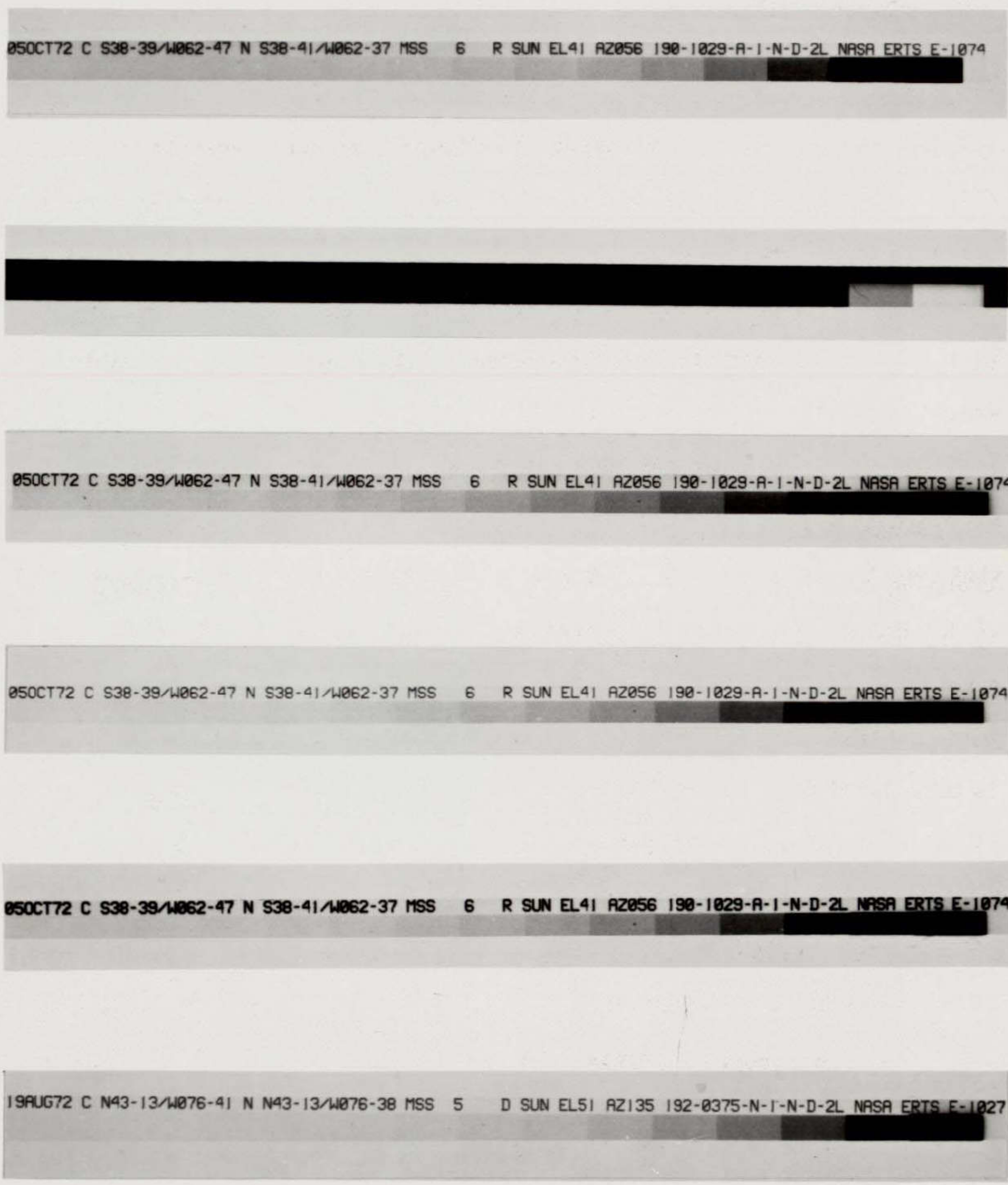
Results

The first four images in Figure 3 are enlargements of 70mm P-1, N-2, and P-3 ERTS gray scales printed to reveal the edge sharpness of the high density positive step. The lower two images are enlarged P-3 scales made in Rochester and at EDC (from a different P-1 original). This last image demonstrates the degree of flare deemed objectionable around ERTS step 15.

Details at the edge of these scales are best shown by the microdensitometer traces in Figure 4. The P-1 image is very sharp, changing from density 0.08 to 1.88 in 0.050mm. The black background of the contact-printed N-2 is also sharply bounded, but light has spread into step 15 reducing edge sharpness and causing an irregular gradient from 0.8 to 0.4 density that covers 0.4mm. This broad edge is reproduced at high density in the contact-printed P-3 in which additional unsharpness is produced by light spreading from step 15 into the low density background.

In Figure 4, the distance axis for the trace from the enlargements has been compressed by 3.37X to permit direct comparison with traces from contact prints. The enlarged edge is lower in gradient

STUDY OF HALATION IN ERTS PHOTOGRAPHY



P-1

N-2

CONTACT
P-3
WHITE PLATEN

CONTACT
P-3
BLACK PLATEN

ENLARGED
P-3

EDC
ENLARGED
P-3

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than the contact edge at nearly all points although it achieves an even greater density range because of the Q factor of this specular enlarger. The enlargement made in February 1973 at EDC shows more flare and very low edge gradient.

Flare in the 3.37X enlarger at EDC was reported in April, 1974 as 0.6% to 1.9% based on MIL STD-150A test conducted as part of the second interlaboratory survey. At the same time the enlarger at GSFC showed 2.3% to 11.2% flare but seemed to produce acceptable sharpness at high contrast edges. Apparently this test measures the uniformity of illumination across the enlarger field i. e., flare over fairly large angles. On the other hand, the objectionable flare in EDC enlargements stems from narrow-angle scatter or unsharp imagery of high contrast edges. This problem has been reduced at EDC by cleaning and adjusting the enlarger optics and it will be substantially eliminated on receipt of the new K&E enlargers with Tropel lenses.

When exposed in a white light printer SO-467 film reproduces ERTS images with adequate sharpness. There is some spreading of light across high contrast edges in contact printed N-2 and P-3 frames. However, this effect is so reduced by a yellow absorbing dye that there is only a small exposure change between prints made on black or white platens. Depending on lens and printer quality, enlargements show more losses than contact prints and the edge gradient is spread over a larger distance.

Further improvement in quality can often be obtained by using ultraviolet radiation in contact printing. Figure 5 compares P-3 images contact printed on SO-467 film using ultraviolet and blue light on the KODAK Colorado Printer at EDC. A Corning 5970 glass filter was used in one beam of the printer to make the ultraviolet print. High contrast details in the ultraviolet print are much sharper; note this gain around the frame number (102) and at the edge of step 15 in the gray scale. The edges of lakes—imaged very black in this infrared positive—show much clearer detail and less flare in the ultraviolet print.

Figure 6 reveals the extent of this improvement by photomicrographs and density traces of the step 15 edge on the ERTS gray scale. Exposure by ultraviolet is increasingly confined to the surface layers as the radiant intensity drops at the edge. This effect is not caused directly by the yellow dye in the film but is the result of natural absorption of scattered ultraviolet energy by the silver and gelatin. The yellow dye produces sharper images in blue light printing (with some loss in speed) but it is relatively transparent to ultraviolet radiation. This absorbing dye is used in KODAK Fine Grain Aerial Duplicating Film 2430 (ESTAR Base) and in SO-467 film but not in KODAK Aerographic Duplicating Film 2420 (ESTAR Base). Improvement in high contrast tribar resolution on ultraviolet prints can approach 100% compared to white light exposures on 2420 film. Ultraviolet printing causes less gain in the sharpness of low contrast detail and its advantage is less on 2430 and SO-467 films in which the yellow dye shifts much of an unfiltered tungsten exposure to ultraviolet wavelengths.

An ultraviolet filter may not improve image quality in ordinary enlargers, as any reduction in halation in the print film may be offset by greater lens aberrations and flare at shorter wavelengths.

Conclusions and Recommendations

Image flare or edge broadening occurs to some degree in all ERTS print stages after the P-1. Maintenance of intimate contact between original and print film and use of specular illumination restricts this loss to that inherent in the SO-467 film. The increase in flare caused by a highly reflective platen is noticeable but small; however, a black platen is recommended.

Two effects are noted in prints of high contrast edges a loss in gradient and a reduction of density range over which high gradient is maintained. A ΔD of 1.90 in the P-1 is reduced to 1.4 in the N-2 and to 1.25 in a contact-printed P-3. The N-2 and P-3 stages also show "density tails" into the area of lower exposure that can cause the full P-3 edge to cover 0.3 millimeter.

Edges in enlargements are lower in gradient and, especially for the EDC printer, show narrow-angle flare caused by lens aberrations that are most prominent for off-axis areas.

FIGURE 5

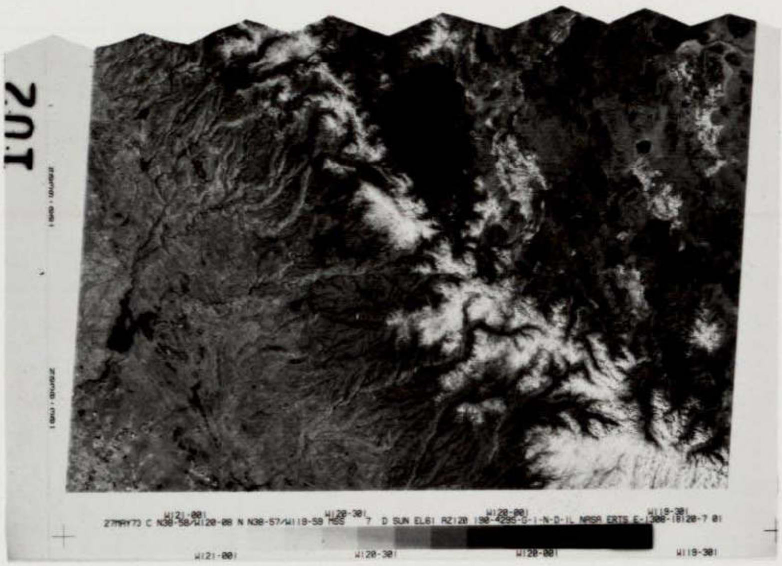
ERTS CONTACT PRINTS

MADE WITH BLUE AND ULTRAVIOLET RADIATION

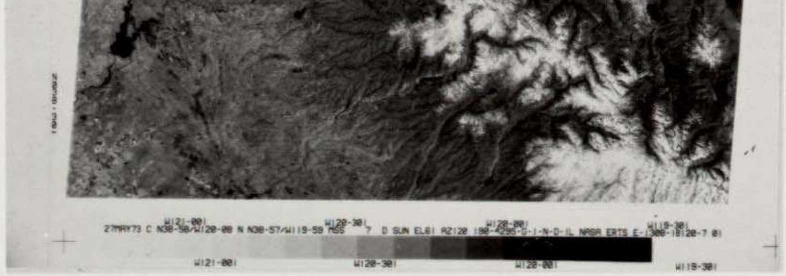
KODAK COLORADO PRINTER AT EDC

100 FT. / MINUTE

KODAK AERIAL DUPLICATING FILM (ESTAR BASE) SO-467



BLUE LIGHT



ULTRAVIOLET

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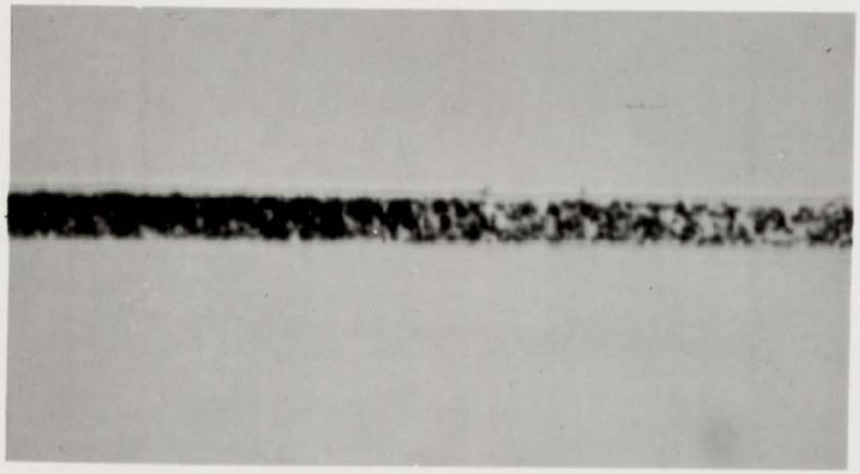
PHOTOMICROGRAPHS AND DENSITY TRACES
OF ERTS STEP 15 EXPOSED WITH
ULTRAVIOLET AND BLUE RADIATION

KODAK AERIAL DUPLICATING FILM (ESTAR BASE) SO-467

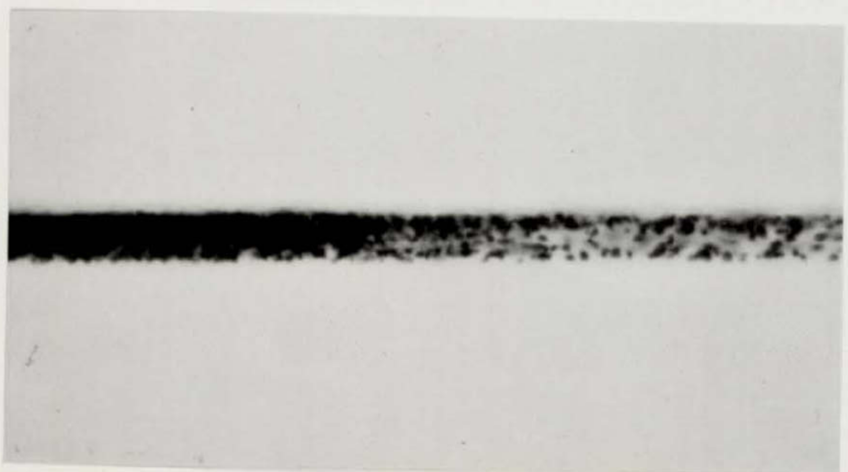
1600X



BLUE

0.071

MILLIMETERS ON FILM



ULTRAVIOLET

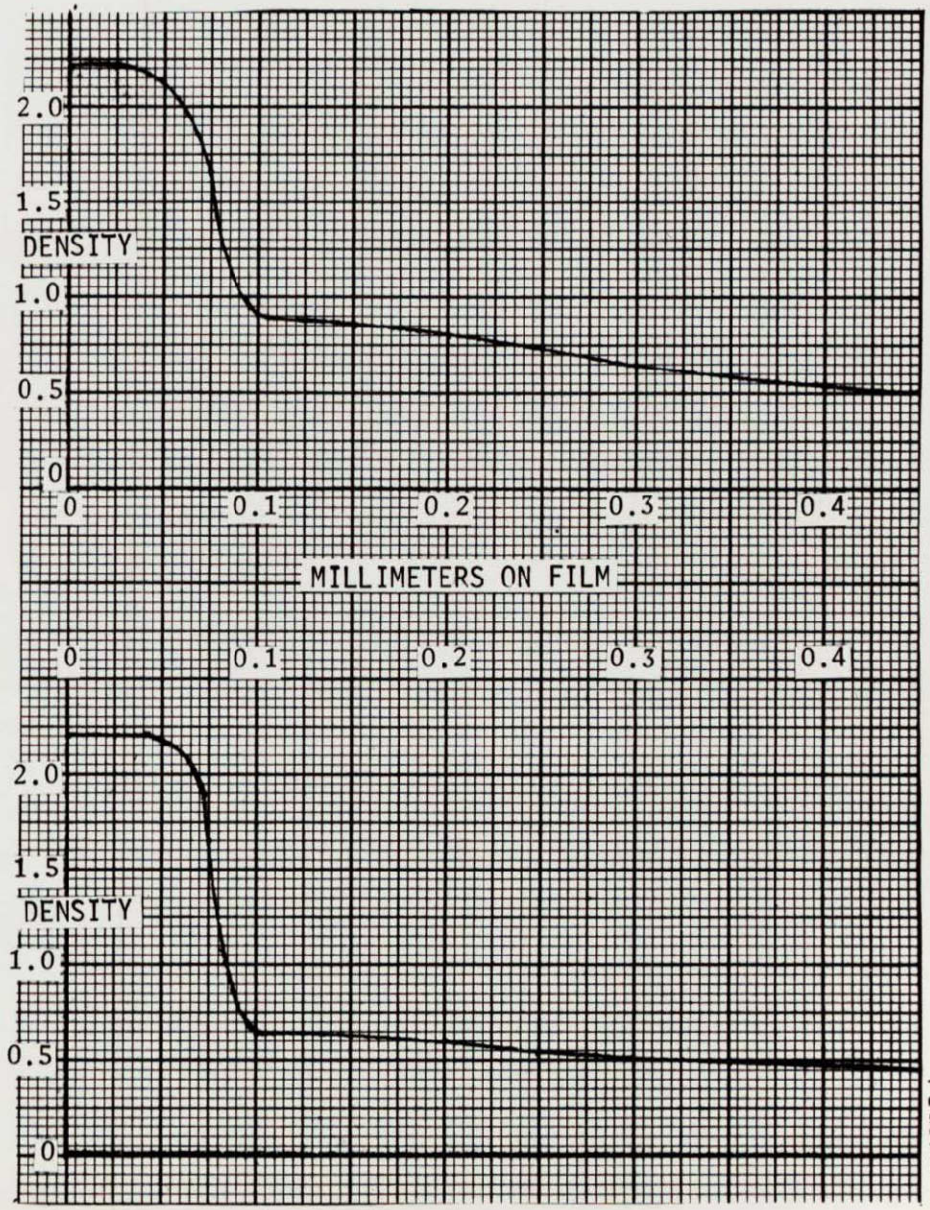


FIGURE 6

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

COMPARISON OF

ERTS PHOTOGRAPHY

FROM FOUR LABORATORIES

This Study is Part of

Work Order #8 Under

Contract NASW-2317

Submitted to
National Aeronautics and Space Administration
Earth Observation Programs
Washington, D. C. 20546

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30 April 1975

Introduction and Summary

An analysis of ERTS scenes printed at three government laboratories was reported in August, 1974 under Work Order No. 5. To monitor improvements in quality and service, a second survey of the same three laboratories was started in December, 1974 and was later extended to include the NOAA facility operated by the General Electric Company in Beltsville, Md.

At the EROS Data Center and the USDA Western Laboratory a blind customer order was placed for one frame used in the previous survey and for a new frame that is part of the EDC quick-response map of the United States. This kind of order insures an unbiased sample of image quality shipped by these agencies to customers. At the Goddard Space Flight Center and the G.E. facility, it is not possible to place a blind order, but a fair sample of their output was obtained.

Orders from USDA and EDC were received in 2 to 3 weeks; this is much faster service than we obtained in 1974. Image quality from the USDA laboratory is also greatly improved for both sharpness and density, but their film-process gamma is twice that at other laboratories and the tone scale is distorted.

Prints from an experimental printer at GSFC were much sharper than any others because a special Tropel lens is used. This gain in quality is especially noticable for off-axis areas and in frames showing snow cover. Tropel lenses are ordered for production printers at GSFC and EDC and are strongly recommended for the USDA and NOAA facilities.

Dirt and scratches are evident on prints from all laboratories, a problem that will be more severe when the Tropel optics are installed.

A survey to obtain quantitative quality measurements is planned for these and other facilities later in 1975.

Procedure

To allow comparison of results from the 1974 survey one of the same scenes was reordered from each laboratory. In addition to this image of Kansas City, Mo. (1398-16273, 25 Aug. '73), a frame showing western New York from the EDC Single Coverage of the U.S. was ordered (1244-15303, 24 March '73). Only 9.5-inch transparencies of Band 5 (red light) were requested.

Agency response to customer orders has greatly improved in the past year. The order mailed from Provo, Utah to the USDA Western Laboratory on 21 January 1975 was received in Provo on 3 February 1975. Similarly, an order sent from Rochester to EDC in Sioux Falls, S.D. on 13 December 1974 was received on 4 January 1975.

Since it is not possible for customers to place orders at GSFC, 9.5-inch transparencies of the two test scenes were requested through the CSTA technical staff.

In Rochester the pictures were evaluated for sharpness and for physical quality. The annotation gray scale below the Kansas City scene was read on the Kodak Densitometer Model 31A using the blue Status A filter. Selected areas of the scenes were enlarged 7.5 times and printed to show image quality both on and off axis.

On 2 April '75 during a visit to the General Electric Laboratory in Beltsville, Maryland, we obtained from A. Rossi a 9.5-inch enlargement showing an area in Montana. This frame (1719-17432, 12 July 1974) is representative of black-and-white enlargements made by G.E. under

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ORIGINAL PAGE IS POOR

contract to NOAA for the 3-color ERTS map of the United States. All three bands were checked for optical and physical quality, and two areas at 15mm and 85mm off axis in Band 5 were enlarged 7.5X for inclusion in this report. Densities of the scene gray scale were read in blue light and plotted against the blue light densities of the original P-1 image.

Results

Table I summarizes the physical and photographic quality evaluation of each frame. In the absence of formal ground targets, image quality is assessed by judging the apparent sharpness of the EBR scan lines and by the accutance of edges on cultural details in the scene. Micro contrast and flare are also noted along with the number of scratches and physical defects. Figures 1 and 2 are 7.5X enlargements of small areas in the prints.

In this survey GSFC printed the two scenes on both the EN-70 production enlarger and on the General Electric research printer equipped with a Tropel lens and illuminator. The advantage of the Tropel optics is most apparent in the off-axis views in Figure 1. Scan lines are readily visible at 95mm off axis while similar prints from other laboratories show no scan lines and have a much softer image.

The superb lens and specular illumination in the Tropel system prominently reveal all scratches and dirt on the 70mm original film. These defects are easily seen in the frame margins and also can be found over most of the scene. On the Kansas City scene most of the scratches are white in the EN-70 print, while the Tropel print shows predominently black scratches. This effect may be caused by different angles of

TABLE I
PHYSICAL AND IMAGE QUALITY OF ERTS FRAMES

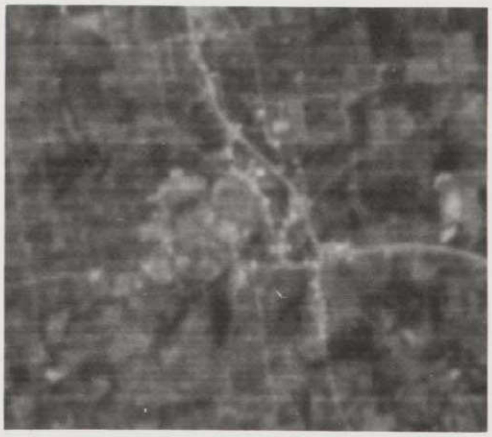
Laboratory & Frame No.	Separation of N-S Fiducials on W Side, mm	Image Quality	Physical Quality
GSFC-EN-70			
1244-15303-5	202.6	No scan lines center or corners Best in ring 50mm off axis	4 white scratches/cm along film 30 black or white dirt/cm^2 at edges
1398-16273-5	202.6	Sharpest in 50-60mm ring Scan lines on axis and at west edge	3-5 white scratches/cm Black dirt in margins One 1mm fiber
GSFC-Tropel			
1244-15303-5	201.4	Scan lines visible all over, best in SW corner, poorest in NW corner	4-5 black scratches/cm along film, 60 cinch marks, 0.5mm long, Newton rings, Black dirt very common, esp. in margins.
1398-16273-5	201.5	Scan lines very sharp all over frame	4-10 black scratches/cm., 1-2 large white dirt/cm^2, some dirt same as on EN-70
EDC			
1244-15303-5	201.1	No scan lines visible, print appears thin and contrasty in upper scale	0-1 white scratch/cm, 10-15 black dirt/cm^2 in both scene and margins
1398-16273-5	201.3	Flare around step 15 Dmax and frame No. Few scan lines on axis, faint in corners	5 large white scratches, many 1mm cinch marks/cm^2, new scratches added since '74 survey, 20 black dirt/cm^2 in margins
USDA			
1244-15303-5	202.4	Soft, scan lines only in 60mm ring, High contrast image	0-1 white scratch/cm, 3-10 dirt marks/cm^2 black and white
1398-16273-5	202.4	Much better density and sharpness than last survey, scan lines in center and faintly at west edge, many small Newton rings, high contrast image	Clean, less than 1 dirt mark/cm^2 0-1 white scratch/cm

FIGURE 1

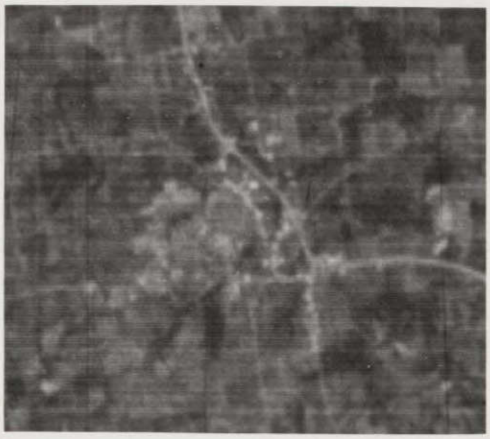
ERTS PRINT COMPARISON

SCALE
1:133,000

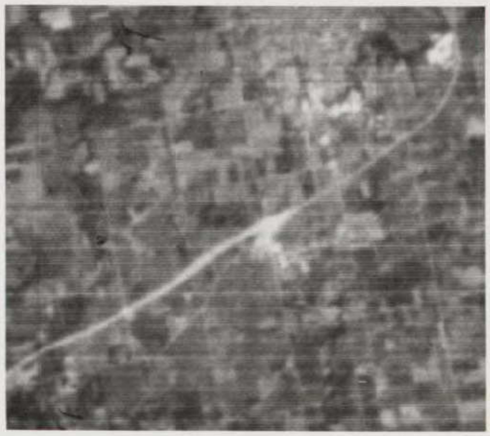
25MM OFF AXIS		95MM OFF AXIS

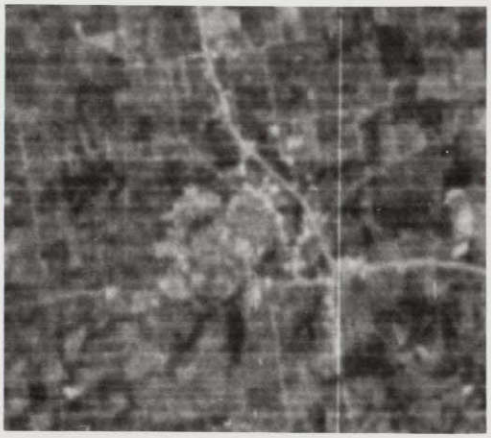


GODDARD
SPACE
FLIGHT
CENTER
EN-70
LENS

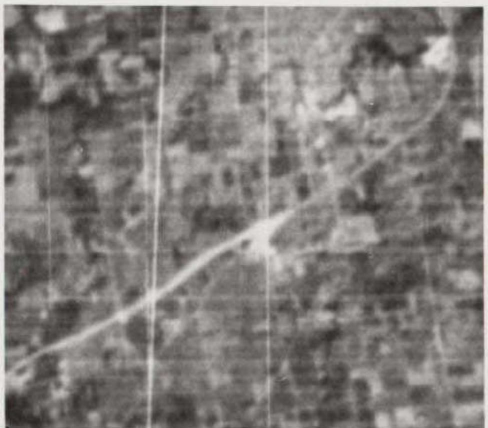


GODDARD
SPACE
FLIGHT
CENTER
TROPEL
LENS





EROS
DATA
CENTER



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USDA
WESTERN
LABORATORY

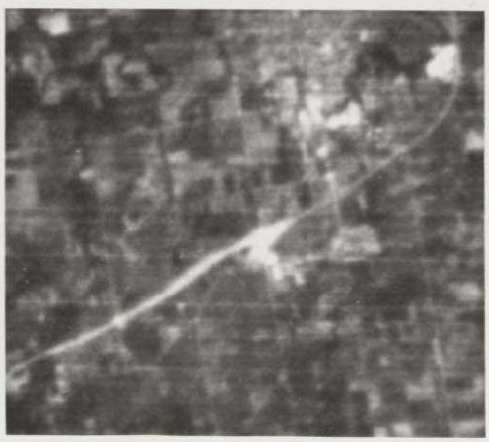

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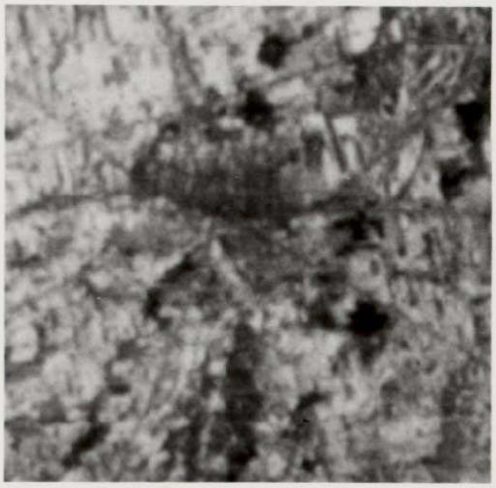
FIGURE 2

ERTS PRINT COMPARISON

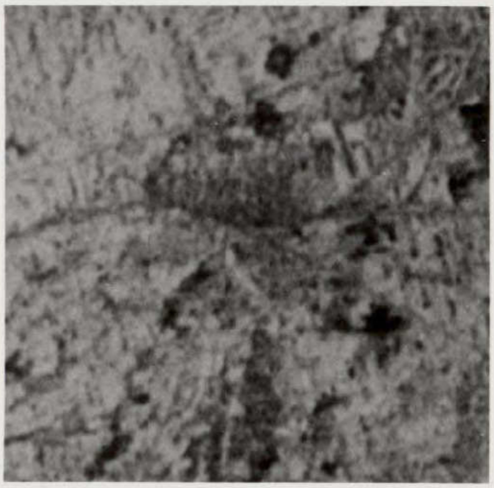
SCALE 1:133,000



GODDARD SPACE FLIGHT CENTER

EN -70

TROPEL



EDC

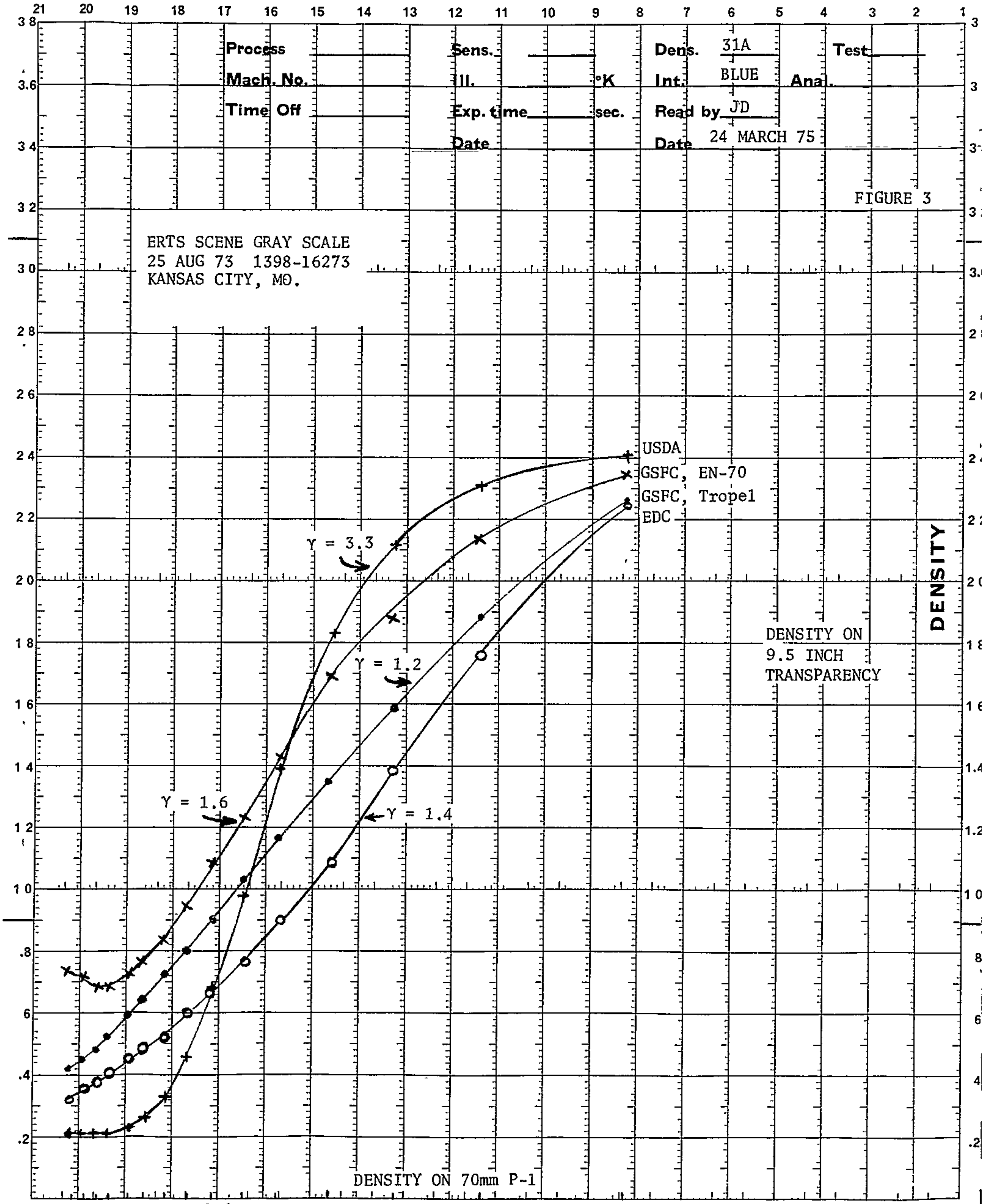
USDA

USDA WESTERN LABORATORY

FEB 1974

FEB 1975

Emul. No.________ **Eastman Kodak Company** Process Date______



careful in handling archival films, and additional cleaners, air filters, and control procedures may be needed to minimize dirt and scratches.

In addition to quality measurements, Table I lists the separation between north and south fiducial marks on the west side of the frame. Both the USDA prints and GSFC production prints on the EN-70 show a separation close to 202.5mm. Fiducials on prints made at EDC have a separation of 201.2mm, a difference in enlargement factor of 0.65%. This measurement was also made on 3.37X enlargements obtained at the laboratory operated by General Electric Company for NOAA in Beltsville, Md. This value of 202.6 listed in Table II agrees well with that from USDA and GSFC.

Table II summarizes quality measurements made on NOAA prints of ERTS frame 1719-17432. This image of an area in Montana is from a set covering the United States in Bands 4, 5, and 7; two areas from the Band 5 frame are enlarged 7.5X in Figure 4, and a tone reproduction curve is shown in Figure 5.

The GE frames show considerable flare around heavily exposed infrared images of lakes and the Dmax step of the gray scale. Although a comparison of identical areas from NOAA and the other laboratories was not made, Figure 4 shows faint scan lines on axis but rather soft imagery 85mm off axis. Lens aberrations off axis are also shown by distorted images of pinholes at the edge of the 70mm N-2. The fiducial cross marks are well imaged but appear on a lighter background area that is marred by scratches. Generally dirt and scratches are not prominent, possibly because of lens and illumination quality, but Bands 4 and 7 are marked by many water spots and brown stains. The NOAA gray scale in

TABLE II
PHYSICAL AND IMAGE QUALITY OF ERTS FRAMES
NOAA-GENERAL ELECTRIC CO.
FRAME 1719-17432, MONTANA, 12 JULY 1974

Band	Separation of N-S Fiducials on W Side, mm	Image Quality	Physical Quality
4	202.5	Scan lines clear on-axis and on west edge, soft in corners. Black pinhole images show poor lens quality in margins.	5 to 11 oval brown stains, 1 to 2mm long across film near gray scale, white dirt up to 1mm long, about 1/cm^2, very few scratches.
5	202.7	Large flare around step 15 Dmax of gray scale, coma and astigmatism evident in black pinhole images.	Fiducials covered with scratched, transparent density patch.
7	202.6	Strong flare around lakes and cloud shadows, scan faint in center and to south west, no scan lines in rest of frame.	40 to 60 drying marks or water spots/cm^2 especially along eastern half of frame, spots are 0.05 to 0.1mm diameter.

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ERTS PRINT COMPARISON
SCALE 1:133,000

NOAA
GENERAL ELECTRIC LABORATORY
BELTSVILLE, MARYLAND
NIKON ENLARGER LENS

15MM OFF AXIS

85MM OFF AXIS

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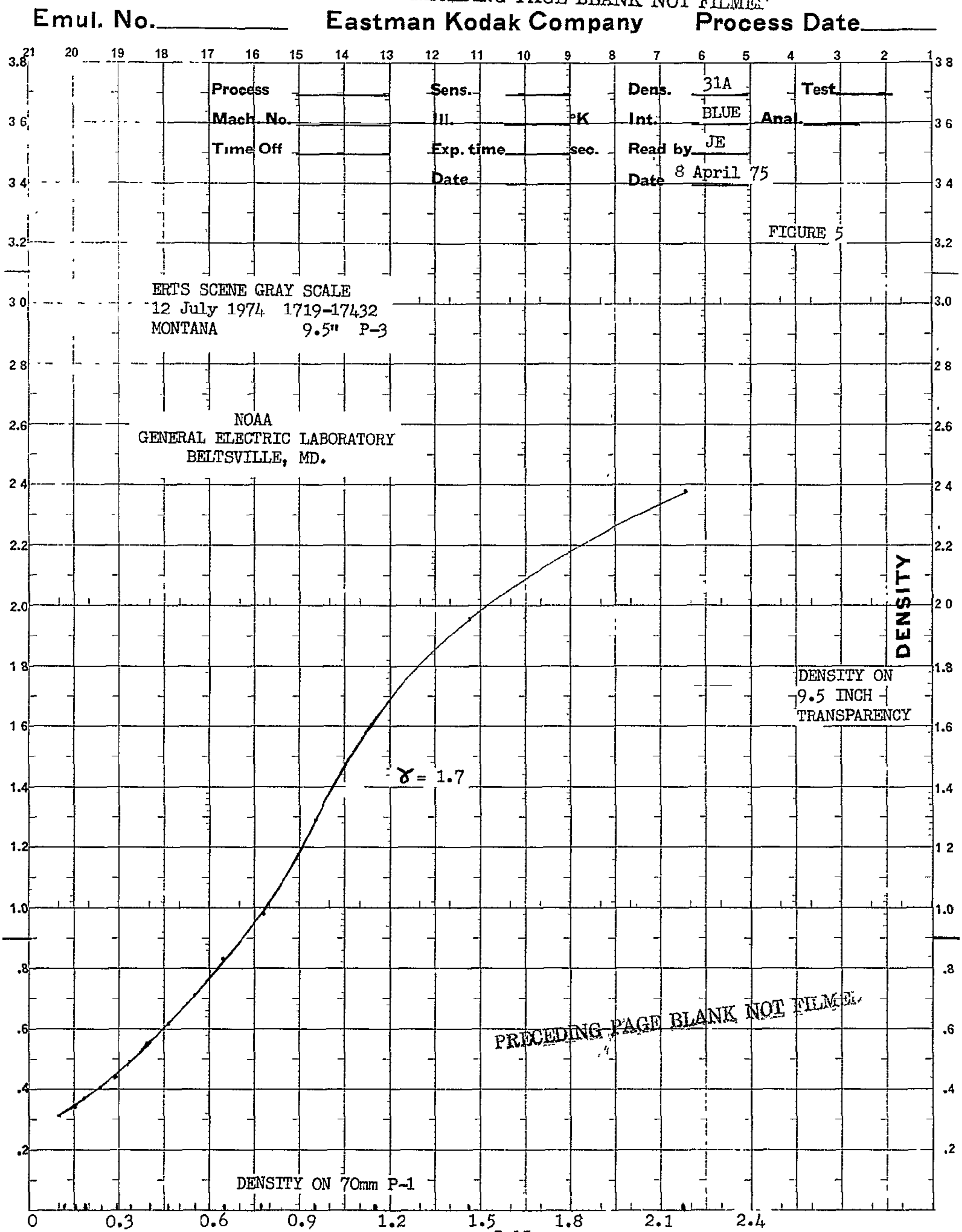

Figure 5 has a good density range but shows more distortion than the EDC curve and is similar to the EN-70 at GSFC.

Conclusions and Recommendations

1. Compared to the survey in 1974, this test revealed much faster service from EDC and USDA and improved image density and quality at the USDA laboratory.

2. The value of the Tropel lens for 3.37X enlargements was very evident, especially on snow covered scenes and in imaging off-axis areas. However, the Tropel lens and illuminator clearly reveal scratches and dirt that would be overlooked by other optical systems.

3. The enlargement factor at EDC is 0.65% less than that at GSFC, USDA, and NOAA.

4. Image quality at NOAA is similar to that at other laboratories, but soon will be inferior after Tropel lenses are operational at the other facilities.

5. A quantitative quality check at these and other laboratories using a Kodak test frame is planned later this year.

CALIBRATION OF

DENSITOMETERS AND SENSITOMETERS

IN EARTH RESOURCES PHOTO

LABORATORIES

This study is part of
Work Order #7 under
Contract NASW-2317

Submitted to
National Aeronautics and Space Administration
Earth Observation Programs
Washington, D. C. 20546

Prepared by

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Approved by George T. Keene

June 26, 1975

Summary

Radiometric calibration was calculated for sensitometers at the Johnson and Kennedy Space Centers, the Wallops Flight Center, and the Ames Research Center. Both black-and-white and color infrared film was used along with several color filters. Future calibrations should be run by engineers at the Johnson Space Center using the procedures described in this report.

Concurrent with the sensitometer work Kodak personnel checked several densitometers at the NASA centers and at other earth resources photo laboratories. Differences between readings of a black-and-white film strip were less than 3%, but variations of over 20% were found in densitometry of a color film neutral scale. Substantial differences were seen between several densitometers at the EROS Data Center even when instruments were nominally of the same model and manufacturer. Large differences (10%) between two instruments reading color film at Goddard Space Flight Center were also found.

Kodak engineers will re-check most of these densitometers using an NBS standard strip later in 1975.

Introduction and Procedure

At a quarterly review meeting Mr. L. Jaffe requested that Kodak assist in calibrating sensitometers used in the NASA aircraft program for earth resources photography. While sensitometric gray scale exposures are applied to most aircraft photography, some laboratories still omit this step and others use instruments of unknown or doubtful calibration. The main purpose of this work is to calibrate sensitometers at four NASA sites by photographic comparison with a Kodak lb sensitometer in Rochester.

In addition, densitometry at Kodak was compared to that at the four sites and at three other facilities, as this information was readily obtained in the course of the work on sensitometers.

To complete calibration in a reasonable time only one black-and-white and one color film were used. Near-aim coatings of KODAK Plus-X Aerographic Film 2402 (ESTAR Base) and KODAK Aerochrome Infrared Film 2443 (ESTAR Base) were selected. Exposures were made on the Kodak Sensitometer Model lb using simulated daylight and Kodak Wratten filters identical to those used on the NASA aircraft for exposure of these films. Samples of each exposure were processed and measured at Kodak, and the radiometric exposure at step 11 on the gray scale was calculated as described in the next section.

Exposed strips and unexposed rolls of both films were carried to Wallops Flight Center and were shipped in dry ice to Kennedy Space Center, Johnson Space Center, and the Ames Research

Center. Exposures made on this rawstock by the NASA center were processed along with the Kodak exposures. Both strips were read on a densitometer at the center through filters appropriate for the material; usually readings from two gray scales were combined to get an average value. Later most of the test strips were read at Kodak to allow a second calculation of sensitometer radiance which was averaged with the value calculated at the center.

At each of the four centers density readings were made of two gray scales on 2402 film and one on 2443 film. These test strips were also read using densitometers at GSFC, EROS Data Center, and the USDA Western Laboratory in Salt Lake City. Values obtained from these instruments were compared with those measured on the Kodak Densitometer Model 31A in Rochester. Other densitometers at Kodak were also included in the survey.

Sensitometer Calibration

Photographic sensitometry may be used to predict the response of a film-process combination if the effects of several critical factors are controlled. The spectral contribution of these elements is important as photographic films are not uniformly sensitive to radiation of all wavelengths. Two light sources of differing energy distributions may produce different densities even though the total energy on the film is identical. Each combination of light source, filter, and film must be handled as a unique case, with the spectral quality of sensitometry and flight exposure carefully matched.

Since film and processes can vary in their response to light, it is vital that the actual batch of flight film is calibrated in the anticipated process. Different processes may change edge effects, spectral sensitivity, and resolution, as well as the overall speed and contrast. Radiometry from color film images requires elaborate analysis because of development interactions between the three emulsions that depend on the degree of exposure in each layer.

Most films yield different densities for a series of constant exposures each applied for a different combination of time and intensity. To avoid this problem the exposure time in camera and sensitometer should not differ by more than a factor of five.

A fundamental assumption in sensitometer calibration is the additivity of exposures made at several wavelengths. This principle states that film sensitivity can be found by summing the sensitivity at each wavelength multiplied by the relative illumination at that wavelength. Since this calculation is done for a specific density level, a comparison of sensitivity calculated for two different filters or light sources will be valid only if the film does not change gamma as a function of exposing wavelength.

After proper correction or calibration of these several factors, the Kodak sensitometer is calibrated using the following procedure:

$$H_{IP_\lambda} = H_{s_\lambda} \cdot t_{f_\lambda} \cdot t_{o_\lambda}$$

where

H_{IP_λ} = spectral irradiance on the film, watts/m^2/5nm

H_{s_λ} = spectral irradiance from lamp, watts/m^2/5nm at distance of film

t_{f_λ} = spectral transmittance of filters

t_{o_λ} = spectral transmittance of sensitometer optics

Figure 1 shows, H_{IP_λ}, the film irradiance which is integrated with the peak normalized spectral sensitivity for the film. An example of this function is shown in Figure 2 for KODAK High Definition Aerial Film 3414 (ESTAR Thin Base). This curve defines the "effective" energy that causes a given density (usually 1.0) at each wavelength. The final integration between wavelengths λ_1, and λ_2 is

$$E = 1000 \cdot T \cdot 10^{-D_{11}} \int_{\lambda_1}^{\lambda_2} H_{IP_\lambda} \cdot \left(S/S_p \right)_\lambda \, d\lambda$$

where

E = radiometric film exposure at step 11, ergs/cm^2

1000 = conversion factor, $\frac{\text{watt-sec}}{m^2}$ to ergs/cm^2

T = exposure time, seconds

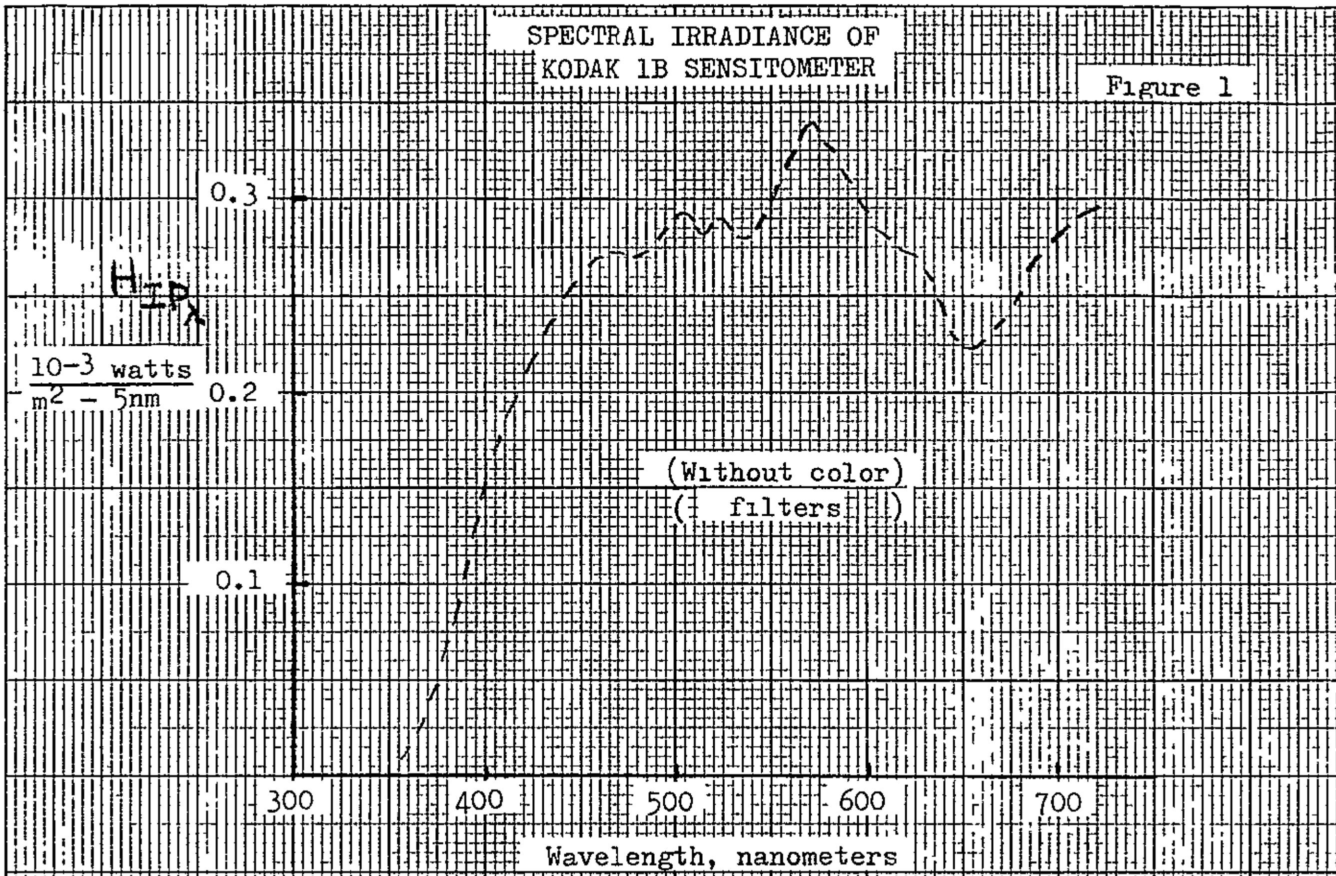
D_{11} = density of step 11 of step tablet

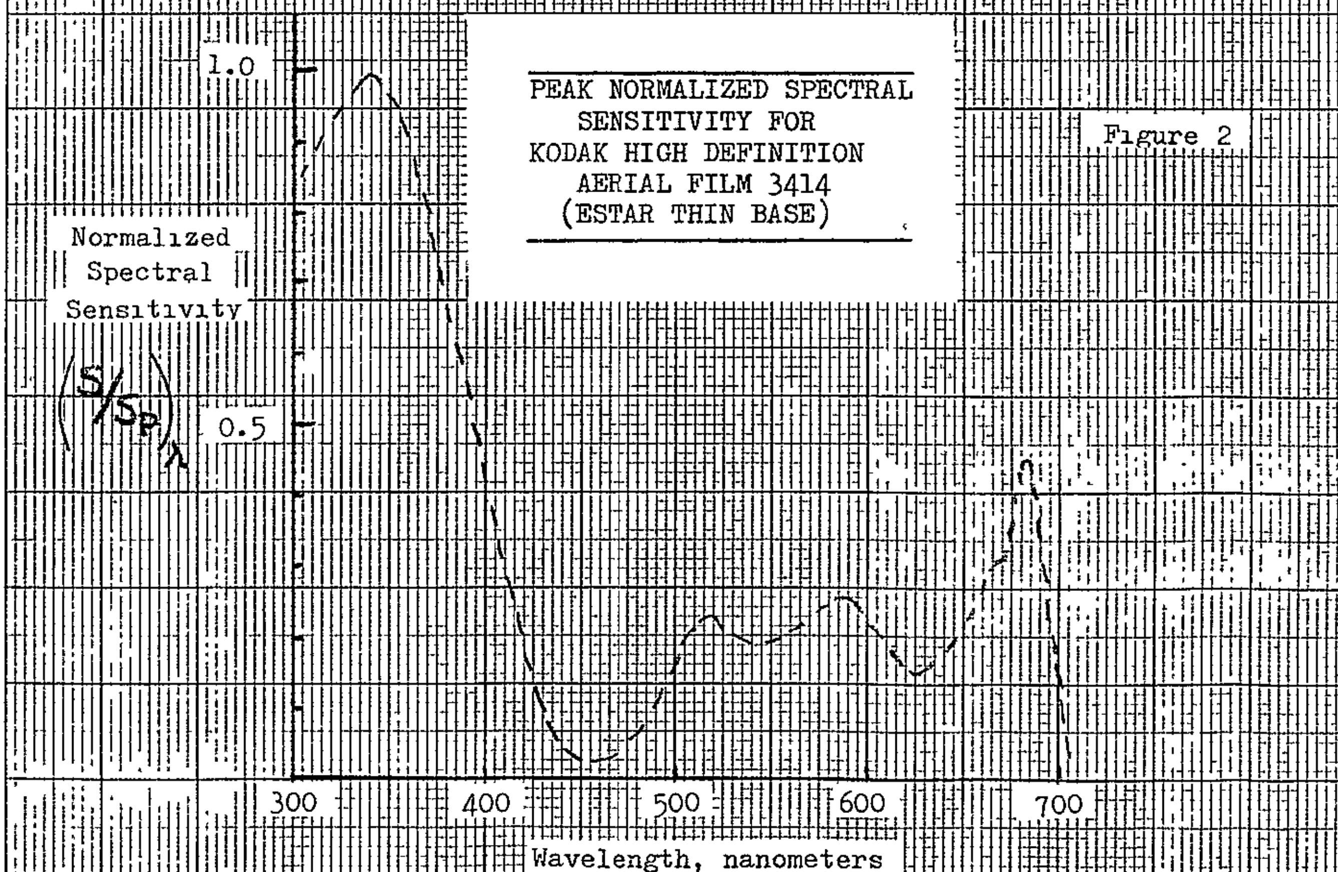
S_λ = film sensitivity, ergs/cm^2/5nm

S_p = peak film sensitivity, ergs/cm^2/5nm

The radiometric exposure at step 11 may be used to calculate the exposure at other steps by proper allowance for the density differences of the steps. Assuming a neutral step tablet, differences in density are numerically equal to changes in the <u>logarithm</u> of exposure.

After calibration of the Kodak instrument, sensitometers in other laboratories are calibrated by simultaneously processing film





VISIGRAPH
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10X10 PER HALF INCH

strips exposed on each instrument using similar filters and exposure times. The density at step 11 on the Kodak exposure is plotted on the curve from the laboratory exposure. The difference in log exposure from this point to step 11 is applied to the Kodak calibration to find the laboratory value at step 11. The calculation is often repeated using several film strips and densitometers to improve confidence in the calibration.

Tables I and II list the radiometric exposure for the Kodak and NASA sensitometers on Kodak 2443 film and on Kodak 2402 film using several filters. Identical Kodak Wratten filters were used at Kodak and NASA, and exposure times were closely matched except at Wallops Flight Center where reciprocity failure may slightly affect the calculation. In Tables I and II note that "computer logarithms" are used in which negatives values increase continuously from zero.

There are other methods for defining film exposure in a sensitometer, but all have deficiencies. A common calibration is expressed in meter-candle-seconds, a photometric unit derived by integration of the film irradiance and the photopic response of the eye. This procedure yields a step 11 calibration that is constant for all films and filters. In a confusing manner, the effect of color filters is treated as a shift in film speed rather than as a change in irradiance that actually occurs. For example, a sensitometer with a source deficient in infrared radiation could have the same step 11

TABLE I

SENSITOMETER CALIBRATION

FOR

NASA EARTH RESOURCES AIRCRAFT LABORATORIES

KODAK PLUS-X AEROGRAPHIC FILM 2402 (ESTAR BASE)

	Sensitometer	Wratten Filter	Exp. Time Sec.	Log Exposure ergs/cm^2 @ Step 11
EKCo.	Kodak 1b	12	1/25	-0.591
KAD	637F (C5900 + P2043)	23A	1/25	-0.835
	3000°K	25	1/25	-0.906
		57	1/25	-1.182
		57A	1/25	-0.868
		58	1/50	-1.591
		59A	1/25	-0.950
		47B	1/25	-1.301
		None	1/25	-0.343
JSC	Kodak 1b	25	1/25	-0.986
	C5500 (C5900 + P2043)	57	1/25	-1.272
	2850°K	47B	1/25	-1.401
KSC	Mead Star	12	1/64	-0.561
	C5900 + P20430	25	1/64	-0.786
	3200°K	57A	1/64	-0.848
		47B	1/64	-1.261
WFC	Tech Ops	12	1/250	-0.821
	KG4 + FG10	25	1/250	-1.086
		58	1/250	-2.241
		47B	1/250	-1.861
ARC	Kodak Mod. 60	23A	1/10	-1.205
	C5900 + EK301	59A	1/10	-1.160
		None	1/10	-1.173

NOTE: These radiometric exposures are "computer logarithms" in which negative values increase continuously from zero.

At KAD the 2402 film was processed in a Kodak Versamat Processor (Spec. 693B) using MX641 chemicals, 2 racks, 8 ft./min at 88°F.

TABLE II

SENSITOMETER CALIBRATION

FOR

NASA EARTH RESOURCES AIRCRAFT LABORATORIES

KODAK AEROCHROME INFRARED FILM 2443 (ESTAR BASE)

	Sensitometer	Exp Time Sec.	Log Exposure ergs/cm^2 @ Step 11		
			R	G	B
KODAK	1b 637F + Wr. 12 filters 3000°K	1/100	-1.913	-1.678	-1.499
JSC	Kodak 1b C5500 + Wr. 12 2850°K	1/100	-2.083	-1.798	-1.609
KSC	Mead Star C5900 + P2043 + Wr. 12 3200°K	1/64	-1.358	-1.088	-0.972
WFC	Tech Ops. KG4 + FG10 + Wr. 12	1/250	-2.078	-1.978	-1.834
ARC	EG&G Mk. VI Wr. 12 + 2.62 ND Silver	1/100	-1.803	-1.618	-1.439

NOTE: These radiometric exposures are "computer logarithms" in which negative values increase continuously from zero.

At KAD the 2443 film was processed in a Kodak Versamat Processor, Model 1811 using EA-5 chemicals with the first developer at 120°F.

photometric calibration as one with a large infrared output. However, the response of an infrared sensitive film exposed through visual blocking filters would be quite different in the two sensitometers.

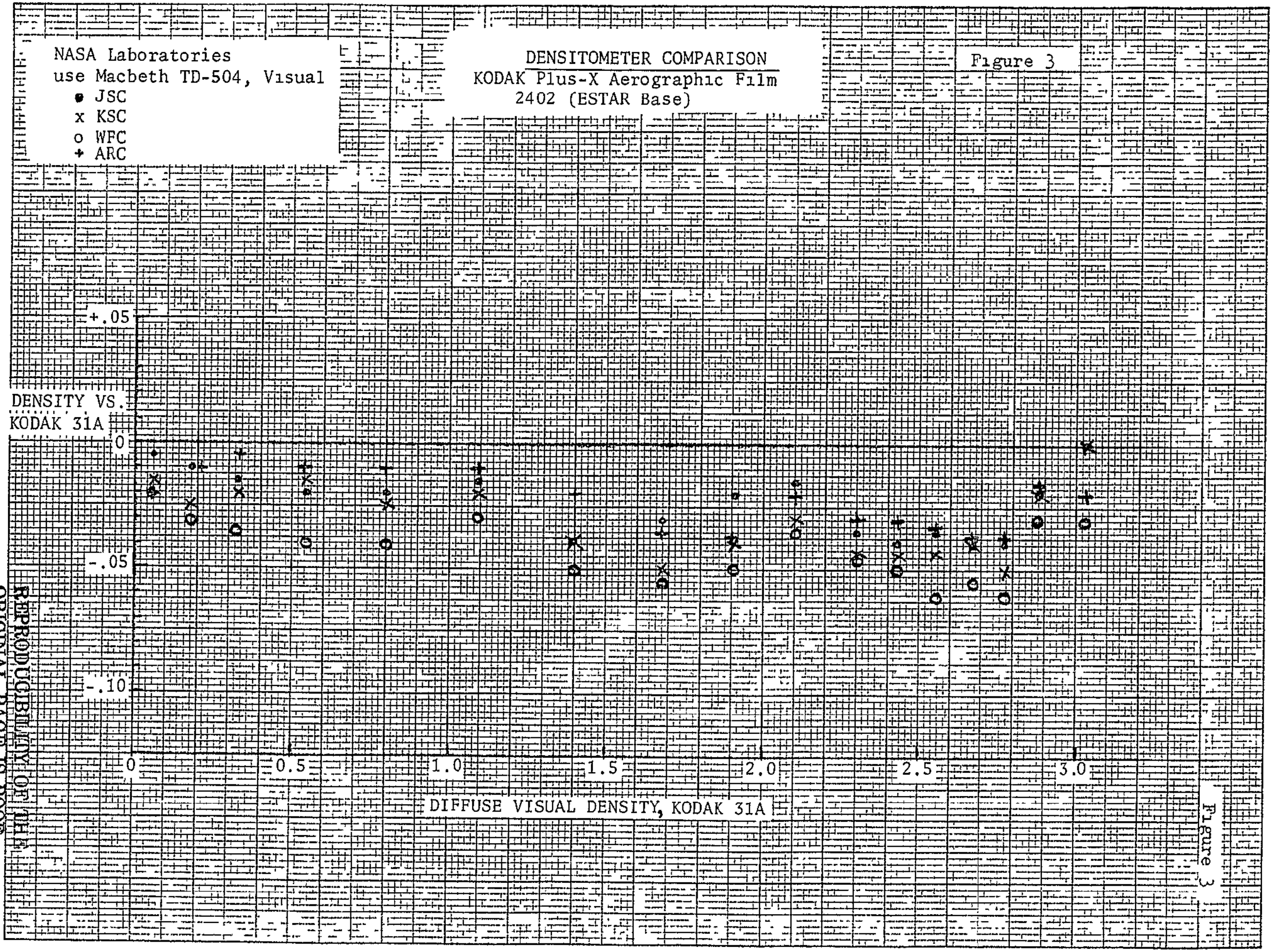
Densitometer Calibration

Black-and-White Film

For each laboratory, readings from two black-and-white strips were compared to those made on the same strips using the Kodak 31A densitometer. These differences were averaged to obtain the data plotted in Figures 3 and 4. Similar data from seven densitometers at EDC is tabulated in the "V" column of Table III. At several laboratories readings made on a second day confirmed the earlier values. Many instruments read lower densities than the Kodak 31A values but most are within 0.05 of this standard. The Macbeth TD-504 at WFC gives the lowest readings of any of the NASA flight centers. All densitometers at EDC closely match the Kodak 31A readings for the 2402 film strips.

Two important factors in reading black-and-white densities are the color of the illumination and the emulsion position. Conventionally, all gray scales are read with the emulsion up and facing the phototube. Densities are usually higher if read with the emulsion down since more of the light scattered by the silver grains misses the collecting aperture when the emulsion layer is further away from the phototube. The following readings from 2402 film illustrate this point:

K&E [redacted] TO THE [redacted] 359-12
KEUFFEL & ESSER CO MADE IN U.S.A.



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K+E 10 X 10 TO THE 1/2 INCH 359-12
KEUFFEL & ESSER CO. MADE IN U.S.A.

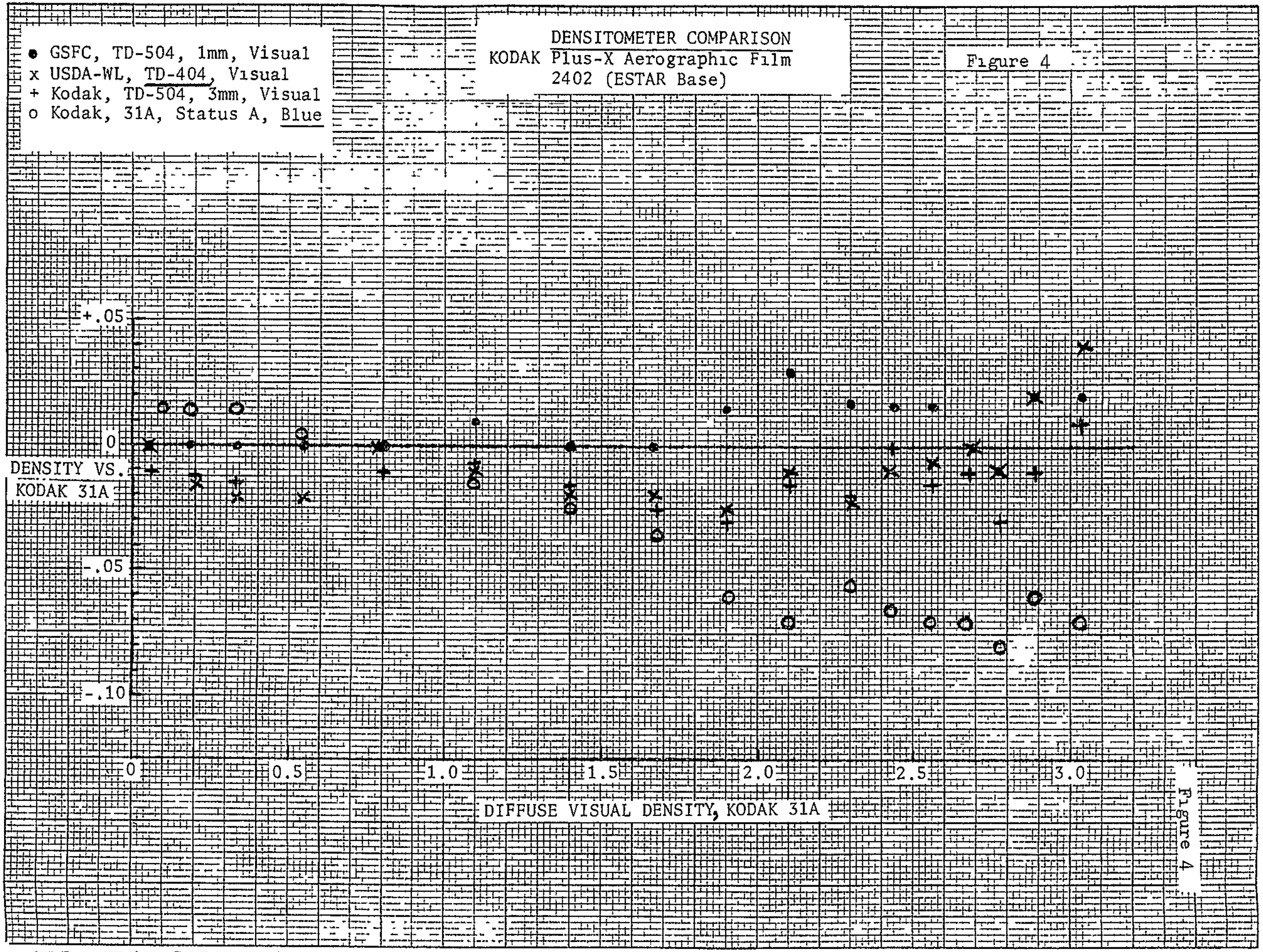

Figure 4

TABLE III 11 March 1975

TEST DATA FOR EDC DENSITOMETERS

Step	KODAK 31A V	KODAK 31A R	KODAK 31A G	KODAK 31A B	Photolab TD-504 Inspection #1 V	R	G	B	Photolab TD-504 Inspection #5 V	R	G	B	Incoming Inspection Gratag V	R	G	B
1	3 03	27	20	19	3 05	.26	16	17	3 02	26	14	16	-	24	16	.18
2	2,99	35	22	23	3 00	.34	19	.21	2 95	39	18	20	-	33	.20	21
3	2 94	48	25	26	2.95	45	21	.24	2 90	52	20	22	-	43	.23	25
4	2 88	67	28	30	2 88	63	25	28	2 86	73	25	25	2,87	63	.27	29
5	2 84	.93	35	.35	2 83	90	32	33	2 78	1 03	32	29	2 81	89	.33	33
6	2,77	1 32	48	42	2 75	1 30	45	40	2 70	1 45	46	34	2 74	1 27	47	.40
7	2 67	1 81	73	53	2 66	1 77	69	50	2 62	1 95	.73	44	2 64	1 71	73	50
8	2 55	2 28	1 06	69	2 55	2 25	1 04	67	2 50	2 43	1 10	61	2,54	2 16	1 07	68
9	2 43	2 64	1 41	96	2 43	2 63	1.41	97	2 40	2 79	1.47	87	2,44	2 52	1.40	95
10	2,30	2 88	1 78	1 41	2 30	2 88	1.78	1 40	2 26	2 99	1 85	1 29	2,28	2 74	1.75	1 37
11	2 10	3.00	2 15	1 97	2 11	3 02	2 15	1 98	2 07	3 09	2 22	1 79	2,12	2 86	2 12	1 89
12	1 91	3 10	2 47	2 58	1 91	3 11	2 50	2 58	1 86	3 14	2 55	2 40	1 93	2 95	2 44	2,46
13	1 68	3.15	2 72	3 16	1 69	3 16	2.73	3 16	1 63	3 18	2.78	2.90	1,69	3 00	2 68	2 99
14	1 40	3 19	2 88	3 60	1 40	3 16	2 90	3 65	1 35	3 20	2.95	3 29	1.42	3 03	2 83	3,39
15	1 09	3 20	2 96	3 84	1 10	3 22	3 00	3 96	1 05	3 20	3 04	3 51	1 12	-	-	-
16	80	3 21	3 02	3 98	79	3 22	3 04	4 12	.75	3 20	3.09	3 63	83	-	-	-
17	54	3 22	3.05	4.04	52	3 23	3 05	4 22	50	3 20	3 09	3 64	.55	-	-	-

Step	Incoming Inspection Macbeth TD-504 V	R	G	B	Custom Lab - Color GAM Inc V	R	G	B	Color Registration Macbeth TD-504 V	R	G	B	Process Control Photo Lab TD-504 V	R	G	B
1	3 02	23	.14	16	2 98	22	.17	19	3.01	23	.14	16	3.02	23	14	16
2	2,99	.31	15	.20	2 91	29	.20	21	2.96	31	.16	18	2,97	30	16	19
3	2,93	43	18	.23	2 86	39	23	.24	2 91	.43	19	.21	2 92	.42	18	.22
4	2,90	62	.23	27	2 85	55	.27	27	2 85	63	.23	26	2 87	62	22	26
5	2 81	90	.31	33	2 77	78	35	31	2,80	90	.30	31	2,80	90	29	.31
6	2 73	1.28	44	41	2 70	1 10	.48	37	2,71	1 27	42	.38	2 72	1 27	42	.38
7	2,65	1,75	69	52	2 61	1 50	.71	47	2,63	1 76	68	.49	2 64	1,74	68	.49
8	2 53	2,21	1 03	.69	2 50	1 92	1 02	.64	2,52	2 21	1 02	.66	2 53	2.20	1 02	.67
9	2,42	2 60	1 38	.96	2 40	2.27	1.36	90	2,41	2 58	1 36	.93	2 41	2.57	1 36	.95
10	2 28	2 85	1 76	1 41	2 26	2 52	1.71	1.27	2,27	2 82	1 75	1 35	2,27	2 81	1 74	1.36
11	2,09	2 99	2 12	1,95	2 09	2 69	2.05	1 72	2,09	2 96	2 10	1 89	2 08	2,94	2 11	1 92
12	1 89	3,07	2 44	2 52	1 89	2.78	2,35	2 16	1 89	3 04	2 42	2,46	1 88	3,03	2 41	2 48
13	1 66	3,12	2 71	3 11	1 66	2 85	2 59	2,55	1 66	3 09	2 66	3 02	1 65	3,08	2 65	3,04
14	1 38	3,16	2 86	3,54	1 38	2 89	2 75	2 82	1,37	3 13	2 82	3,42	1 37	3,12	2 82	3 45
15	1 07	3 16	2 95	3 81	1 08	2,92	2 84	2,98	1 07	3 13	2 90	3,63	1 07	3 12	2 91	3,69
16	.78	3,17	3 00	3,97	.78	2 93	2 91	3,06	79	3 14	2 96	3 78	.78	3 13	2 96	3,83
17	.51	3,18	3 00	4 01	52	2 94	2 93	3,10	50	3 15	2 99	3,85	51	3,13	2 98	3 90

V = Visual filter reading of gray scale on KODAK Plus-X Aerographic Film 2402 (ESTAR Base)
R, G, B = Status A densitometry of gray scale on KODAK Aerochrome Infrared Film 2443 (ESTAR Base)

Densitometers

Photolab Inspection #1, TD-504, 1490B
Photolab Inspection #5, TD-504, 2814A
Incoming Inspection, Data Management, Gratag
Incoming Inspection, Data Management, TD-504, 1383B
Custom Lab Color, GAM Inc , 126F, 72894
Color Composite Registration, TD-504, 1489B
Process Control, Photo Lab, TD-504, 1445B

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Instrument	Emulsion Position Up	Emulsion Position Down
Kodak 31A	0.79	0.81
USDA, TD-404	2.10	2.13
WFC, TD-504	0.74	0.78
	0.97	1.00
	1.22	1.25
	2.07	2.11

The magnitude of this effect depends on the amount of scattering caused by the image; it may differ for other black-and-white films and is usually near zero for color film densities as these dyes scatter little light.

The difference between readings made through blue and visual filters is shown in Figure 4 where the blue Status A filter in the Kodak 31A densitometer yields densities up to 0.08 lower than the visual filter in the same instrument. In the following chart other instruments and filters do not show exactly the same differences, but there seems to be a tendency for blue readings to be higher than visual values at low densities and lower at high densities:

Blue Vs. Visual Densities on Kodak 2402 Film

	Visual Density					
Densitometer	0.20	0.80	1.50	2.00	2.50	3.00
Kodak 31A	+.02	0	-.03	-.05	-.07	-.08
EDC, TD-504, 1383B	+.03	+.03	0	-.01	-.03	-.01
EDC, Gratag, Inc. Insp.	+.01	0	-.01	-.03	-.02	-.02

This relationship may also change for other films in which image tone differs from that of 2402 film. Usually, blue densities more closely approximate printing densities than do visual filter readings when unsensitized print films are used. However, visual readings are satisfactory for control of a printer or process in which only minor excursions are expected.

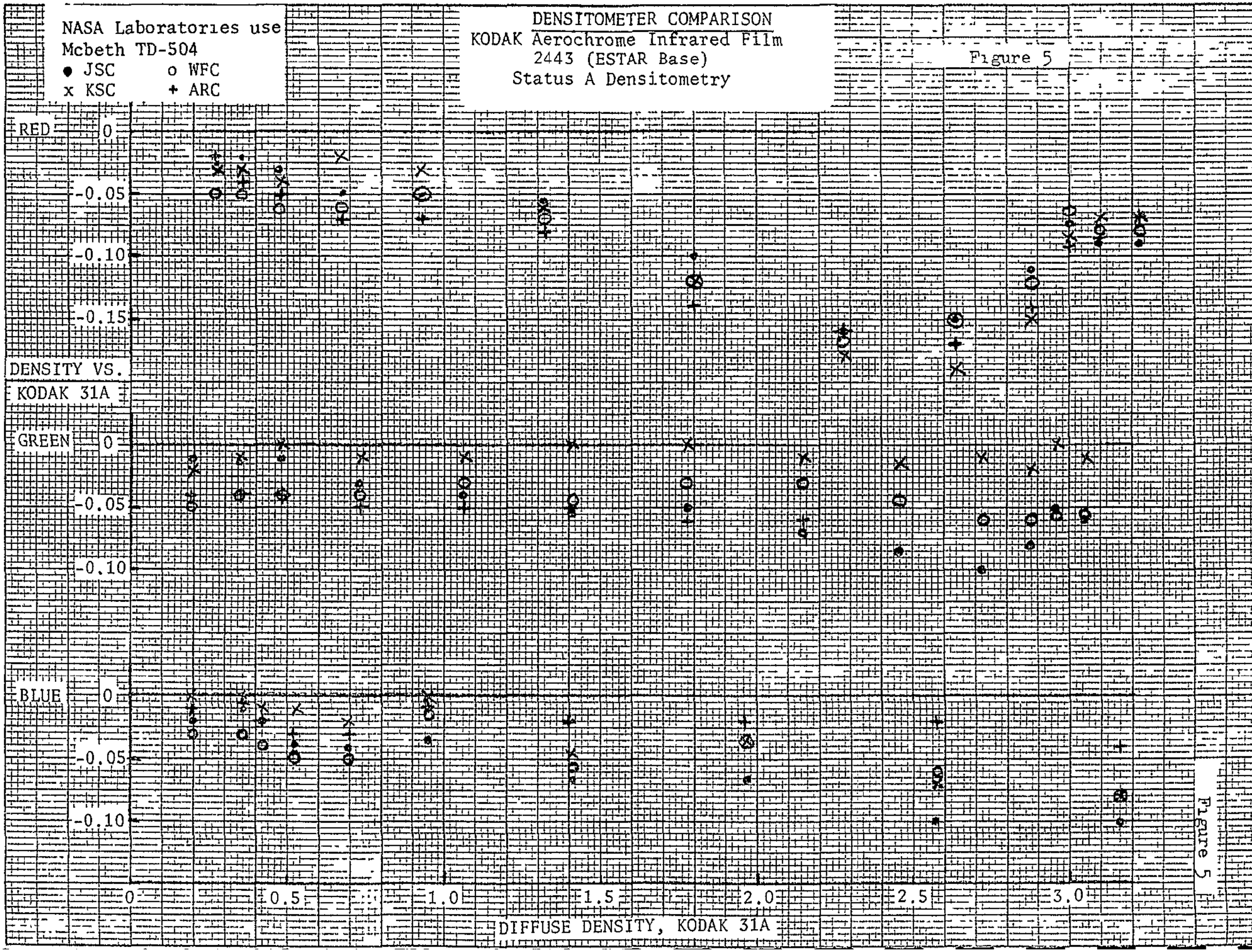
Color Film

Densities read from the 2443 color film are more variable than those from 2402 film. Table III and Figures 5, 6, and 7 show deviations from the Kodak 31A of up to 0.20 at densities between 2.0 and 3.0. Red and blue densities show the widest excursions, with the GAM and Inspection No. 5 at EDC showing the largest difference from the 31A values. At GSFC the Macbeth TD-504 in the photo lab gave very high red densities even at densities as low as 1.0. Following this test, this instrument was removed from service for repairs.

The TD-504 densitometers at the four flight centers (Figure 5) show a remarkably similar trend of densities lower than the 31A readings. Red values reach a minimum at density 2.5, then rise to nearly equal the 31A density. Other TD-504 instruments at Kodak, GSFC, and EDC do not show this pattern, some producing very high red densities.

Densities from the Kodak 31A were most closely matched by the TD-504 Inspection No. 1 at EDC and the TD-504 in the Engineering Lab at GSFC.

K+E 10 X 10 TO THE 1/2 INCH 359 12
KEUFFEL & ESSER CO



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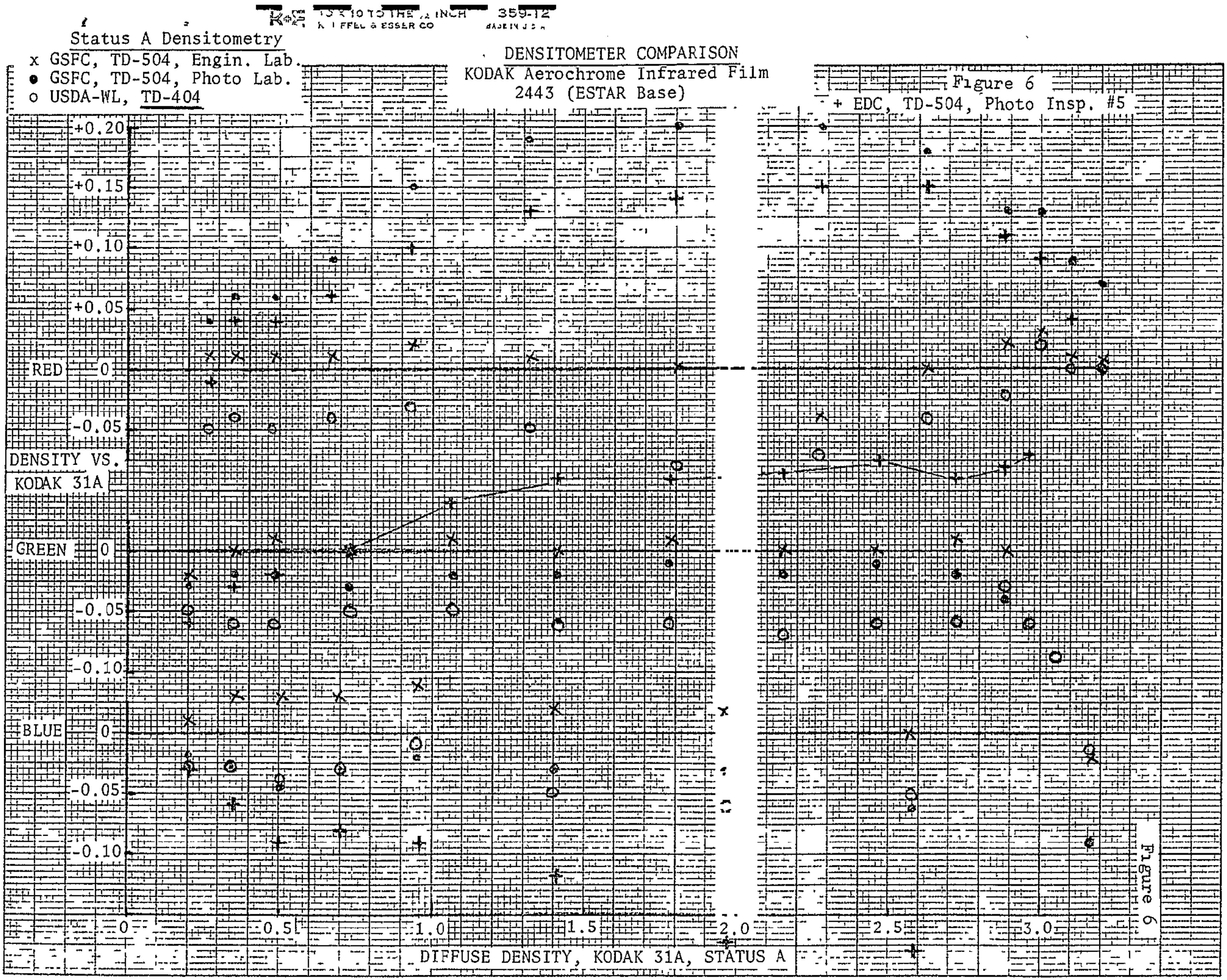
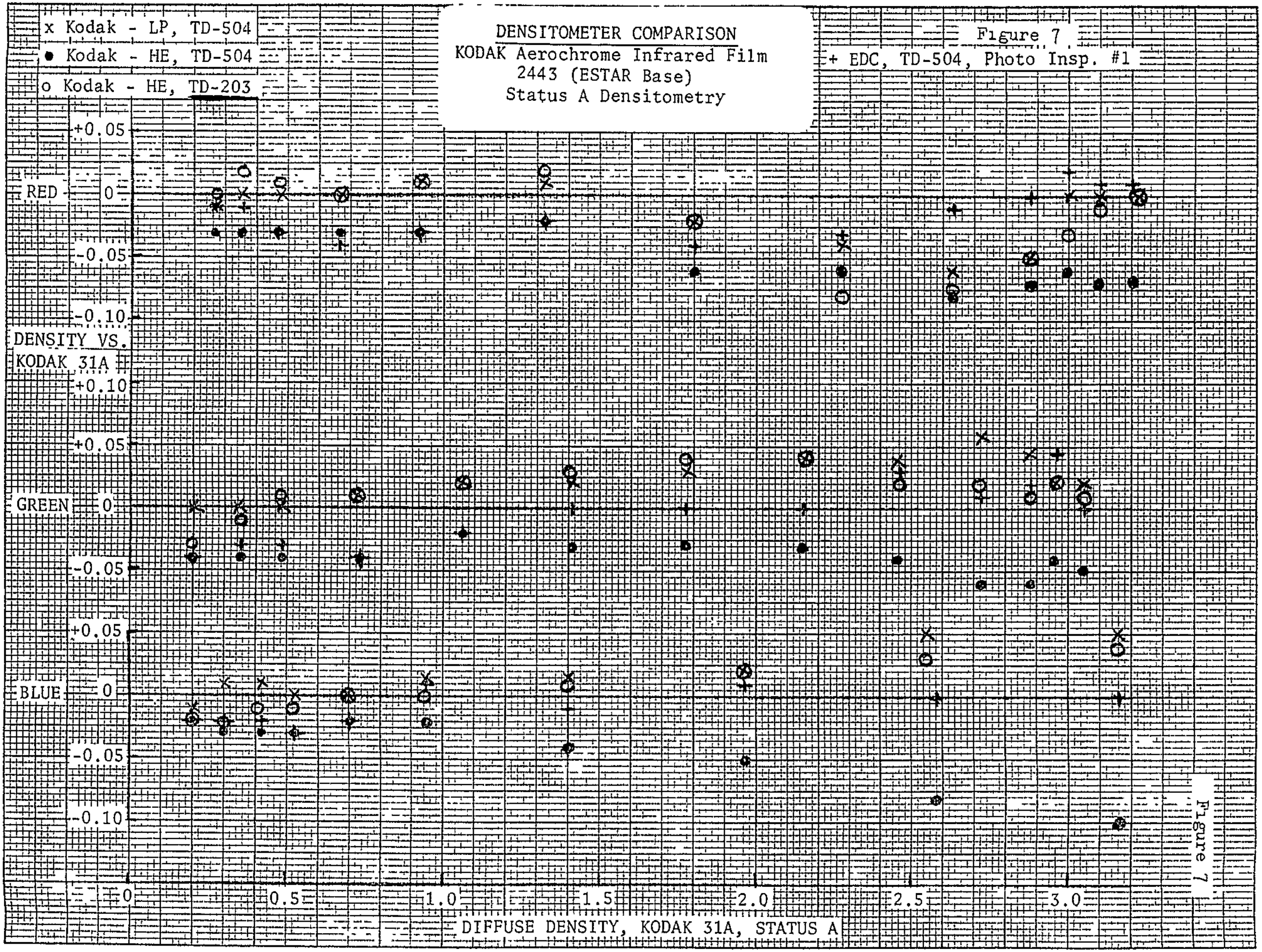

K&E 10 X 10 TO THE 1/2 INCH 359-12
KEUFFEL & ESSER CO. MADE IN U.S.A.
Status A Densitometry
x GSFC, TD-504, Engin. Lab.
● GSFC, TD-504, Photo Lab.
o USDA-WL, TD-404
DENSITOMETER COMPARISON
KODAK Aerochrome Infrared Film
2443 (ESTAR Base)
Figure 6
+ EDC, TD-504, Photo Insp. #5
+0.20
+0.15
+0.10
+0.05
RED 0
-0.05
DENSITY VS.
KODAK 31A
GREEN 0
-0.05
-0.10
BLUE 0
-0.05
-0.10
0
0.5
1.0
1.5
2.0
2.5
3.0
DIFFUSE DENSITY, KODAK 31A, STATUS A
Figure 6

K+E 10 X 10 TO THE ½ INCH 359-12
KEUFFEL & ESSER CO. MADE IN U.S.A.



The Macbeth TD-504 instrument is zeroed prior to each use but lacks other controls except for a capped slope control on the rear of the machine. Adjustment of this control on TD-504 densitometers at Kodak permits a fairly close match to the 31A performance. In this condition red densities are close to 31A values while green and blue densities are slightly high.

While there may be argument about using the Kodak 31A as an absolute standard, there should be close agreement among all densitometers at one laboratory. Densities read daily from a check strip for several weeks will establish the normal variability of each instrument. Subsequent deviations in daily values outside of these 2-sigma limits should shut down the densitometer for maintenance by the manufacturer or service laboratory.

Recommendations

Because substantial differences in densitometry were found at these laboratories Kodak personnel are planning a second survey after some of the instruments are adjusted. Black-and-white densitometry should be checked using an NBS calibrated strip. Changes to the Macbeth 504 densitometer to improve the uniformity of color film densitometry should be explored.

Since the sensitometers at four NASA flight centers were calibrated for only two films and for a few filters, additional calibrations should be run using the same procedure. Kodak will supply peak normalized spectral sensitivity curves for this work, but we recommend that future sensitometer calibrations between NASA facilities be run by engineers at the Johnson Space Center. Personnel at this photo laboratory are skilled in photographic photometry and have the proper equipment for this work.

EVALUATION OF
LANDSAT IMAGES FROM
INPE-BRASIL

This Study is Part of
Work Order #9 Under
Contract NASW-2317

Submitted to

National Aeronautics and Space Administration
Earth Observation Programs
Washington, D. C. 20546

Prepared by

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Approved:

6 February 1976

Summary

Five months after an order was placed we received and evaluated Landsat enlargements at 1:1,000,000 scale made at the INPE Brazil laboratory. Prints made from an INPE recording were compared with ones of the same scene taken on a different date and recorded by the NASA Goddard Space Flight Center. The films, processes, and equipment used at INPE were not reported to us and undoubtedly influence the differences found between the GSFC and INPE images.

Generally enlargements from the INPE negatives are sharper than those made by INPE from GSFC 70mm N-2 records. The GSFC prints have a grain pattern and do not reveal EBR scan lines in most cases. While the INPE prints are usually better, they show a 2 or 4 times difference in image sharpness across the frame.

The INPE prints often contain diffuse spots, especially evident in border areas, that may be water drying or chemical marks. In addition, large areas are covered by a fine black "dirt" that could be a form of static electrical mark caused by high humidity when unwinding the print film.

Prints from the INPE record have a more linear tone scale, but both INPE and GSFC prints have a Dmax that averages 1.4 rather than the desired 2.0.

Introduction

As part of our service to NASA under this contract, Kodak engineers have evaluated the image quality of earth resources photography at several U.S. government facilities. In 1975 Mr. L. Jaffe requested that we extend this appraisal to the Intituto dePesquisas Espaciais (INPE), the government laboratory at which Landsat photography is reproduced in Brazil. Accordingly on 23 June 1975 an order was placed to Sr. Gradiola Fernandez, Administrative Director, INPE for several Landsat scenes in black-and-white positive transparencies at a scale of 1:1,000,000. We requested images of seacoast areas in Bands 4, 5, and 7, and hoped that enlargements from the same scene might be obtained from a 70mm negative supplied by the NASA Goddard Space Flight Center and from magnetic tapes recorded in Brazil directly from the spacecraft.

On 25 August we received a letter from Sr. Marcio Barbosa, Chief of the Data Bank Division, noting problems caused by cloud cover and poor quality in the images requested, but promising airmail shipment the following week. Blank forms for additional orders were also enclosed.

The requested 9.5-inch transparencies were sent at no charge on 27 November and were received on 8 December 1975 in Rochester. Although Sr. Barbosa enclosed two scenes from INPE and two from GSFC negatives, there was no flow sheet showing production steps, materials, printers or processing, and this information was requested in our letter of 9 December acknowledging the shipment. This request was repeated in a telegram sent to Sr. Barbosa on 7 January 1976, but despite the lack of this information an evaluation and report of image quality was prepared.

Evaluation of Images

The following 9.5-inch transparencies were received and analyzed:

Scene No.	Recording Laboratory	Brazil Coastal Area	Bands	Date of Overflight
122211	INPE	North	4,5	11 July '73
121356	INPE	South	4,5,7	9 May '75
12203	NASA	North	4,5,7	9 Oct. '73
12335	NASA	South	4,5,7	30 July '73

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It is apparently not possible for Landsat to send the same Brazilian scene directly to the INPE receiver and later (via the spacecraft tape recorder) to the NASA-GSFC antenna. However, INPE was able to provide Landsat pictures taken on different dates of areas on the north and south coasts of Brazil. Frames of the north area had nearly identical ground coverage in the INPE and NASA records, but the INPE frame showed about 60% cloud cover. Overlap between INPE and NASA frames was only 50% in the south coast coverage. This condition makes difficult accurate comparison of image quality, as the test areas in the two frames appear in different parts of the camera and enlarger fields.

Since we have not been able to learn from INPE the films, processes, and printers used to prepare these transparencies, the following flow chart is assumed based on reports from Kodak and other visitors to the INPE laboratory:

INPE Magnetic Tape	Framing → Electron Beam Recorder	Kodak SO-219 Film 70mm N-1	3.37 X Durst Enlarger → Rodenstock lens	9.5-inch P-3 Positive Transparency
NASA GSFC Magnetic Tape	Continuous → Electron Beam Recorder	Kodak SO-438 Film 70mm P-1	Kodak Colorado Contact Printer →	Kodak SO-467 Film 70mm N-2

Tables I and II summarize observations on the physical and photographic quality of these transparencies obtained by inspection on an illuminator at magnifications up to 10X. Generally, scan lines from the electron beam recorder are more prominent in the INPE print, but this record is more variable in sharpness across the frame than is the NASA print. Probably the change in sharpness is caused by misalignment in the enlarger between the 70mm negative and the 9.5 inch film. The degree of unsharpness varies considerably between frames but enlargements from the INPE N-1 are always sharp in the southwest

TABLE I

PHYSICAL AND PHOTOGRAPHIC QUALITY OF
9.5-INCH LANDSAT TRANSPARENCIES

SOUTH COAST

Scene No.	Flight Date	Recording Facility	Comments
12335-4	30 July '73	NASA	Scan lines barely visible, E. side better than center or W. side. Very low dirt level, about 1/cm^2. Fine grain or Newton Ring pattern.
12335-5	"	"	Much softer than band -4, few scan lines, only on E. side. Fine black "dirt" over 1/3 of width.
12335-7	"	"	Soft, no scan lines, worse than -5. No scratches, black dirt about 1/cm^2 "Grain" pattern prominent in gray scale.
121356-4	9 May '75	INPE	Strong scan lines in SW corner, no scan lines in NE corner. "Measles", 10/cm^2, about 0.6mm diameter, black center light halo. Hundreds of black "dirt" on N 1/3 of frame (humid static?). Two black scratches in SW corner.
121356-5	"	"	NE corner very soft; square pixels evident; black dirt or static along S. edge. Banding every 6 or every 15 scan lines. "Measles".
121356-7	"	"	NE corner soft but better than -5, worse than -5 on axis, random scan line banding, six white dropout lines.

Scale on INPE print is 1.95% smaller than NASA print.

Frames overlap only 50%.

INPE print generally sharper than NASA print; "Grain" or Newton Rings hurts NASA quality.

TABLE II

PHYSICAL AND PHOTOGRAPHIC QUALITY OF
9.5-INCH LANDSAT TRANSPARENCIES

NORTH COAST

Scene No.	Flight Date	Recording Facility	Comments
12203-4	9 Oct '73	NASA	Severe dropouts obscure every 6th line over central 50mm & all of S. half of frame. Scan lines very faint. S. edge sharper than N., E. sharper than W. edge. Dirt about $2/cm^2$, no scratches, "grain" is soft.
12203-5	"	"	N and NW very soft, poor on axis, but some scan lines visible. Worse than -4 generally.
12203-7	"	"	Many dropouts, especially every 5th group of 6 scan lines. Scan lines faint, better than -5.
122211-4	11 July '73	INPE	Same coverage as 12203, but 60% cloud cover. Extremely soft at N. and E. edges. Defocus causes doubled edges. Excessive scan line banding in SW corner. "Measles" about $3/cm^2$, faint.
122211-5	"	"	Same sharpness differences across frame as in -4.

Scale on INPE print is 2.33% smaller than NASA print.

corner and soft in the northeast corner; sometimes this difference is a factor of 2X or 4X in quality.

This pattern is not exactly repeated in enlargements from the GSFC N-2 where the east side of the frame is usually better than the west side. If these prints were all made at the same time on one enlarger, then the prints show that the two electron beam recorders may differ in sharpness across the frame. However, the appearance of the INPE images makes an optical problem more likely than an EBR problem.

Figures 1 and 2 are 7X enlargements from several of the transparencies that compare image quality in common areas of both sets of prints. Interpretation of Figure 1 is confused by annual and seasonal differences in flight dates. However, areas were selected that are approximately the same distance off axis in each frame, making comparisons of image quality fairly valid.

The INPE 2nd generation prints generally reveal more scene details than do the 3rd generation prints from the GSFC record. Scan lines are much sharper and there is no confusing grain pattern. The scale of the INPE print averages 2% smaller than that from the NASA record, a difference that must be caused by adjustment of the electron beam recorder if a fixed enlarger setup was used for making both prints.

The top and bottom pair of scenes in Figure 2 illustrate the substantial difference in sharpness between northeast and southwest corners of the INPE prints. In addition these enlargements show the "black dirt" (Frame 121356) and excessive banding (Frame 122211) described later in Tables I and II. The middle pair of scenes in Figure 2 illustrates the severe periodic dropout on the GSFC recording of 9 October 1973.

Further evidence for soft enlarger quality is the lack of dirt and scratches on these images. In addition to some defocus and tilt in the enlarger, it is possible that INPE uses diffuse illumination rather than a specular light source. A lamp filament sharply focused by condensers will reveal many scratches and dirt particles that are hidden by diffuse illumination.

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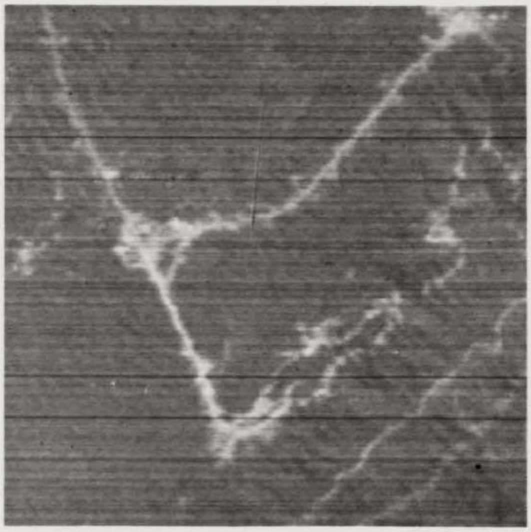
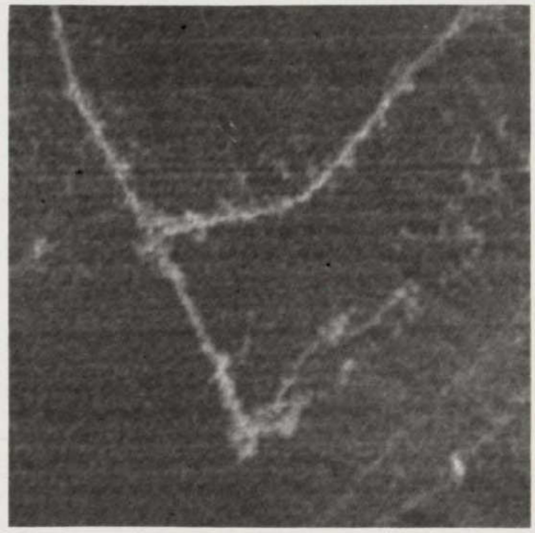
LANDSAT SCENES OF BRAZIL FIG. 1

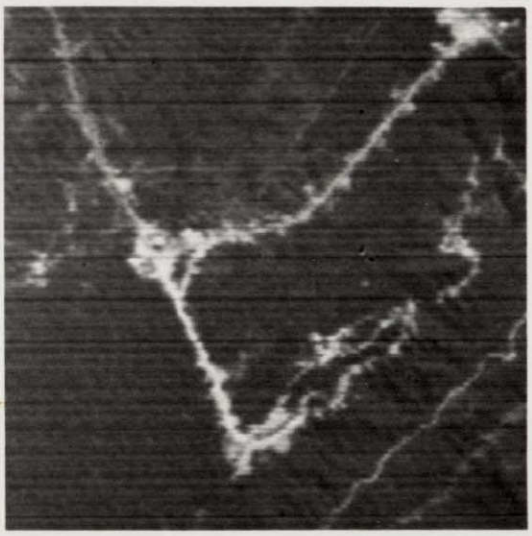
SCALE 1:143,000

121356 9 May 75 INPE-BRAZIL		12335 30 July 73 NASA - GSFC

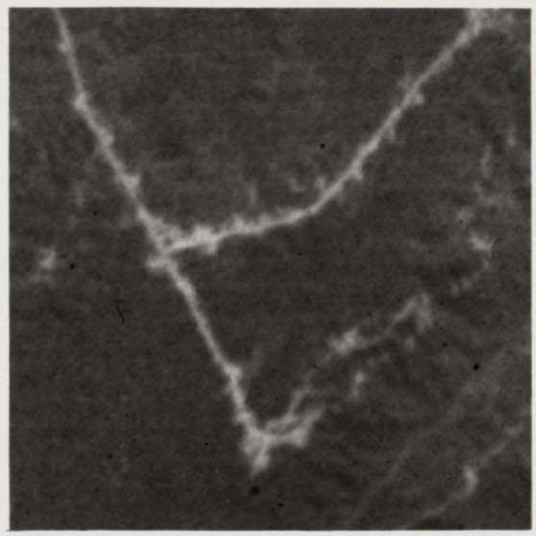


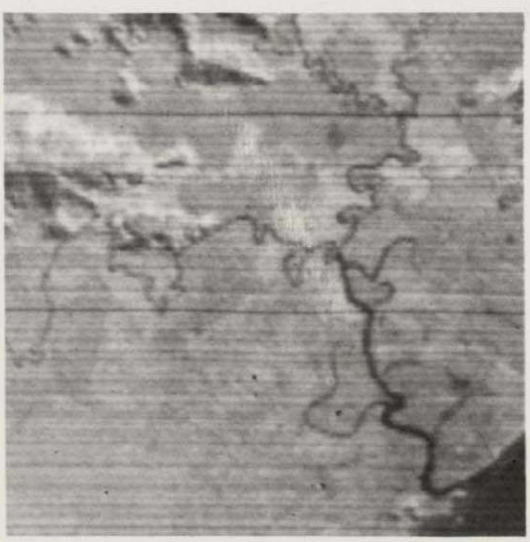
BAND 4





BAND 5





BAND 7

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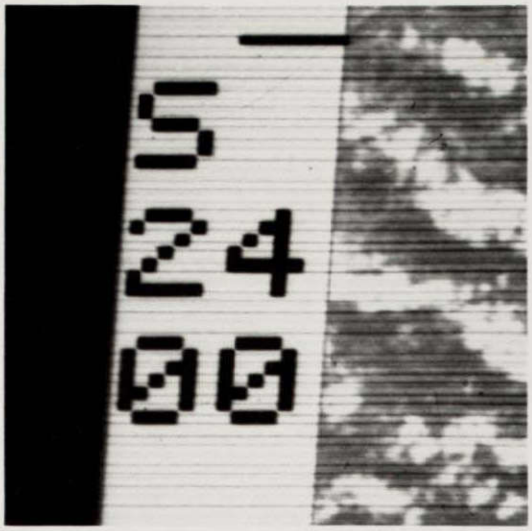
REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

FIG. 2

LANDSAT SCENES OF BRAZIL
SCALE 1:143,000

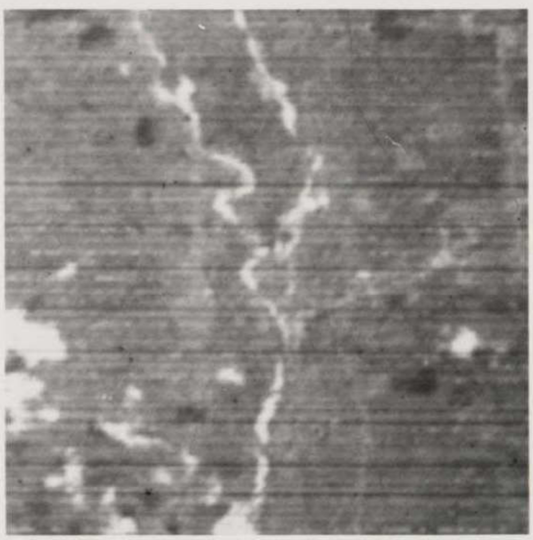


INPE-
BRAZIL
121356
9 May 75

BAND
4

SW CORNER

NE CORNER



BAND
4

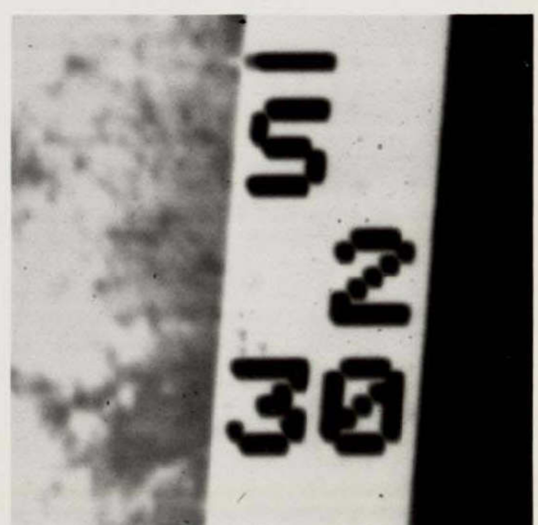
INPE-11 Jul 73-122211

GSFC-9 Oct 73-122-3

INPE-
BRAZIL
122211
11 Jul 73

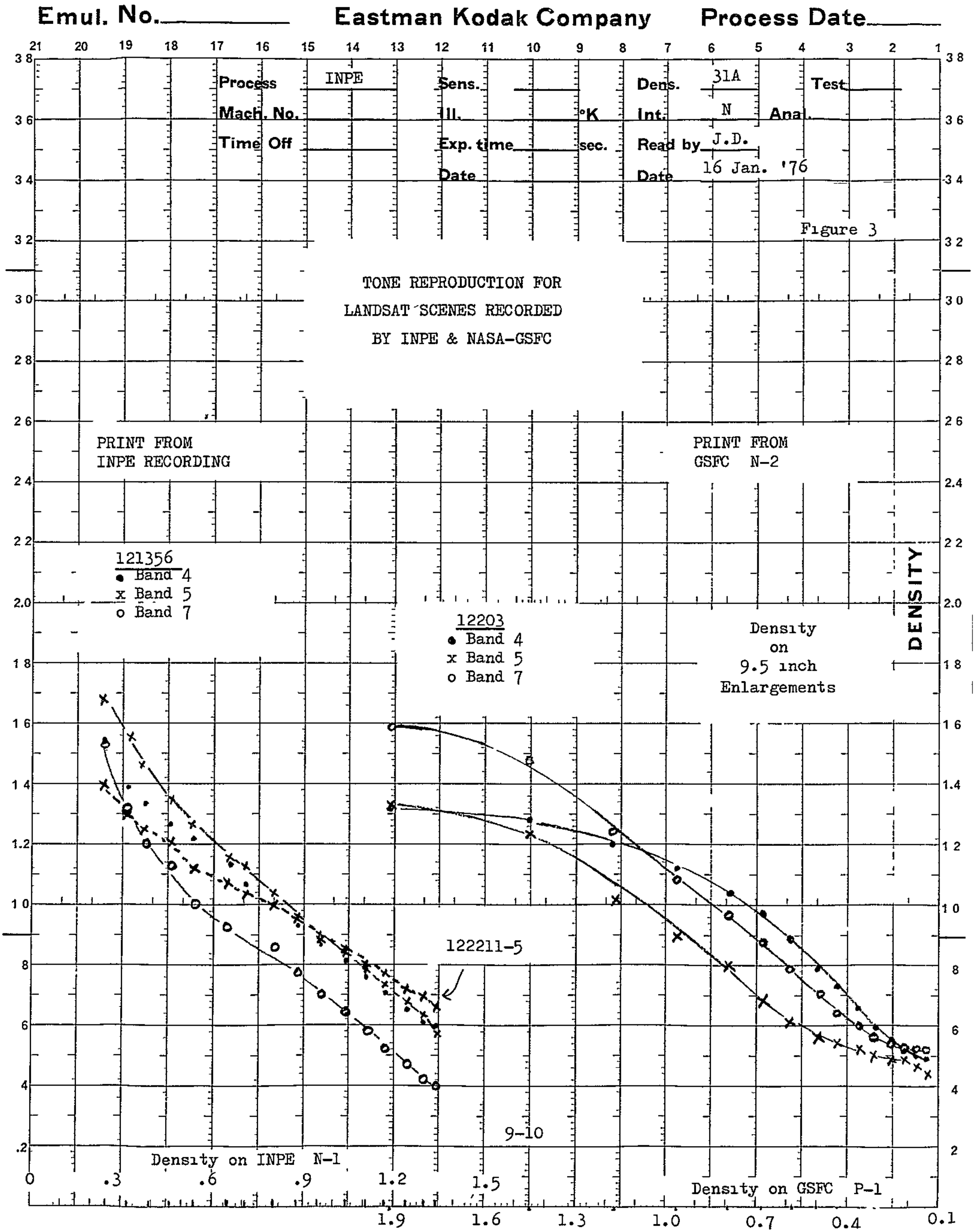
BAND

4



SW CORNER

NE CORNER


Emul. No.
Eastman Kodak Company
Process Date
Process INPE
Sens.
Dens. 31A
Test
Mach. No.
Ill.
°K
Int. N
Anal.
Time Off
Exp. time
sec.
Read by J.D.
Date
Date 16 Jan. '76
Figure 3
TONE REPRODUCTION FOR
LANDSAT SCENES RECORDED
BY INPE & NASA-GSFC
PRINT FROM
INPE RECORDING
PRINT FROM
GSFC N-2
121356
• Band 4
x Band 5
o Band 7
12203
• Band 4
x Band 5
o Band 7
Density
on
9.5 inch
Enlargements
DENSITY
122211-5
9-10
Density on INPE N-1
Density on GSFC P-1

(SO-219) while the other should show 30% higher gamma because of the Q-factor of the coarser-grained N-2 made on SO-467 film. Any conclusions regarding tone reproduction are doubtful without more information about enlarger flare and sensitometric measurement of film and processing characteristics.

Conclusions and Recommendations

It apparently is not possible to obtain a direct comparison of image quality in which a single scene is recorded and printed by both NASA-GSFC and INPE laboratories. The comparison scenes received from Brazil include the confusing effects of seasonal and annual changes and probably represent different photographic stages of reproduction. Despite these factors it is possible to make some recommendations:

1. We should compare the sensitometry, films, and printing techniques used by Brazil with those used at GSFC. This information has been requested and should be received soon.

2. A delivery time of 5 months seems excessive for black-and-white prints from Brazil, but may simply reflect difficulties in starting this laboratory.

3. It would be interesting to see color prints made at INPE, as the quality of the three bands of information varied considerably in our sample.

4. Major adjustments are necessary in the INPE enlarger or the electron beam recorder (or both) to correct the large differences in image quality across the frame.

5. Evaluation of images on prints from a special test target as used at EROS Data Center and GSFC would yield interesting quantitative data concerning the INPE operation.

6. A new lens and more specular illuminator for the INPE enlarger would probably produce a large increase in sharpness. This change might also reveal considerable physical artifacts that are not common on these test prints.

7. The source of "measles" and "black dirt" seen in several INPE prints should be found and eliminated. Humidity control may be an important factor in solving these problems.

THIRD COMPARISON OF PRINTING FACILITIES FOR EARTH RESOURCES PHOTOGRAPHY

This Study is Part of
Work Order #8 Under
Contract NASW-2317

Submitted to
National Aeronautics and Space Administration
Earth Observation Programs
Washington, D. C. 20546

Prepared by
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Approved by

31 March 1976

Introduction and Summary

Since the last survey of earth resources printers was reported in April 1974, several laboratories have made significant changes in equipment and operations. Accordingly, materials for a third survey were distributed to engineers at Goddard Space Flight Center, EROS Data Center, and the USDA laboratory at Salt Lake City. Test targets also were delivered to personnel at Johnson Space Center and Kennedy Space Center, but reduced printing operations at these laboratories precluded participation in this survey. Prints were first made late in 1975, then as new printers were installed, additional test images were exposed and evaluated early in 1976.

Although the survey yields a quantitative measure of many important attributes of image quality, it does represent only a single sample of printer output. Problem areas should be verified by repeated testing to determine trends and true levels of performance.

Since the 1974 survey, image sharpness of the EDC 13X Devere enlarger and the 3.37X film enlargers A & B has greatly improved. However, the Durst enlarger shows low resolution and relatively high geometric distortion. Resolution from the Kodak Colorado printer at this laboratory should be checked frequently, as our test shows an unusually large variation in sharpness across the frame.

The Tropel lens and illuminator on the GSFC EN-46 printer sets a new standard for image quality in a 3.37X enlarger. It shows good tone reproduction, produces very high sharpness (especially in off-axis areas), and has low flare.

For all printers the uniformity of illumination is satisfactory at less than 0.06 log exposure across the frame. In addition geometric distortion is ± 0.3% or less for all printers in this survey.

Tone reproduction for all film printers is generally acceptable when the print is made with sufficient exposure. The EDC film enlargers show an especially linear tone scale. Paper prints from all laboratories are severely compressed in both highlights and shadows because of rather high paper contrast and the long density scale (2.0) of our test target.

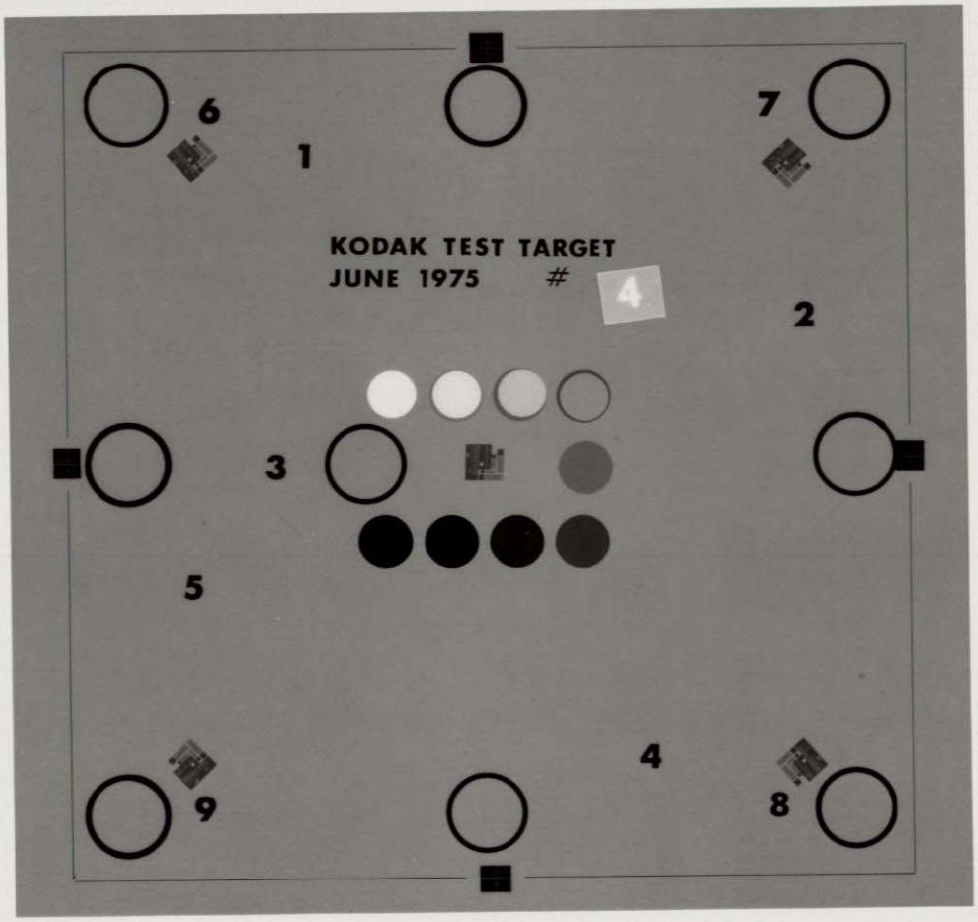


FIGURE 1

TEST FRAME FOR INTERLABORATORY PRINTER SURVEY. THE 5-INCH AND 70MM TARGETS HAVE IDENTICAL PATTERNS SPACED TO COVER THE FULL FRAME AREA. TRIBARS OF 2:1 CONTRAST RANGE FROM 8 TO 120 LINE PAIRS/MM.

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

original target to obtain the MTF for the printer plus print film—a more meaningful curve for comparison of laboratory performance.

Densities of uniformity patches and gray scale steps were read through a visual filter on an Eastman Electronic Densitometer Model 31A. Both the uniformity and gray scale measurements included nine areas in the frame.

Geometric distortion was monitored by measuring the length of one tribar array (about 4mm) on axis and in each of the four corners. The Goertz microscope used for this test had a measuring precision of ± 0.003 mm.

Flare in enlargers was evaluated according to MIL-STD-150A. In this procedure a clear field with a diagonal black stripe subtending 1 degree is imaged onto the print material simultaneously with a calibrating step tablet taped to the raw stock adjacent to the stripe image. Comparison of densities at several points in the stripe image with equivalent densities in the step tablet image allows calculation of percent flare light.

Table I lists a description of printing and processing conditions and equipment used for each test image. In some cases data are incomplete or were not reported. Several third generation prints were prepared at GSFC according to the following flow chart:

70mm (+) 1 Kodak target	Colorado →	70mm (-) 2 SO-467	ECP-K →	70mm (+) 3 SO-467
	Colorado →	70mm (-) 2 SO-467	EN-46 Tropel →	241 mm (+) 3 SO-467
	EN-46 Bendix →	241mm (-) 2 SO-467	Mk II-D →	241mm (+) 3 SO-467
	EN-46 Bendix →	241mm (-) 2 SO-467	MK II-C →	241mm (+) 3 Paper

TABLE I

Characteristics of Printer Test

Lab	Printer	Print Material	Contact or Lens	Other Print Data
USDA	Klimsch	4421	Contact	1.6 secs. exp., Tung-Halogen lamp; 641-85°-10 fpm
	Mk II	4421	Contact	1.3 secs. exp., Aristo SO-39; 641-85°-10 fpm
	Salzman-Pavelle	Kodabrome	f/11	25 secs. exp., Tung-Halogen lamp; Kreonite -80°-5 fpm
	EN-70 (GSFC)	SO-467	Bendix f/5.6-150mm	4 secs. exp., Tungsten; 641-85°-7 fpm
	Devere - film	4421	f/8 -150mm Rodenstock	3.37 X enlarger
	Devere- paper	Kodabrome	f/8-150mm Rodenstock	2 secs. exp., Tungsten; Kreonite - 77° -5 fpm
EDC	ECP-70	SO-467	Contact	1.4 secs. exp., 641-$15\frac{1}{2}$ fpm; 70mm frame printer
	Film A&B	SO-467	3.37X-6 inch	1.1 secs. exp., 641-$14\frac{1}{2}$ fpm
	Durst A	Paper	f/22, Nikor	10 secs. exp., very diffuse illumination
	Colorado	SO-467	Contact	Ultraviolet filter
	Devere	Paper	Rodenstock	13.X enlargement
GSFC	EN-46	SO-467	Bendix f/5.6-150mm	Original production enlarger
	EN-46-Tropel	SO-467	Tropel f/3.5-150mm	New lens and mercury arc illuminator
	Mk II-D	SO-467	Contact	
	Mk II-C	Paper	Contact	
	ECP-K	SO-467	Contact	70mm frame printer
	Colorado	SO-467	Contact	Ultraviolet filter
EKCo.	BPE (Beacon)	2420	f/17.8 - 10.75"	6 secs. exp., 641-70° -20 fpm
	Niagara	2420	Contact	100 fpm, Corning 9863; 75° - 100 fpm

4421 is KODAK Aerographic Duplicating Film 4421 (ESTAR Thick Base)

SO-467 is KODAK Aerial Duplicating Film (ESTAR Base) SO-467

2420 is KODAK Aerographic Duplicating Film 2420 (ESTAR Base)

Results

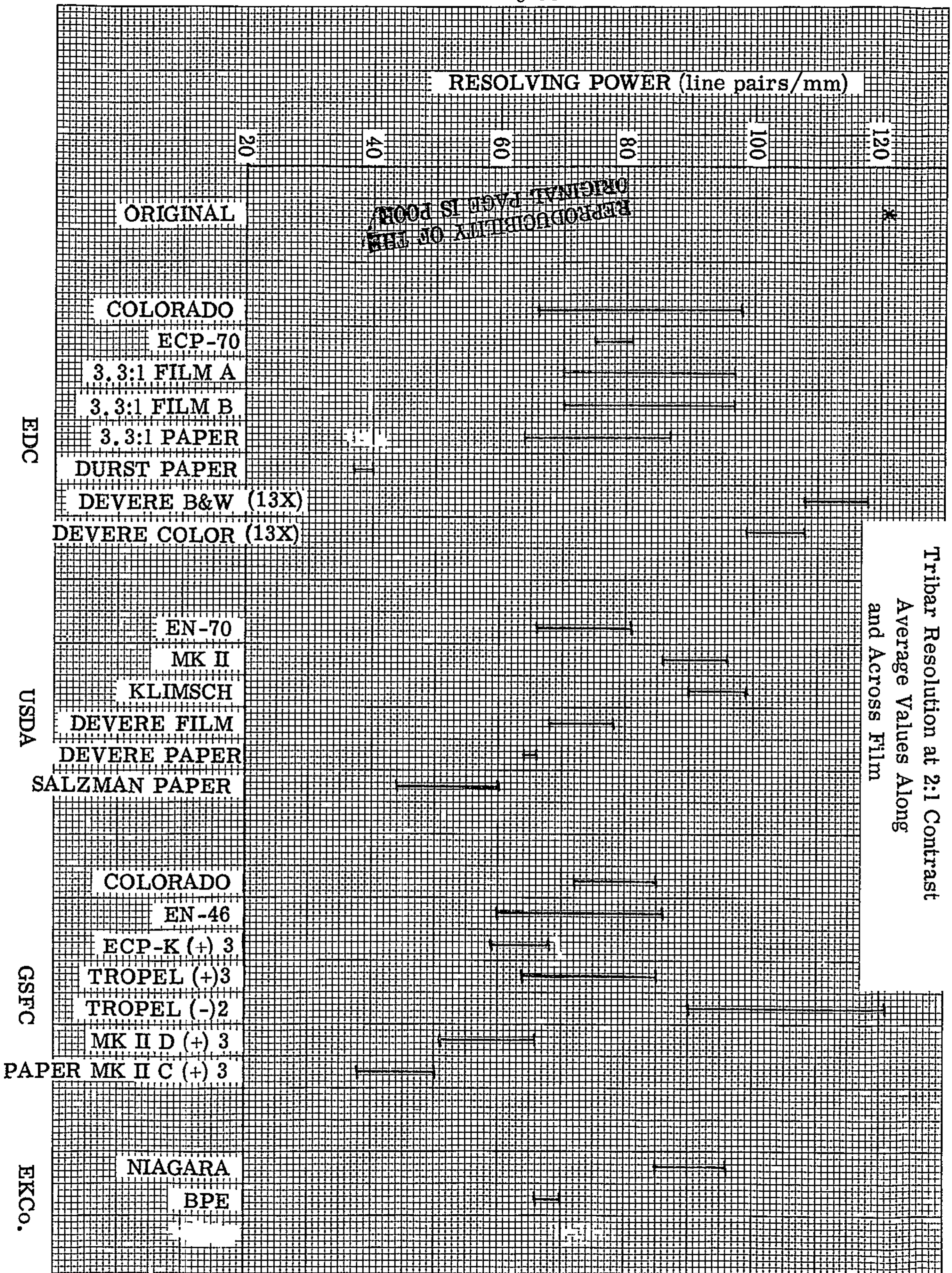
Tribar Resolution

In Figure 2 the limiting resolution on the original target (121 line pairs/mm) is compared with the best value (usually on axis) and the worst corner value for resolution on each of the prints referred to the 70mm scale. Enlargements in Figure 3 illustrate differences in on-axis image quality. Best performance is generally 95 to 100 lp/mm for all except the Devere enlargers working at 13X at EDC. These machines are much improved from the results of our last survey. The EN-46 with the new Tropel lens and illuminator at GSFC is notably better than other 3.37X enlargers - it reveals the full 121 lp/mm in most patterns with only one corner droping below 100 lp/mm. Mr. J. Polger, Technicolor photo scientist at GSFC, attributes this loss to a slight buckling of one corner of the film in the glass gate; further adjustments are planned on this EN-46 machine. Overall performance at GSFC averages below that at other centers because four of the prints are third generation images on which the average resolution is only 60 lp/mm.

The EN-46 at GSFC, and the Colorado 3.3X film enlargers at EDC show a wide range in resolution across the frame. This characteristic has been noted previously for the EN-46, and it will be replaced soon by an enlarger with Tropel optics. Since this range in performance from the EDC Colorado printer is unexpected, a retest was run in January 1976 to obtain the following average resolution values from three prints:

Retest, lp/mm					First Test, lp/mm	
Center	Corners				Center	Worst Corner
82	72	76	61	64	98	66

The retest data show more consistent performance, but this uniformity is obtained more by lowering on-axis resolution than by raising quality in the



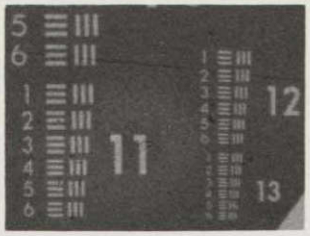
INTERLABORATORY PRINTER SURVEY
Tribar Resolution at 2:1 Contrast
Average Values Along
and Across Film

Figure 2

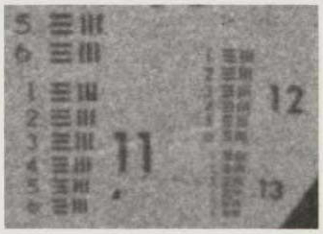
K+E 10 X 10 TO ½ INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1323

ENLARGEMENTS
OF AXIAL TRIBAR IMAGES
50X FROM ORIGINAL SCALE

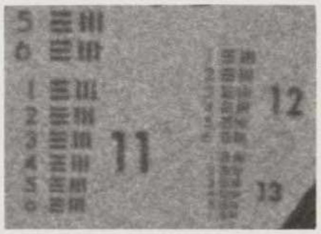
FIGURE 3



ORIGINAL TARGET
(+)1



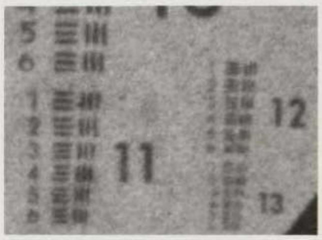
COLORADO/EDC
70(+)1-70(-)2



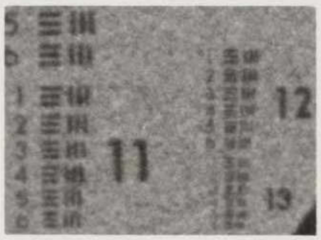
ECP-70/EDC
70(+)1-70(-)2

3.3XFILM-A/EDC
70(+)1-9½(-)2

3.3XFILM-B/EDC
70(+)1-9½(-)2



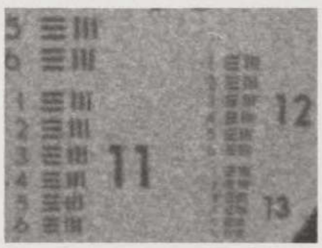
MKII/USDA
70(+)1-70(-)2



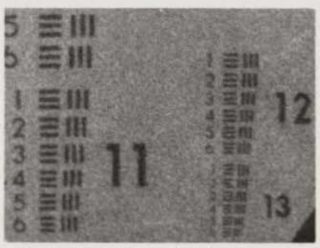
KLIMSCH/USDA
70(+)1-70(-)2

EN-70/USDA
70 (+)1-9½(-)2

DEVERE FILM/USDA
70(+)1-9½(-)2



COLORADO/GSFC
70(+)1-70(-)2

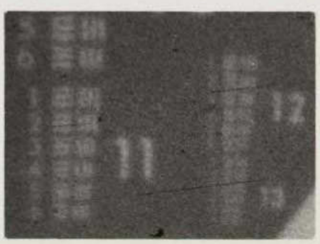


TROPEL/GSFC
70(+)1-9½(-)2

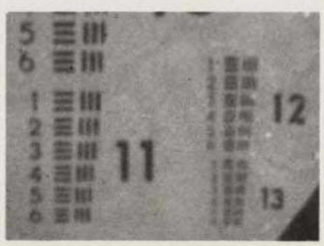
EN-46/GSFC
70(+)1-9½(-)2

TROPEL/GSFC
70(+)1-COLO-9½(+)3

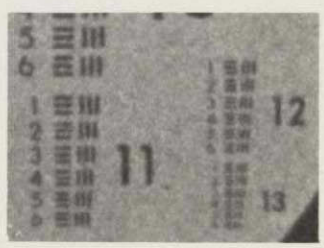
ECP-K/GSFC
70(+)1-COLO-70(+)3



MKIID/GSFC
70(+)1-EN46-9½(+)3



BPE/EKCo.
70(+)1-9½(-)2



NIAGARA/EKCo.
5(+)1-5(-)2

K+E 10 X 10 TO ½ INCH 7 X 10 INCHES KEUFFEL & ESSER CO MADE IN U S A 46 1323

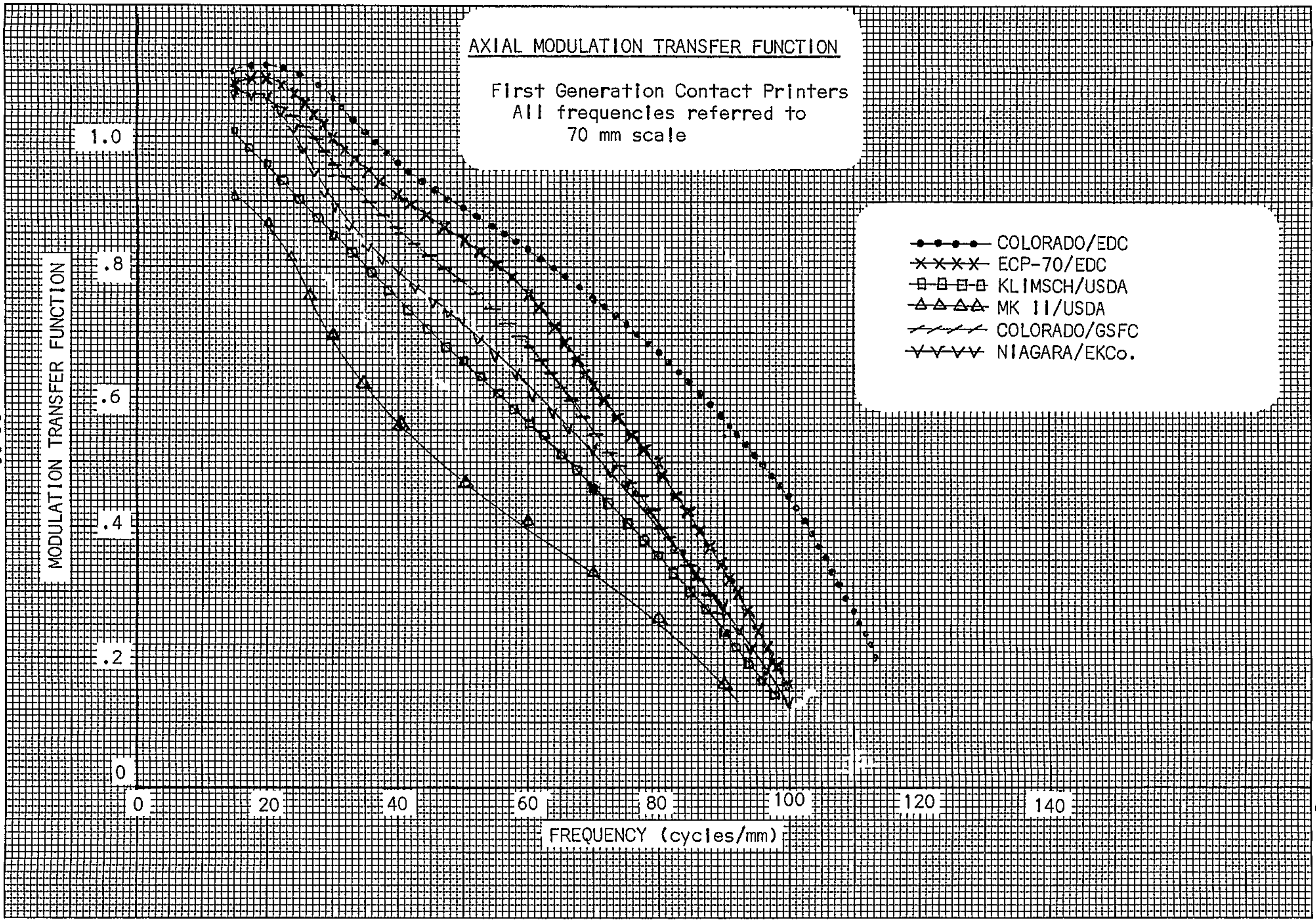


Figure 4

K+E 10 X 10 TO ½ INCH 7 X 10 INCHES KEUFFEL & ESSER CO MADE IN U.S.A. 46 1323

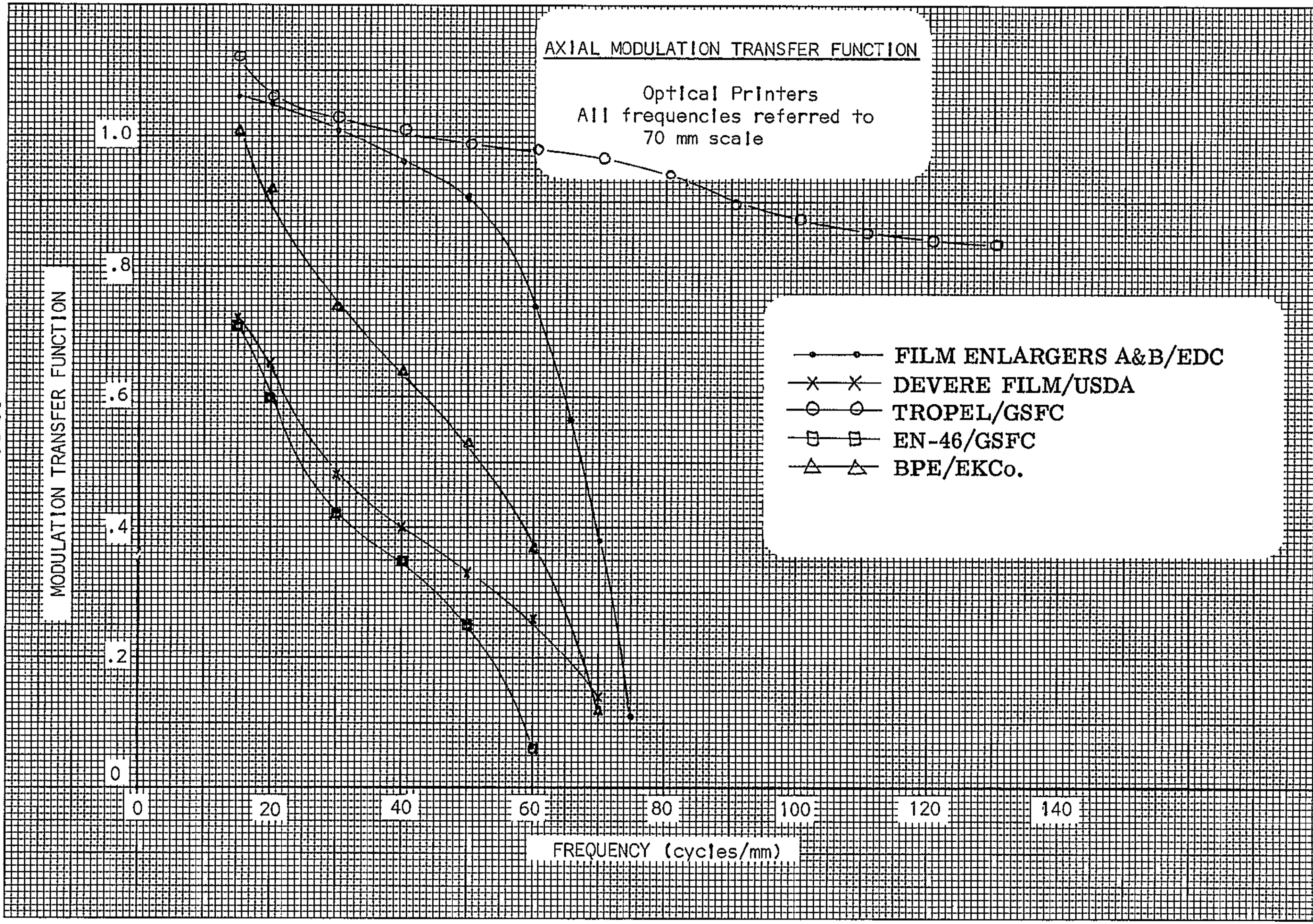


Figure 5

K+E 10 X 10 TO ½ INCH 7 X 10 INCHES
KEUFFEL & ESSER CO MADE IN U.S.A.
46 1323

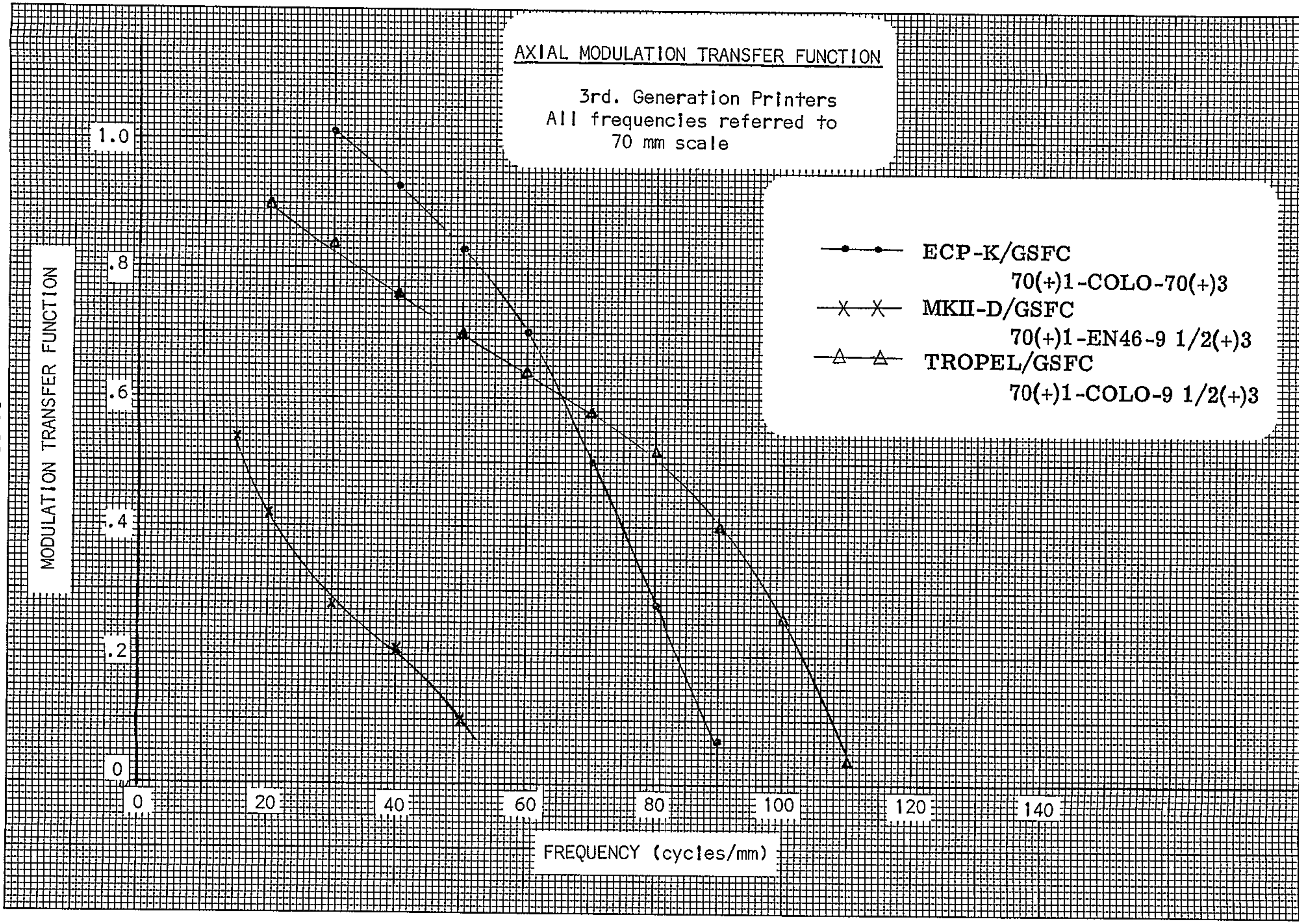


Figure 6

frequencies in the Landsat scene. The Kodak Beacon Enlarger (BPE) is essentially diffraction limited but at f/17 gives poor performance at 3.37X. The high tribar performance of the A and B film enlargers at EDC is reflected in the good MTF curve in Figure 5, while the relatively low quality from the EN-46 at GSFC is also revealed.

This machine also influences results in Figure 6 where the EN-46 is used in one case to make an enlarged negative that is subsequently printed on the Mk II-D at GSFC. Both MTF and tribar resolution are low in this third generation record. A much better third generation image is obtained when the Tropel lens is used to enlarge a 70mm negative made on the Colorado printer.

Illumination Uniformity

Radiometric fidelity can be obtained in Landsat printers only if the scene is uniformly illuminated during the printing exposure. Data in Figure 7 show this property by plotting on a rather expanded scale the density extremes around each frame compared to the on-axis value. Since most film prints are made at a gamma close to 1.0, deviations in density on these images correspond well with variations in log illumination across the field. Most film printers show variations in a frame of 0.05 to 0.07 log exposure or less.

Paper printers display more apparent variation in illumination (up to 0.12 range in density on Figure 7), but most of this difference is caused by gammas of 1.6 to 2.2 found in Landsat paper prints. Generally illumination uniformity is satisfactory for printers in this survey.

Geometric Distortion

Uniformity of magnification in Landsat imagery is important in assessing its value for cartography. In Figure 8 almost all printers show off-axis magnification that is within ± 0.3% of the axial value. Paper

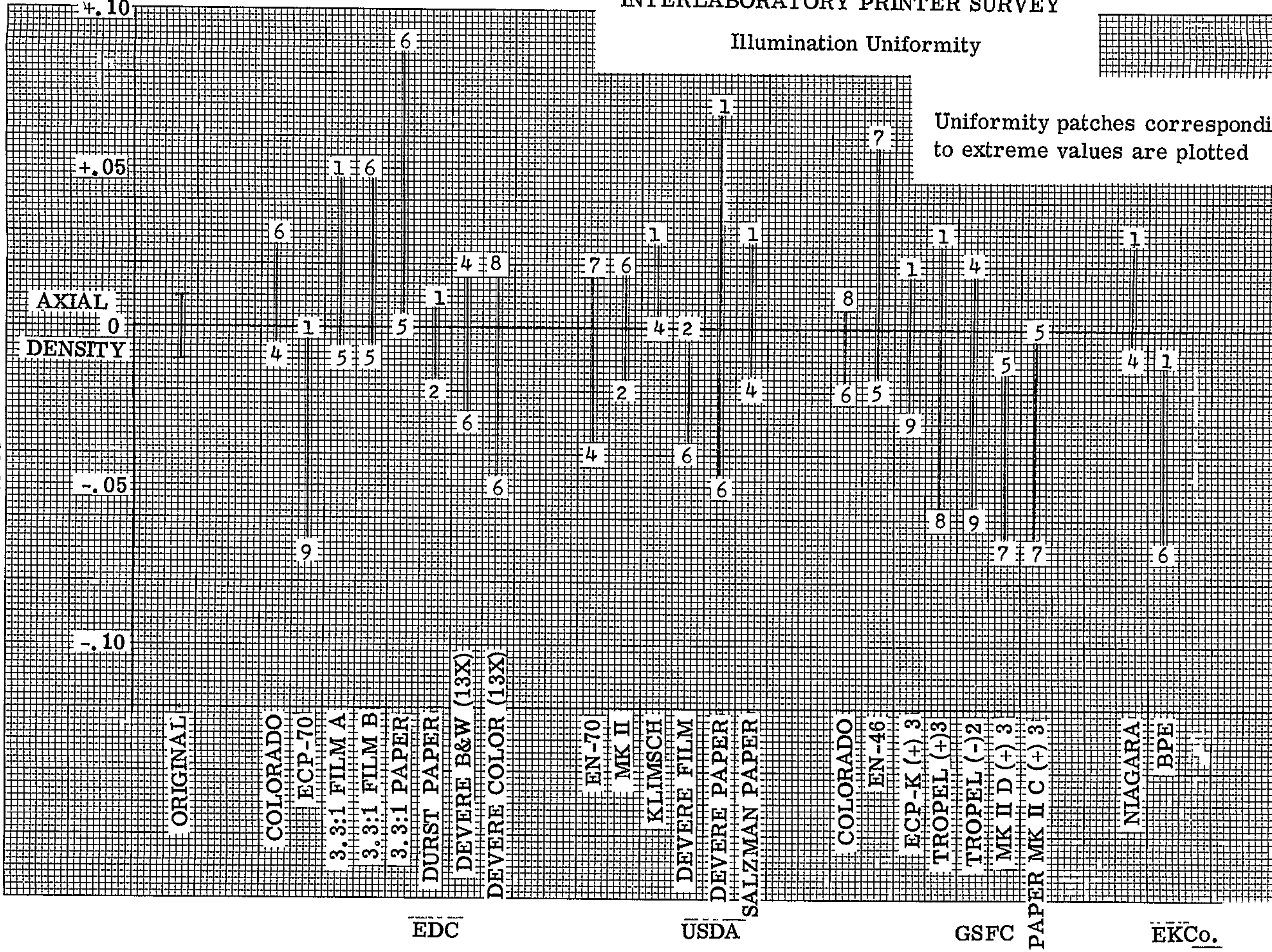
K+E 10 X 10 TO ½ INCH 7 X 10 INCHES KEUFFEL & ESSER CO MADE IN U.S.A. 46 1323

Figure 7

INTERLABORATORY PRINTER SURVEY

Illumination Uniformity

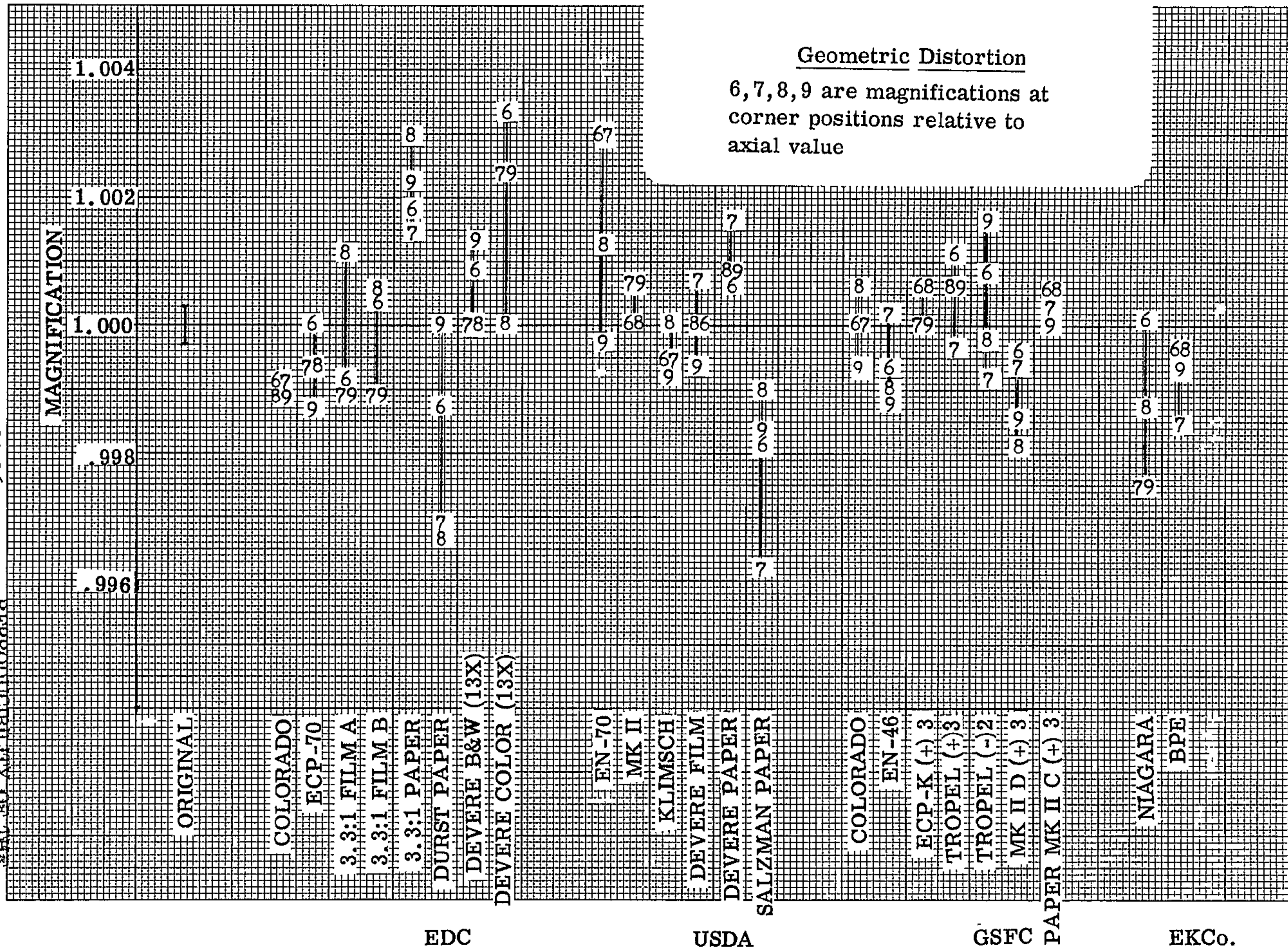
Uniformity patches corresponding to extreme values are plotted



10-15

K [redacted] X 10 [redacted] INCH [redacted] INCH [redacted]
KEUFFEL & ESSER CO. MADE IN U.S.A.

INTERLABORATORY PRINTER SURVEY



10-16

Figure 8

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

enlargers at USDA and EDC exhibit the widest range of magnification, while the EN-70 at USDA is the only film printer that reaches 0.3% distortion. Enlargers are better in this regard than in previous surveys.

The absolute amount of magnification on axis is also an important parameter, as this value determines the nominal scale of the Landsat prints. Table II summarizes magnification measured on axis over a distance of 4mm at the 70mm scale. Most enlargers producing prints at 1:1,000,000 scale yield magnifications within ± 0.3% of the nominal 3.369X value. The Durst at EDC usually is not used for this work and was apparently not carefully set for this particular test.

Tone Reproduction

In Figure 9-12 tone reproduction curves are plotted as density on the print (out) vs. density of the original nine-step target (in). Most film prints that are properly exposed show a fairly linear tone relationship, with the film enlargers A and B at Eros Data Center yielding a particularly straight line. The EN-46 at GSFC is rather non-linear at high input densities because of substantial flare in this enlarger. An explanation for a similar effect in the Niagara contact printer at Rochester is not evident unless the print film had a very sweeping toe shape. Three of the film curves in Figure 10 show distortion at low densities because these USDA prints were printed too low on the film reproduction curve.

Tone reproduction on paper prints is severely distorted at both high and low densities, and third generation tone reproduction is especially non-linear in Figure 11. With midscale gammas of 1.3 to 2.2 and a Dmax of about 1.5, these printing papers cannot accept more than 60% of the density range

TABLE II

AXIAL MAGNIFICATION FOR LANDSAT ENLARGEMENTS

EDC	Magnif.	GSFC	Magnif.
Film A	3.367	EN-46	3.363
Film B	3.368	Tropel (-2)	3.370
3.3 Paper	3.356	Tropel (+3)	3.374
Durst	2.849	Mk II C (+3)	3.363
Devere B&W	13.44	Mk II D (+3)	3.367
Devere Color	13.52		

USDA	Magnif.	EKCo.	Magnif.
EN-70	3.356	BPE	3.372
Devere Film	3.367		
Devere Paper	3.368		
Salzman	3.371		

Figure 9

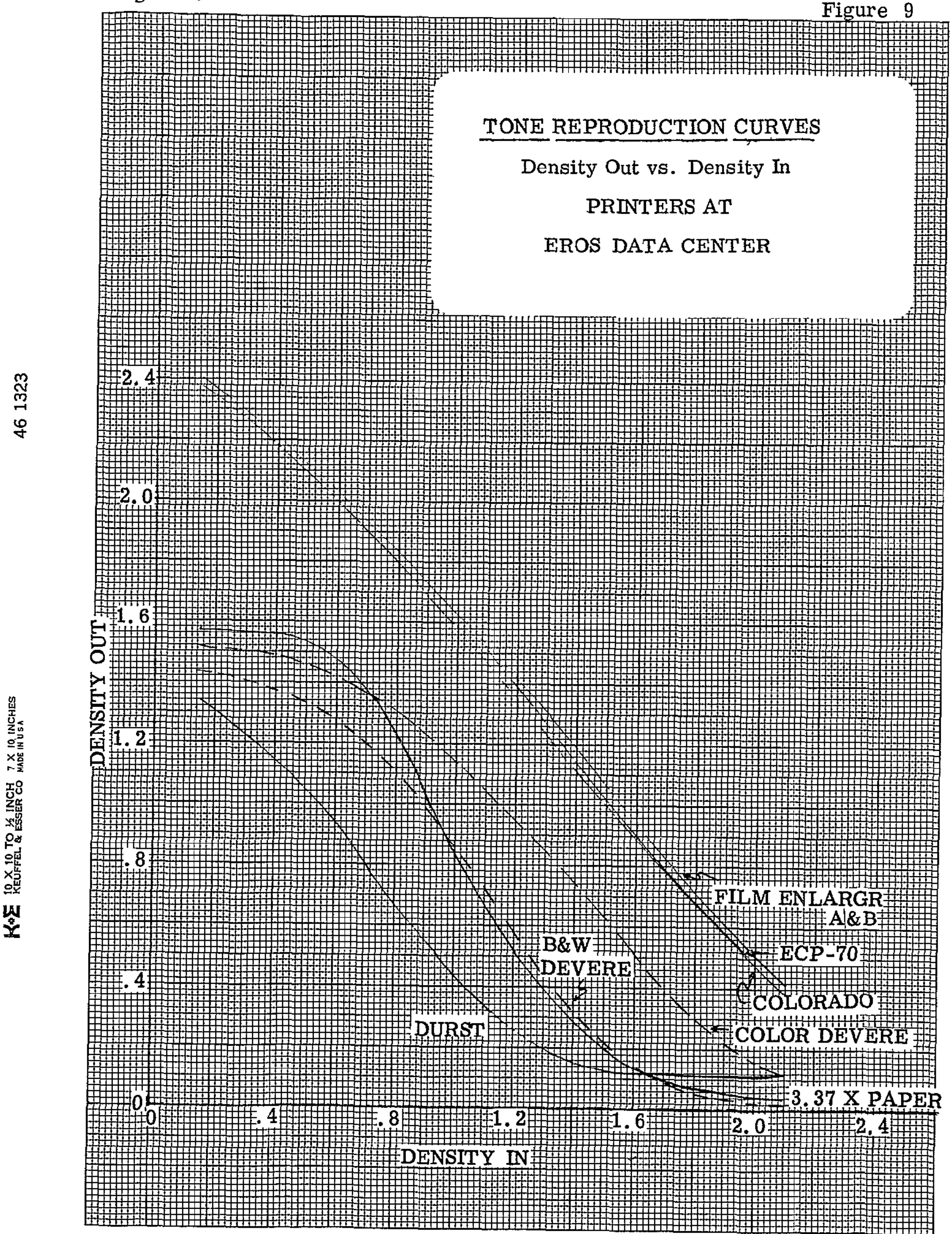
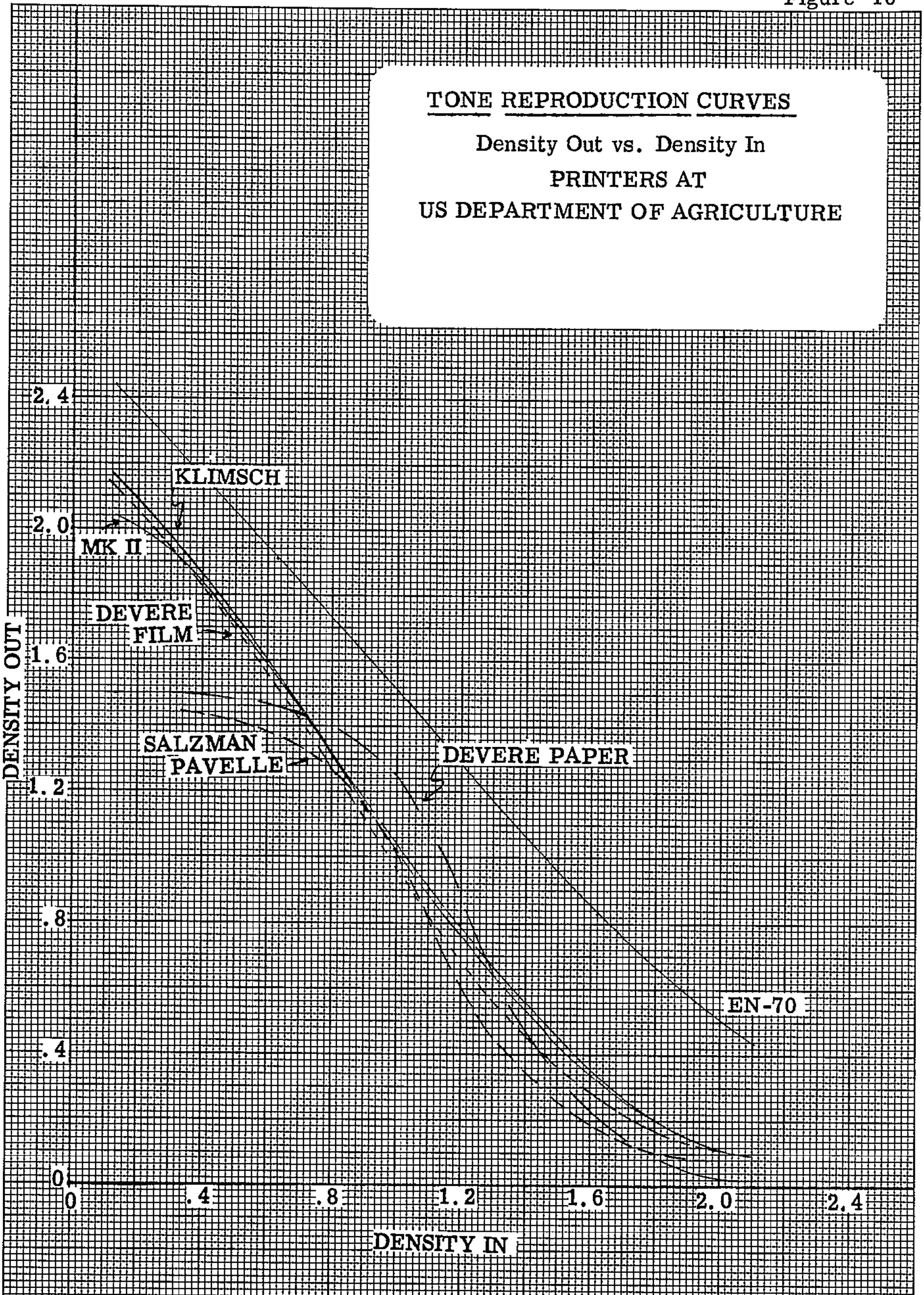


Figure 9
TONE REPRODUCTION CURVES
Density Out vs. Density In
PRINTERS AT
EROS DATA CENTER
DENSITY OUT
2.4
2.0
1.6
1.2
.8
.4
0
DENSITY IN
0
.4
.8
1.2
1.6
2.0
2.4
FILM ENLARGR A&B
ECP-70
COLORADO
COLOR DEVERE
B&W DEVERE
DURST
3.37 X PAPER
46 1323
10 X 10 TO ½ INCH 7 X 10 INCHES
KEUFFEL & ESSER CO MADE IN U.S.A.

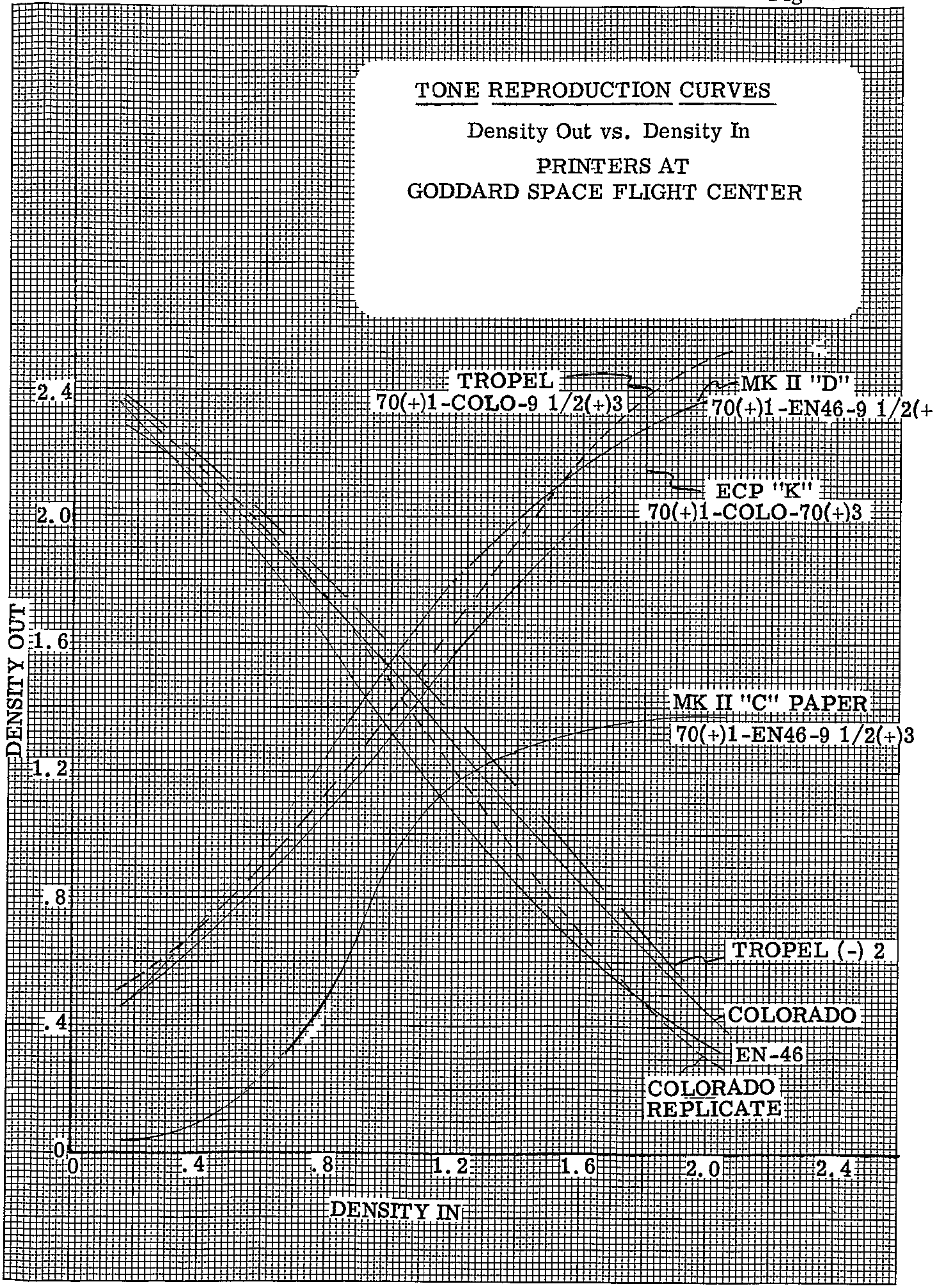
Figure 10



46 1323

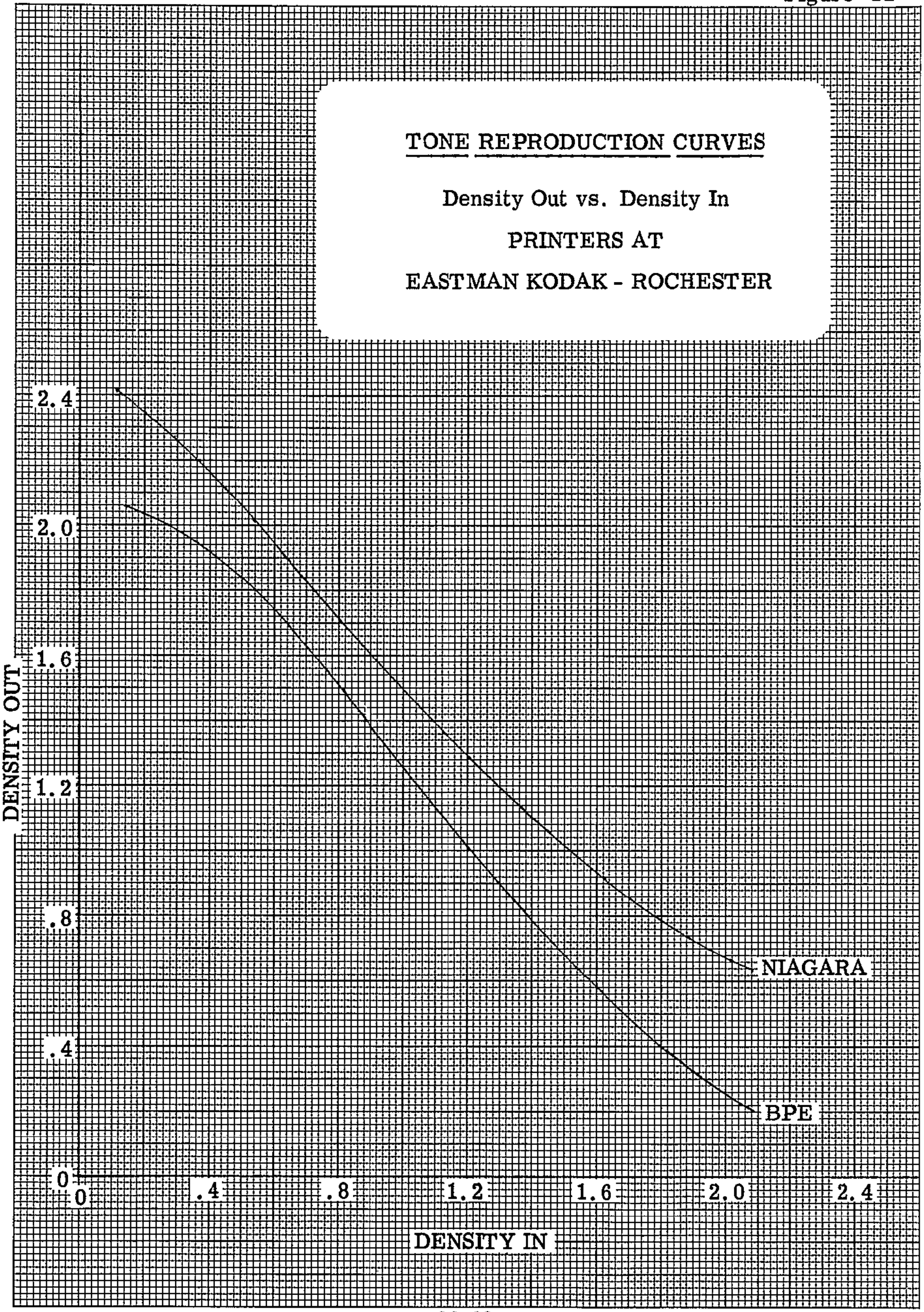
K&E KEUFFEL & ESSER CO. MADE IN U.S.A.

Figure 11



46 1323

K+E 10 X 10 TO ½ INCH 7 X 10 INCHES KEUFFEL & ESSER CO MADE IN U.S.A.



REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1323

on the original target. An original record of lower density range or the use of lower gamma paper would produce more linear tone reproduction in paper prints. These conditions would reduce the number of prints rejected for high or low density but might bring complaints about "hazy" or low contrast prints.

Flare

Measurements of flare light could be made on only a few optical printers, since the gamma on several paper prints was too high to show density from flare light in the test stripe. In other cases steps on the gray scale could not be clearly identified on the paper print and sensitometric calibration of the test was impossible. The following flare values were obtained at five positions diagonally across the frame:

PERCENT FLARE

	Frame Position				
Printer	Corner	1/2	Center	1/2	Corner
USDA					
Salzman	4.7	5.4	5.8	5.2	4.4
EN-70	3.0	4.9	8.7	5.4	3.2
GSFC					
EN-46, Bendix lens	1.8	5.8	7.4	4.9	1.8
EN-46, Tropel lens	0.4	1.0	1.2	0.7	0.4
EDC					
3.37X Paper	Less than 1.5% at all points				
Durst A	Less than 3.1% at all points				
Film A	0.4	0.5	1.4	0.8	0.8
Film B	0.4	0.5	1.5	0.8	0.7
Devere B.&W.	No density in stripe				
Devere Color	Step tablet not clearly identified				
EKCo.					
BPE	0.4	0.5	0.6	0.5	0.4

The EN-46 with Bendix lens and the similarly equipped EN-70 at USDA continue to have high flare because of an on-axis hot spot. This condition is corrected in the new Tropel lens and illuminator. Flare in the Salzman is rather high, while that in the two film enlargers at EDC is exceptionally low - a factor contributing to the very linear tone reproduction from these machines. Because it operates over a narrow field angle at f/17, the Kodak BPE shows very low flare.

Conclusions and Recommendations

1. The Tropel lens and illumination system on the EN-46 printer at GSFC shows an outstanding MTF curve and high tribar resolution. Off axis quality is especially good relative to other lenses.

2. Resolution from the 13X Devere enlarger at EDC is much improved over that in the last survey, but the Durst at EDC has low resolution and relatively high distortion.

3. The Kodak Colorado printer at EDC shows too large a range in resolution across the frame; its performance should be checked frequently.

4. At USDA the Salzman enlarger yields lower sharpness than other USDA printers.

5. Compared to results in previous surveys, the ECP-70 printers at EDC and USDA give fairly good resolution but are still not equal in sharpness to other printers in both laboratories.

6. The 3.37X film enlargers at EDC have nearly identical image quality and are especially sharp on axis, but their MTF curve falls off rapidly beyond 60 lp/mm.

7. Uniformity of illumination is satisfactory in all printers. The range in log exposure across the frame is 0.06 or less.

8. Geometric distortion has been reduced in several enlargers and now is less than ± 0.3% for all printers.

9. Film prints show a gamma near 1.0 with the EDC A and B enlargers yielding especially linear tone reproduction because of low flare in these machines.

10. Image tones are severely compressed in highlights and shadows of paper prints because of high paper contrast and the long density range (2.0) of the original target.

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