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HIGH RESOLUTION CPA STUDY.(U)
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Final Technical Report
April 1977

HIGH RESOLUTION CPA STUDY
C & C Research Incorporated

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Concurrent Photon Amplification (CPA) was originally developed as a technique for increasing the effective film speed of materials for use under low light conditions. It has now been successfully adapted for use in high resolution photography. By applying CPA techniques to slow-speed high-resolution film materials, these may be used to replace conventional films so as to provide photographic collection systems with at least twice as much resolution while working in the exposure index range from 32 to 1600. —> cont. next page (cont'd)		

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Experiments conducted show that Kodak PAN-X film, with a speed of 32 and a resolution capability of approximately 80 line pairs per millimeter, can be replaced by KODAK 5069 in combination with Concurrent Photon Amplification and special processing to yield a photographic system resolution over 200 line pairs per millimeter and an effective film speed of 100 or more. In a similar fashion, Kodak TRI-X film with a speed of 400 and resolution capability of about 40 line pairs per millimeter can be replaced by a high resolution system based on Kodak 2496 film, CPA and special processing. This system provides resolution over 100 line pairs per millimeter and effective film speeds in the 800 to 1000 range.

→ The CPA high resolution photographic system offers an additional advantage of increasing the resolution latitude, so that a given level of resolution is attained over a wider range of exposures; thereby increasing the probability of mission success.

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EVALUATION

This effort is part of the program conducted under Project 5534 (TPO-2) to provide improved photographic techniques for the Air Force.

Concurrent Photon Amplification (CPA) techniques have been extended to low-speed high-resolution films, thereby making them available for use in a variety of applications as substitutes for high-speed but low-resolution films. The techniques employed are based on commercially available materials and can be readily adapted to existing cameras at low cost. As a result, high information content photography can now be accomplished under a wide variety of operational circumstances.

This effort completes the planned series of CPA programs conducted by Rome Air Development Center. The results have been made available to a number of government organizations who are now in the process of adapting CPA technology to individual requirements.

Edward C. Scott

EDWARD C. SCOTT
Project Engineer

I

INTRODUCTION

This task was undertaken to apply Concurrent Photon Amplification (CPA) techniques to black-and-white photographic systems so as to provide a doubling of resolution with equal or greater speed. In previous efforts CPA has been successfully applied to medium or high speed films so as to increase their effective speed for low light level use. The goal of this effort was to obtain higher resolution and greater information content under normal operating conditions. This goal was to be achieved by an increase in the speed of existing very high resolution films so as to make them useable in hand-held 35mm. photography. While earlier efforts were confined to specific films and normal processing, these limits were removed for the High Resolution CPA Study so that an optimized system of film, processing, and concurrent photon amplification for each speed range could be devised.

II

BACKGROUND

Low light level photography has presented complicated problems for many years. In the past, considerable electronic efforts have been expended toward achieving high photographic film speeds. Many processes were evolved whereby greater sensitivity was attained but only by sacrificing image quality, particularly resolution values. The use of CPA results in considerable sensitivity enhancement, while preserving inherent system resolution.

Concurrent Photon Amplification (CPA) is a technique whereby non-image light is added simultaneously to that of a primary imaging exposure enabling previously non-developable latent image to now become developable.

Two distinct mechanisms are involved in producing a latent image that will develop into a picture. The first mechanism is the production of an atom of silver within a given silver halide crystal. Normally, the formation of this single atom requires that a particular sensitivity site on the silver halide crystal be struck by more than one photon of light. When sufficient photons have struck this site, then a single atom of silver is produced, but this atom alone is not enough to promote development.

The second mechanism of latent image formation requires that a number of silver atoms be present in a particular crystal before that crystal is rendered developable. Normal photographic film consists of a silver halide emulsion with a given grain size and distribution. When an exposure is made, some grains receive sufficient light and become developable; some receive inadequate light and do not develop, and still others receive a marginal amount of light and are developable only if developed within minutes or even seconds. However, such development is usually not the case, or for that matter even practical. This loss of the developable, submarginally sensitive silver halide grains happens because, over a matter of minutes and certainly over a period of hours, a recombination occurs between the photolytic silver present at the sensitivity sites of the exposed grains and the bromine which was released. (The image decays). It should be emphasized that recombination affects both mechanisms relating to exposure.

In previous work, J. Mitchell has assumed that the creation of three (3) silver atoms results in a developable latent image nucleus¹. Modern high speed emulsions exhibit photon efficiencies

¹ "Fundamentals of Photographic Theory", T. H. James & G. C. Higgins, Second Edition, Page 61.

of between 10 to 25%. This means that between 12 to 30 photons² are required to produce a developable latent image. Many attempts have been made in the past to bring back or even increase this developable latent image. The majority of these methods used some form of light to hypersensitize (pre-expose) or latensify (post-expose) the film or used chemical means or even a combination of light and chemistry. However, the most efficient use of latensification would be the use of additional non-image light simultaneously with the primary imaging exposure. Otherwise, latent image regression or fading (recombination) could so rapidly and substantially reduce the amount of developable latent image that no significant or meaningful degree of latensification, and hence speed increase, could be attained. Thus, the age of the latent image, due to the original exposure, is an important factor. The benefits obtained in speed gains due to latensification decrease progressively as the time interval increases between exposure and latensification³. It appears, therefore, that some change occurs in the structure of the latent image after exposure and that the small sub-image, sub-developable latent image can fade and lose its ability to promote development⁴. This results in a decrease in emulsion speed or at least, a decrease in attaining the highest possible speed for a given film.

In order to circumvent these shortcomings, C & C Research has developed the technique of Concurrent Photon Amplification (CPA) resulting in considerable speed increases in both black-and-white as well as color films. These CPA speed gains have been achieved while keeping the inherent resolution of any given film and have actually resulted in a marked increase in the dynamic range as well as resolution latitude of such CPA-exposed films.

² "The Image of Grains", Eggers, Lornagner & Moisar, Perspective, Volume 7, 1965, Page 103.

^{3,4} "The Theory of the Photographic Process", Mees-James, Third Edition, Pages 373 - 374.

III

CONTRACT REQUIREMENTS

1. Determination of the spectral, temporal and intensity CPA exposure required to achieve maximum film speed with high resolution films such as Kodak 5069 and 3414 and specialized processing.
- 2.* Determination of the CPA light source requirement, including bulb type, size, number, intensity distribution, illumination uniformity and any timing circuits.
3. Determination of specialized processing methods and procedures to provide maximum speed gain and resolution for use with the optimized CPA exposure on the above films.
4. Determination of the resultant photographic parameters, (i.e., film speed, gamma, resolution, dynamic range, etc.), for the optimum combinations of high resolution films, CPA exposures, and specialized processing methods. The goals for the above parameters are:
 - a. A speed gain of at least eight (8) times.
 - b. A system resolution increase of two (2) times.
 - c. A gamma of 0.8 ± 0.2 .
5. Determination of the interactive effects of CPA enhanced exposure, high resolution emulsion characteristics and unique photographic processing methods.
6. Determination of optimum CPA techniques and associated photo processing methods for use with medium and high speed black-and-white systems that will provide double the system resolution.
- 7.* Determination of methods of incorporating high resolution CPA techniques developed, exclusive of power supply and control system, into previously CPA modified 35mm single lens reflex camera systems without interfering with or degrading any of the camera's normal operations.
- 8.* Provision of a sample kit for each of the three (3) speed categories of film. Each kit shall contain twelve (12) rolls of 36-exposure, 35mm film, CPA exposure recommendations, processing chemicals and complete instructions.
9. Quarterly oral briefings at RADC at such times as designated by the contracting officer with C & C Research, Inc. providing all briefing materials.

* These requirements were deleted by an engineering change dated 15 DEC 76.

IV

APPROACH

Previously, the CPA technique has been applied, for the most part, to various general purpose films and subsequent processing was restricted to the particular manufacturer's developers and film handling instructions. However, in this application of CPA to low speed, high resolution black-and-white films, not intended in themselves for general purpose photography, new developer formulations in conjunction with optimized CPA exposure provided an increase in speed, dynamic range and resolution latitude without loss of peak resolution.

The first part of our effort was devoted to a thorough analysis of the effects of CPA on existing high resolution films, (i.e., Kodak 3414 and 5069).

As mentioned above, only recommended developers were, until now, used when CPA was applied to a given film. Under this effort special developers were designed that produced the most image on the CPA exposed film, i.e. developed to the maximum all CPA affected grains, internal and external sensitivity sites included.

Having established the parameters for small grain, high resolution film/developer systems optimized for CPA, a search was made for larger grain, higher speed film systems that would enable us to achieve a speed to resolution relationship that has heretofore been unattainable.

TECHNICAL RESULTS

A. CONVENTIONAL VERSUS CPA HIGH RESOLUTION PHOTOGRAPHY

The primary goal of this effort was to investigate one or more film/developer combinations to use in conjunction with CPA so as to produce photo systems with increased speed and resolution. During the course of the contract several systems were devised which covered a range of exposure indices from 50 to 1600. This exposure index range envelopes three of the conventional black-and-white films in common use today, i.e. Kodak PAN-X, PLUS-X and TRI-X.

We were successful in devising CPA replacement systems that not only double the resolutions that were achievable with conventional systems, but also provided speed increases of two or more stops.

Table 1 lists the three conventional black-and-white films and their important output parameters. Following these three entries in the table are a list of high resolution CPA systems and their output parameters. The exposure indices that are listed in this table are suitable for use with meters calibrated in the ASA system. Later in this report, film speeds determined sensitometrically at 0.1 above fog are listed. Care must be exercised before attempting to use these sensitometric speeds in your camera, especially in the case of CPA because of the long toe that CPA produces on the D-log E curve. What this long toe does is to increase the number of exposure units between the familiar 0.1 above density speed point and the point on the curve where the slope or gamma is maximum, i.e. the straight line or optimum use portion of the D-log E curve. If any doubt exists as to the useability of this sensitometric speed, it is wise to conduct tests under actual conditions to verify the correct camera settings to be used with a particular CPA high resolution system.

Note that none of the conventional film systems outlined in Table 1 exceed two hundred line pairs per millimeter in resolution whereas all but 2496 and 2498 have at least 200 lnp/mm and four of them exceed 456 lnp/mm or more.

Figures 1 and 2 demonstrate both graphically and pictorially results that can be expected with two CPA high resolution systems. Figure 1 shows conventional PAN-X film (broken lines) processed in Kodak D-76 developer for the recommended 3.75 minutes at 75°F. This is contrasted with a CPA high resolution system consisting of Kodak 5069 High Contrast Copy film, CPA exposure and special processing (CPA-1, 15 minutes @ 90°F, constant agitation). The PAN-X speed is 32 versus 125 for the

CPA system. Maximum resolution is 181 lnp/mm with PAN-X and better than 456 lnp/mm for the high resolution system. In fact, one could vary camera exposure over an eight (8) stop range * with the CPA system and still exceed the performance of PAN-X. The photo inserts in Figure 1 are 25 times enlargements of USAF 1951 resolution targets produced by contact printing in our CPA sensitometer at a density level of 1.0 in each case.

Figure 2, shows, in similar fashion, a comparison of Kodak TRI-X and a high resolution CPA system consisting of Kodak 2496 film exposed to CPA and processed for 30 minutes at 90°F with constant agitation in CPA-1 developer. Film speed for TRI-X is 400 while the CPA system is rated at 1600. Maximum resolution is 144 lnp/mm for the 2496, but only 57 lnp/mm for the TRI-X.

- * One photographic stop is equal to an exposure difference factor of two. Thus, eight stops would be an exposure range of 1:256. On the density-resolution graphs which follow, one log-exposure step equals three and a third stops or an exposure difference factor of ten.

FILM	DEVELOPER	CPA EXPOSURE mcs	BASE DENSITY	E.I.	GAMMA	MAX RES lnp/mm	RES LATITUDE	
							@ 200 lnp/mm STOPS	@ 400 lnp/mm STOPS
CONVENTIONAL @ 75°F, I.A.								
PAN-X	D-76, 3.75 Min	none	0.30	32	0.9	181	7*	-
PLUS-X	D-76, 3.75 Min	none	0.37	125	0.7	91	-	-
TRI-X	D-76, 5.5 Min	none	0.37	400	0.9	57	-	-
CPA HIGH RESOLUTION PHOTO SYSTEMS								
5069	CPA-1, 15 Min. 68° F, C.A.	7.9 x 10 ⁻²	0.23	50	1.6	456	13	4
5069	CPA-1, 15 Min. 68° F, C.A.	2.2 x 10 ⁻²	0.26	125	1.4	456	8	4.2
3414	CPA-1, 14 Min. 68° F, C.A.	1.3 x 10 ⁻²	0.25	160	1.4	456	16	5.3
VTE PAN	CPA-1, 15 Min. 68° F, C.A.	1.05 x 10 ⁻²	0.30	250	1.2	456	6	2
3400	D-19, 30 Min. 90° F, C.A.	1.58 x 10 ⁻²	0.33	160	2.2	203	0.3	-
2498	CPA-1, 4 Min. 90° F, C.A.	2 x 10 ⁻³	0.32	1000	0.9	161	5.7*	-
2496	CPA-1, 30 Min. 90° F, C.A.	4 x 10 ⁻³	0.38	1600	1.45	144	4*	-

* Resolution latitude at 100 lnp/mm

TABLE 1, CONVENTIONAL VERSUS CPA HIGH RESOLUTION PHOTO SYSTEMS

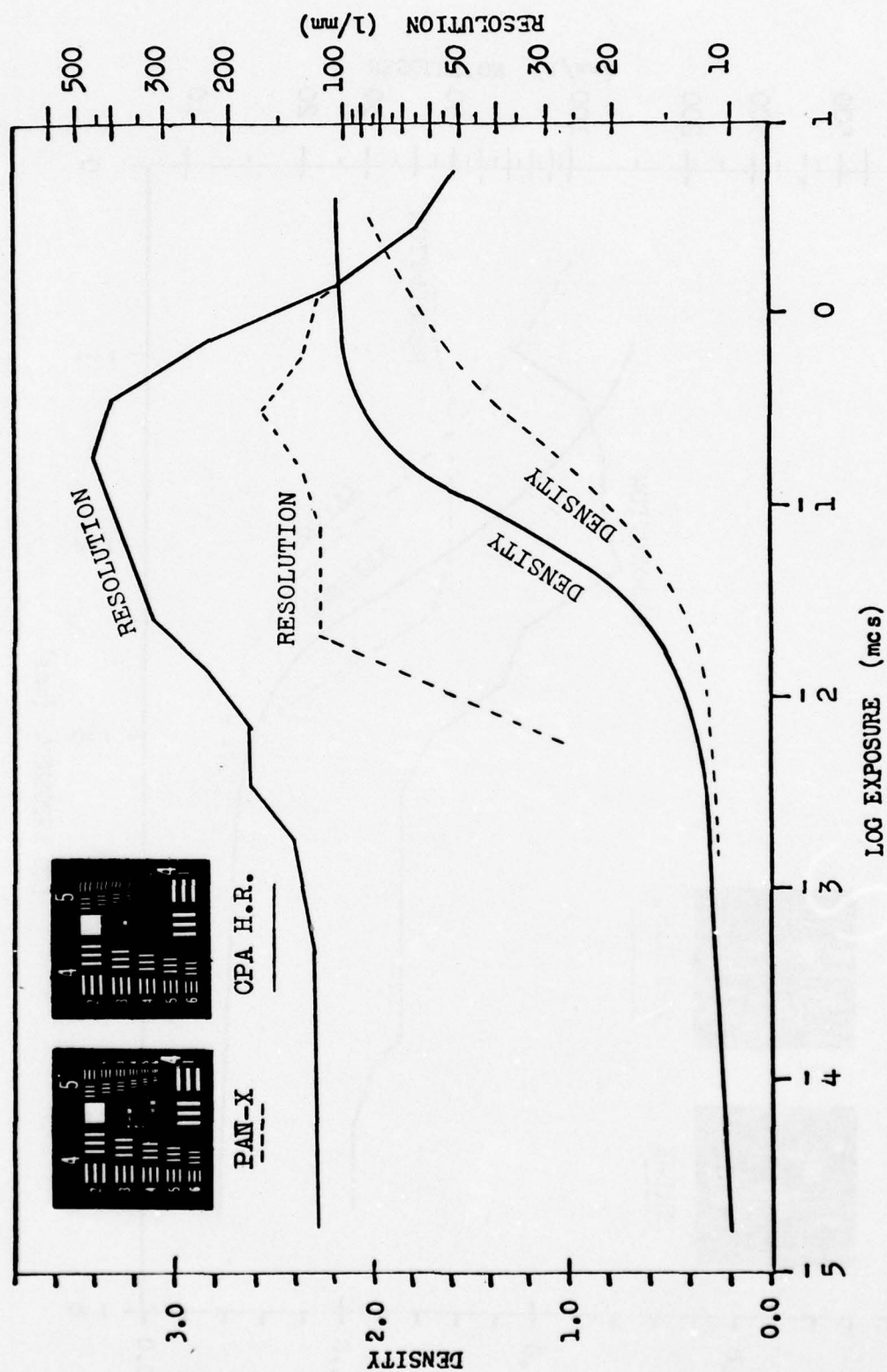


FIGURE 1, CONVENTIONAL PAN-X VS CPA HIGH RESOLUTION PHOTO SYSTEM
 (Inset: 25X Enlargements of USAF 1951 Test Targets)

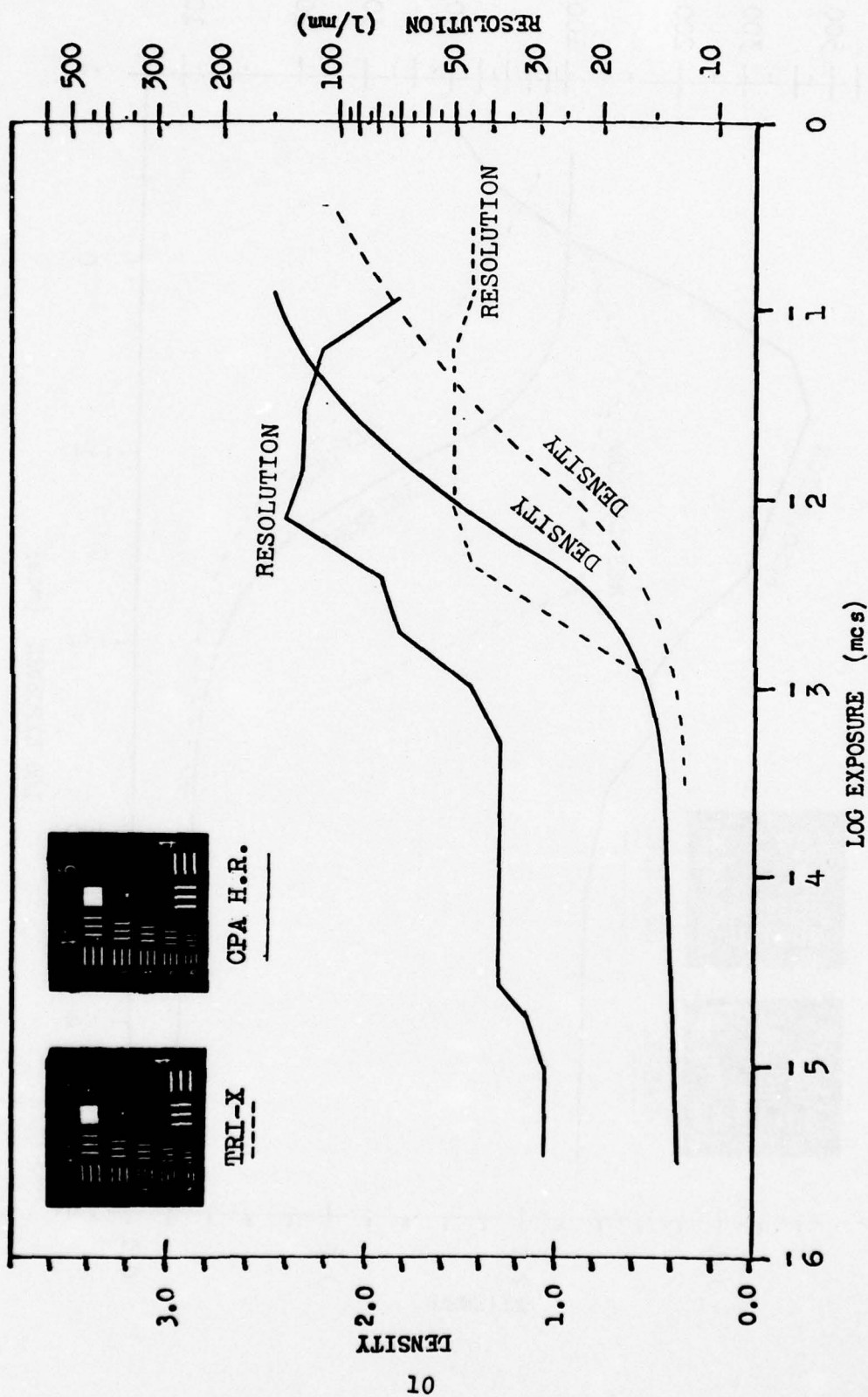


FIGURE 2, CONVENTIONAL TRI-X VS CPA HIGH RESOLUTION PHOTO SYSTEM
(Inset: 25X Enlargements of USAF 1951 Test Targets)

B. EXPERIMENTS WITH 5069 FILM

Since the objective of the High Resolution CPA Study was in part prompted by results obtained with Kodak 5069 High Contrast Copy film processed in a specially formulated developer called "Push Pota"⁵, this combination was chosen as a logical starting point in our investigations for the optimum high resolution system.

Undoubtedly, some investigator spent much time and effort in formulating the original "Push Pota" developer and determining the correct processing parameters of time, temperature and agitation required for obtaining useable continuous tone images from a film designed for an entirely different purpose. However, one, in general, might ask if this 5069/"Push Pota" system was indeed optimized, and in particular was it optimized for use with CPA aided exposures.

In order to investigate this film/developer/CPA combination in a thorough fashion, a full two-level factorial experiment was designed to investigate the four key factors in the system. A full factorial design involving four parameters at two levels required that sixteen (4 to the 2 power) tests be made and analyzed. An inspection of the formula for CPA-1 (Push Pota) developer was made to ascertain which ingredients would most likely affect base fog level, film speed, gamma and resolution. The factors finally chosen for this first experiment were the concentrations of the two developing agents, viz. Graphidone A and Hydroquinone, the concentration of the restrainer, Potassium Bromide, and the processing time at 90°F .

⁵ The origin of the "Push Pota" name is unknown. A Pota developer consisting of sodium sulfite and phenidone was devised by Ms. M. Levy of U. S. Army/ECOM several years ago. This Pota formula was designed to produce extended range development on Aerial Reconnaissance films. Unfortunately, the two are often confused. In an effort to end this confusion, we have renamed the "Push Pota" formulation CPA-1. We will use this new designation throughout the remainder of this report.

CPA-1 (PUSH POTA) DEVELOPER FORMULATION

SODIUM SULFITE	379	gram
GRAPHIDONE A	.76	gram
HYDROQUINONE	19	gram
BORAX	11.4	gram
BORIC ACID	13.3	gram
POTASSIUM BROMIDE (KBr)	3.8	gram
SODIUM BISULFITE	.76	gram
WATER TO MAKE	1	gallon

Each of these factors was considered at two levels: Initially these levels were chosen such that they encompassed the values that existed in the original system. Development times of 15 and 25 minutes were chosen to bracket the original 18 minutes. The concentrations of the three chemical ingredients were as follows: Graphidone A, 0.64 and 0.96 grams/gallon; Hydroquinone, 16 and 24 grams/gallon; and Potassium Bromide, 3.2 and 4.8 grams/gallon.

Using the basic CPA-1 developer, substituting the concentrations stated above, samples were prepared for testing at the two times listed. Sixteen test films, each consisting of two control exposures and four CPA exposures (at different levels) were made on our CPA sensitometer. These films were developed separately in one of the eight sample formulations at 90°F with continuous agitation for either 15 or 25 minutes processing time. The exposed and processed test films were measured and examined for the following output factors: 1) base fog level; 2) minimum density; 3) maximum density; 4) film speed; 5) gamma, and 6) maximum resolution. The data from these sixteen tests was analyzed for single factor effects and two factor interactions, i.e. what effect did increasing the concentration of the three chemical ingredients or increasing the processing time have on the sensitometric parameters of interest when these four factors were considered singly or when paired with one of the other factors. Ordinarily, one would find that the prevalent effect could be traced to a single factor or at most to a combination of two factors.

As a result of this analysis of single factor effects and two factor interactions, two factors were found to be the most prominent. They were the Graphidone A concentration and the processing time. It was found that increasing the Graphidone A concentration from 0.64 to 0.96 gram/gallon lowered the base fog level, increased the maximum resolution, decreased the gamma and

had virtually no effect on film speed. Increasing the processing time from 15 to 25 minutes raised the base fog level, (about the extent that Graphidone decreased it), increased maximum resolution, decreased the gamma slightly and greatly increased the film speed. Two factor interactions involving Potassium Bromide and the two developing agents showed that simultaneously increasing the concentration of each produced a decrease in film speed and maximum resolution.

Based on these findings a second experiment was designed which involved only two factors, viz. Graphidone A and processing time. Except for the Graphidone A concentrations which were chosen to be 1.02 and 2.04 grams per gallon, the basic formula was used. The process times were again 15 and 25 minutes at 90°F with continuous agitation. The two developer variations were prepared and four test rolls of film were exposed with both the control and CPA series as had been done previously. After processing, the film samples were measured and the resulting data analyzed. Our analysis indicated that the best film speed and resolution were obtained at the lower concentration levels of Graphidone A thus indicating that we had increased the Graphidone concentration beyond the optimum. The prolonged development times gave the best results in this experiment, as they had in our initial experiment.

A third experiment was designed which considered the original four factors of Graphidone A, Hydroquinone and Potassium Bromide concentrations, as well as processing time. Reviewing the results of our first experiment we decided on the following: processing times at 90°F would be 15 and 30 minutes; concentration of Graphidone A, 0.96 and 1.92 grams/gallon; concentration of Hydroquinone, 24 and 32 grams/gallon; and the concentration of Potassium Bromide, 1.6 and 3.2 grams/gallon. Proceeding as we had for experiment number one, the developer variations were prepared, test films exposed and processed and the data extracted, tabulated and analyzed.

Our conclusion after examining the above data was that CPA-1 Variation #5 gave the best results considering all the sensitometric parameters. CPA-1 Variation #7 provided the greatest film speed, but at a sacrifice in resolution characteristics. CPA-1 Variation #5 is CPA-1 with the following substitutions: Graphidone A, 0.96 grams/gallon; Hydroquinone, 24 grams/gallon and Potassium Bromide, 3.2 grams/gallon. CPA-1 Variation #7 is the same as # 5 with the Hydroquinone concentration increased to 32 grams/gallon.

It should be noted that these first three designed experiments with Kodak 5069 film and CPA-1 developer were conducted using our normal high contrast resolution target reticle in the sensitometer. It's resolution capability is limited to 228 line pairs per millimeter. In addition, it was discovered that due to a misaligned pressure platen in our sensitometer, some of the early

resolution values obtained with 5069 were misleading because the film was not held in intimate contact with the test reticle. The pressure platen was aligned properly and a new higher resolution test reticle was procured to evaluate this system at level up to 456 line pairs per millimeter.

One anomaly that was never resolved was the behavior of CPA-1 Variation #7 that initially gave the best film speed with 5069 film at a processing temperature of 90°F. When tests were conducted using the high resolution reticle, Variation #7 produced elevated fog levels of 0.4 density units or greater in three separately prepared mixes. Consequently, it was unusable at 90°F, but could be employed at 68°F.

Through a processing error in one of our test runs with CPA-1 and 5069 film, it was discovered that increased resolution latitude at 200 line pairs per millimeter could be achieved at the sacrifice of film speed if the temperature of the developer were kept at 68°F instead of the usual 90°F. Agitation was continuous.

Table 2 below summarizes the results obtained with Kodak 5069 film and CPA-1 developer including Variations #5 and #7 at both 68°F and 90°F with and without CPA.

Figures 3 through 7 show the density/fog exposure and resolution/log exposure curves for Kodak 5069 film processed in CPA-1 developer and its variations at 68°F and 90°F. The dashed curves represent a primary control exposure with no CPA light added, while the solid lines show the same primary exposure augmented by CPA light.

FILM	DEVELOPER	CPA EXPOSURE mcs	BASE DENSITY	SPEED ¹ @ 0.1 ABOVE FOG	GAMMA	MAX RES lmp/mm	RES LATITUDE	
							@ 200 lmp/mm STOPS	@400 lmp/mm STOPS
5069	CPA-1 15 Minutes 68°F C.A.	none 7.9 x 10 ⁻²	0.06 0.23	12 160	2.6 1.6	456 456	5.7 13.0	2.5 4.0
5069	CPA-1 Var 5 15 Minutes 68°F C.A.	none 7.9 x 10 ⁻²	0.04 0.16	10 80	2.65 1.65	456 456	5.7 10.0	3.0 4.0
5069	CPA-1 Var 7 15 Minutes 68°F C.A.	none 5.0 x 10 ⁻²	0.10 0.24	20 160	2.1 1.6	456 456	6.5 10.0	2.0 4.0
5069	CPA-1 15 Minutes 90°F C.A.	none 2.2 x 10 ⁻²	0.12 0.24	40 250	2.0 1.55	456 456	5.6 6.6	2.0 2.0
5069	CPA-1 Var 5 15 Minutes 90°F C.A.	none 4.0 x 10 ⁻²	0.12 0.33	32 160	1.95 1.4	456+ 456+	6.6 8.0	2.5 4.2

¹ It is recommended that these film speeds be used ONLY as trial settings in determining the correct exposure index for a particular application. See Section V A.

TABLE 2, 5069 HIGH RESOLUTION TEST RESULTS

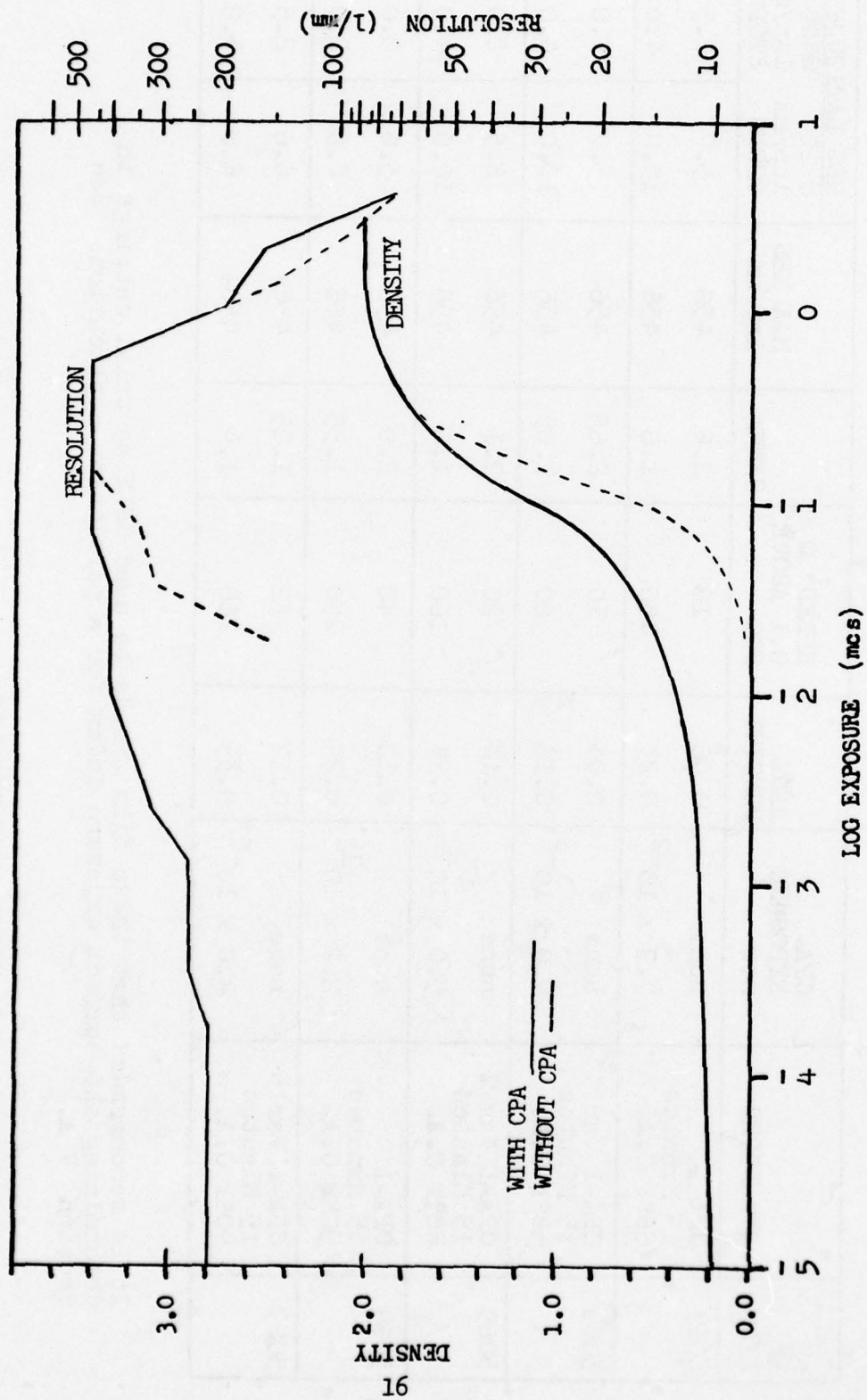


FIGURE 3, 5069 FILM, CPA-1 DEVELOPER, 15 MINUTES @ 68°F, C.A.

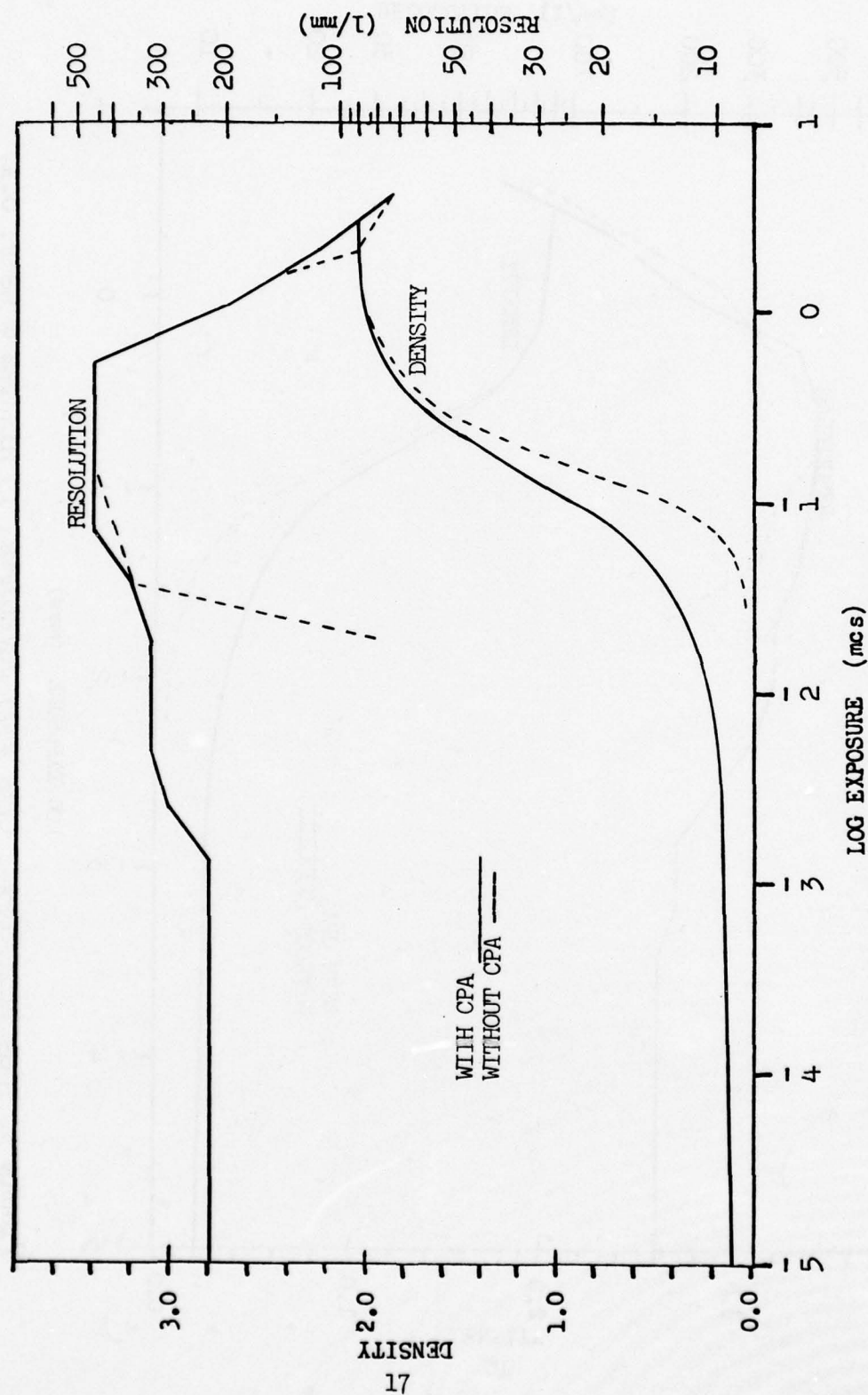


FIGURE 4, 5069 FILM, CPA-1 (VAR # 5) DEVELOPER, 15 MINUTES @ 68°F C.A.

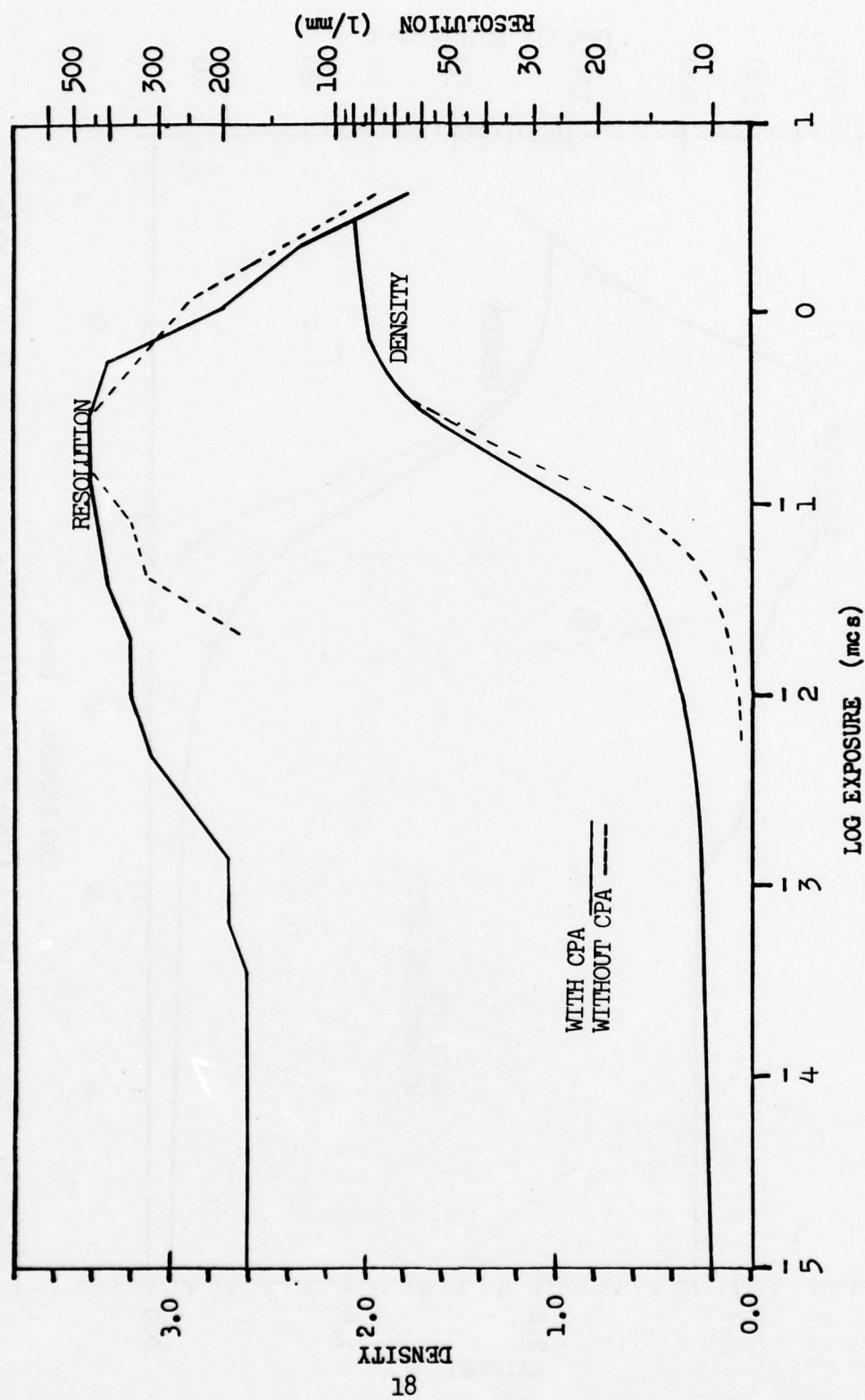


FIGURE 5, 5069 FILM, CPA-1 (VAR # 7) DEVELOPER, 15 MINUTES @ 68°F, C.A.

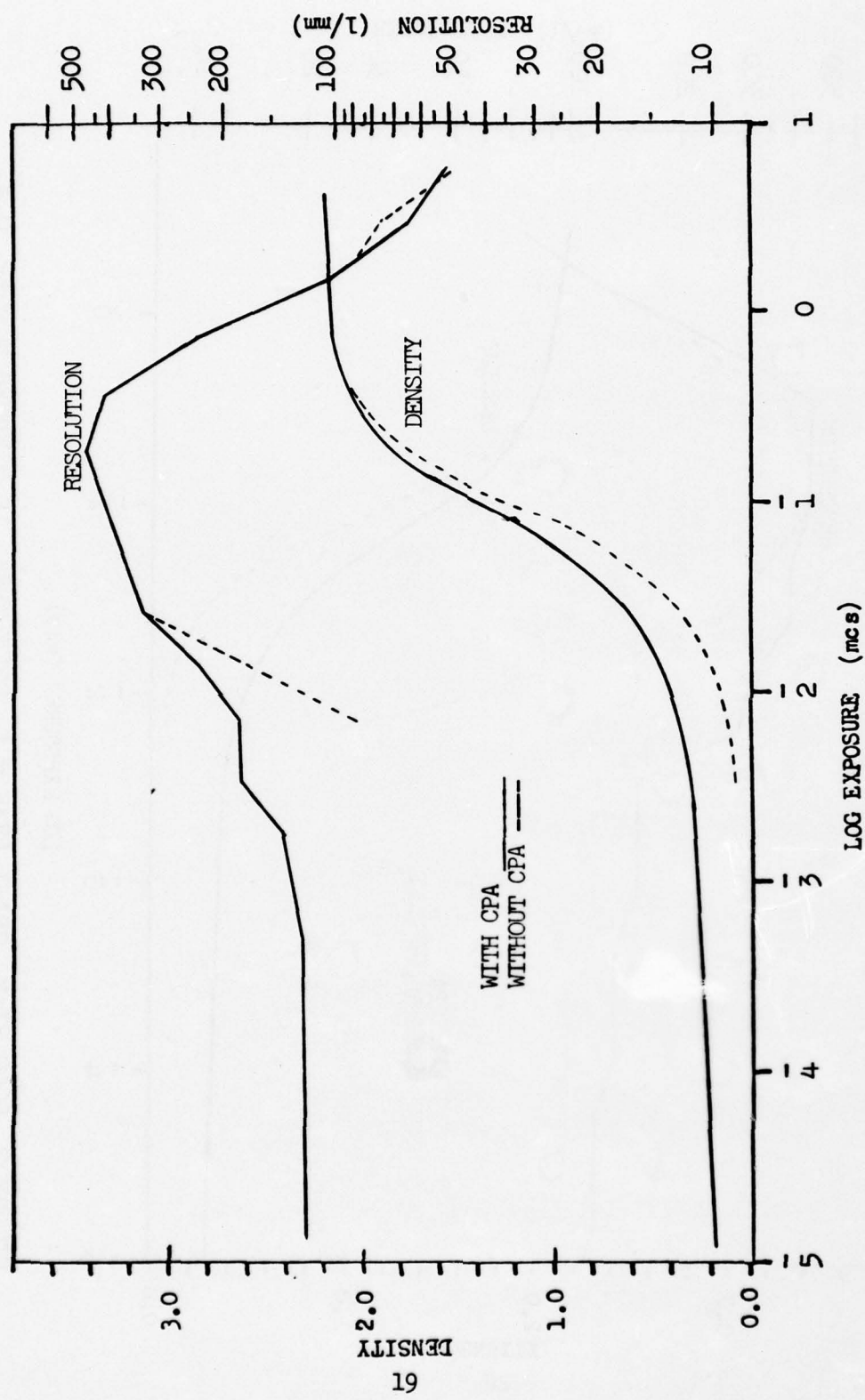


FIGURE 6, 5069 FILM, CPA-1 DEVELOPER, 15 MINUTES @ 90°F, C.A.

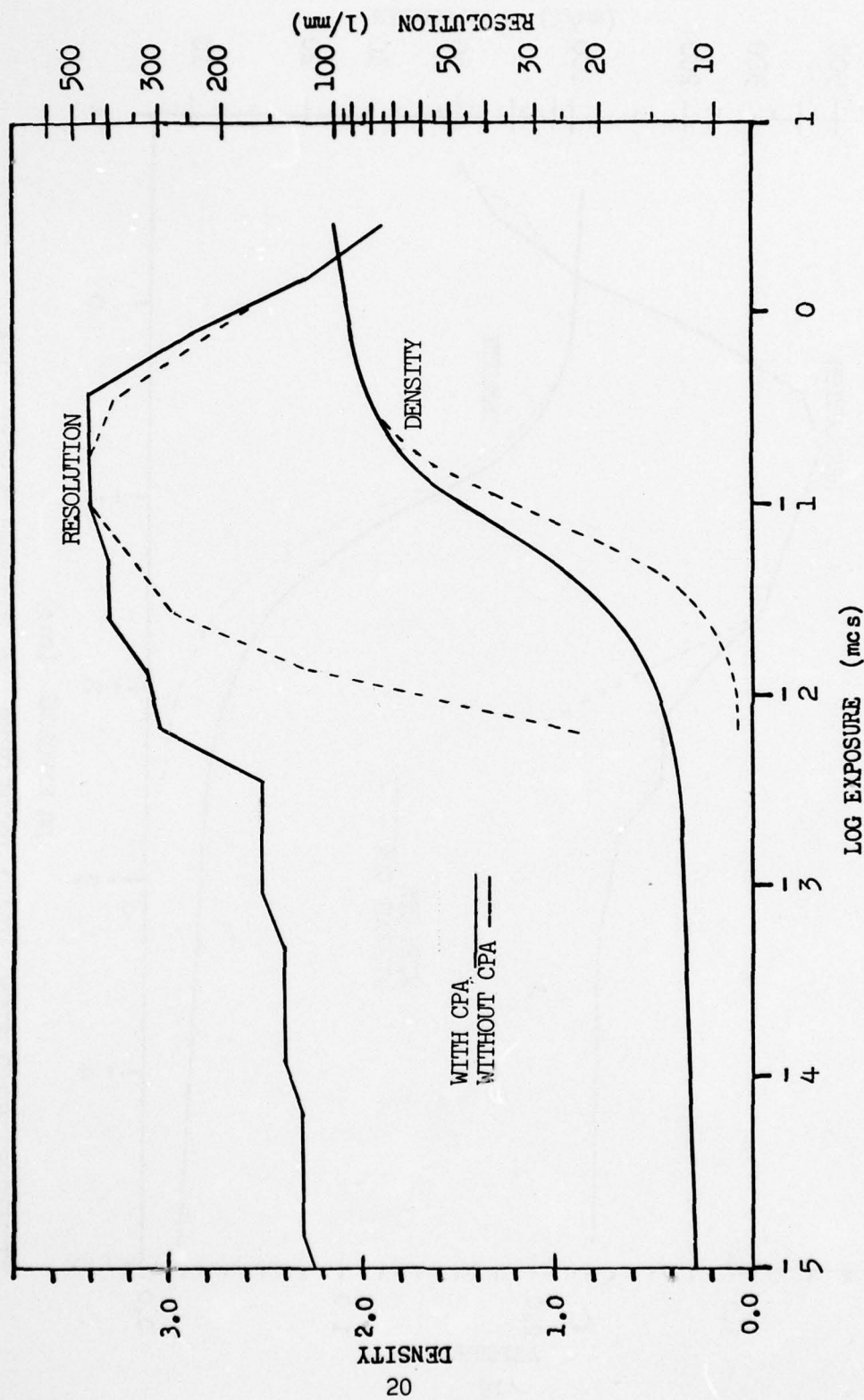


FIGURE 7, 5069 FILM, CPA-1 (VAR # 5) DEVELOPER, 15 MINUTES @ 90°F, C.A.

C. OTHER 400⁺ lnp/mm FILM SYSTEMS

Among the various film emulsions investigated under this effort, two films in addition to Kodak 5069 offered high contrast peak resolution values above 400 line pairs per millimeter. One was Kodak 3414 Aerial Reconnaissance film and the second was the H & W Control VTE Pan.

The Kodak recommended process for 3414 is D-19 at 68°F. Our initial high resolution testing began with this manufacturer recommended developer. Peak resolution values were found to exceed the 456 lnp/mm limit of our test reticle and a resolution latitude at 400 lnp/mm was found to be one and two-thirds stops with the control and three and two-thirds stops with CPA augmented exposures. At 200 lnp/mm the latitude for the control and CPA exposures were 6 and 15 stops, respectively. At this 200 lnp/mm resolution level, the 3414/D-19/CPA combination provided two additional stops of latitude⁶. The gamma was comparable in all cases at 1.6.

⁶ It should be noted that while the 3414 film yielded resolution results equal to or greater than that of its thicker base cousin 5069, the additional capability cannot be attained without extreme effort. First, 3414 film is coated on a thin 2.5 mil base that makes handling in the dark a seemingly impossible task. Only slight pressure is required to flatten the film between the fingers with resultant half-moon shaped stress marks becoming obvious on the processed film. The thin base also required altering the pressure platen on our sensitometer in order to achieve intimate contact with our resolution test reticle. Without this adjustment, peak resolution values did not even approach 200 lnp/mm. The second potential problem area to arise with this emulsion is the fact that it is coated on a clear base without the usual antihalation layer. What this means is that care must be taken to have a platen surface that is uniform and non-reflective to prevent halos from framing around bright spots in the image. It also means loading and unloading cameras in total darkness because this clear base is an efficient light pipe that does not seal the opening of the typical 35mm film cassette. Another potential problem area can be very serious if one is unaware of what is happening. The typical film channel that exists in 35mm cameras is about 7.0 mils deep, or almost 3 times as great as the thickness of 3414. That means that 3414 film can wander back and forth, front to back in a typical 35mm camera over a 4.5 mil depth. Unfortunately, one must maintain the focus on the film to less than 1.0 mil if the performance level of film is to be of value. This is not done easily with existing cameras. By way of comparison, 5069 is coated on a 5.5 mil base that has very little space to wander back and forth. It also has an integral antihalation layer that is removed during processing.

Since the results with 3414 and D-19 were encouraging, tests were initiated with CPA-1 to see if any gain in film speed was possible. Our first series was conducted at 90°F with continuous agitation for 15 minutes in the CPA-1 developer. The resultant test strips were severely fogged. Reducing the time and agitation did not appreciably lower the high fog levels. The temperature was next reduced to 68°F and a series of tests made at various times and with intermittent and continuous agitation procedures. The best combination of processing parameters was found to be 14 minutes at 68°F with 5 second agitation every 30 seconds.

While the control speed was comparable to that achieved with D-19 processing, the speed attained with CPA aided exposures was 650 or double that provided by D-19. The overall gamma with CPA was reduced from 1.6 to 1.4, consequently the exposure latitude was improved. Peak resolution was still in excess of 456 lnp/mm, but the resolution latitude was significantly increased. At 400 lnp/mm the latitude with CPA-1 and CPA was five and one-third stops, a gain of better than one and a half stops over D-19 development. At the 200 lnp/mm level, resolution latitude was found to be 16 stops, one better than D-19 on 3414 and three better than the best combination on Kodak 5069 film.

Our results with 3414 film in both CPA-1 and D-19 developers are summarized in Table 3. Comparison D-log E and R-log E sensitometric curves can be found in Figures 8 and 9 for CPA-1 and D-19, respectively.

The next film system to be evaluated for its high resolution potential was a product of the H & W Company, Control VTE PAN⁷.

Results obtained with the recommended 4.5 control developer were unimpressive. See Table 3 and Figure 10. Tests were then conducted with the VTE PAN film and CPA-1 developer. Results at 90°F showed the same high fog levels as that achieved earlier on 3414, so the development temperature was reduced to 68°F and a new test series conducted. The best results were achieved at 15 minutes with constant agitation. A film speed of 8000 was produced on the VTE PAN film in combination with CPA-1 developer and CPA aided exposure. Although the film had only a two stop

⁷ During the course of our experimentation with this emulsion, we were alerted to the fact that H & W would soon be discontinuing the current VTE PAN. In discussions with Mr. Harold Holden of the H & W Company, he confirmed the fact that the current VTE PAN (made by Agfa-Gevaert) was being phased out to be replaced by an emulsion made in this country by 3M Company. It's characteristics in the toe portion, where we are most interested, would be essentially unaltered. All anticipated changes would be in the shoulder of the characteristic curve. Hence, our test results should be valid for the new film.

resolution latitude at 400 lnp/mm, it did have 13 stops at the 200 lnp/mm level. Our results indicated that VTE PAN film in combination with CPA-1 developer and CPA can be applied to high resolution photography. The various parameters for VTE PAN are listed in Table 3 and Figure 11 shows the full sensitometric curves for VTE PAN and CPA-1 development.

FILM	DEVELOPER	CPA EXPOSURE mcs	BASE DENSITY	SPEED ¹ @ 0.1 ABOVE FOG	GAMMA	MAX RES lmp/mm	RES LATITUDE	
							@ 200 lmp/mm STOPS	@ 400 lmp/mm STOPS
3414	CPA-1 14 Minutes 68°F I.A.	none 1.3×10^{-2}	0.14 0.25	32 650	1.9 1.4	456 456	6 16	3 5.3
3414	D-19 8 Minutes 68°F I.A.	none 1.3×10^{-2}	0.10 0.24	32 320	2.2 1.6	456 456	6 15	1.7 3.7
H & W VTE PAN	H & W 4.5 Control 9 Min 68°F I.A.	none	0.06	80	0.6	114	--	---
H & W VTE PAN	CPA-1 15 Minutes 68°F C.A.	none	0.08	100	1.8	456	6	2
H & W VTE PAN	CPA-1 15 Minutes 68°F C.A.	1.05×10^{-2}	0.30	8000	1.2	456	13	2

25

¹ It is recommended that these film speeds be used ONLY as trial settings in determining the correct exposure index for a particular application. See Section V A.

TABLE 3, 3414 and H & W VTE PAN HIGH RESOLUTION TEST RESULTS

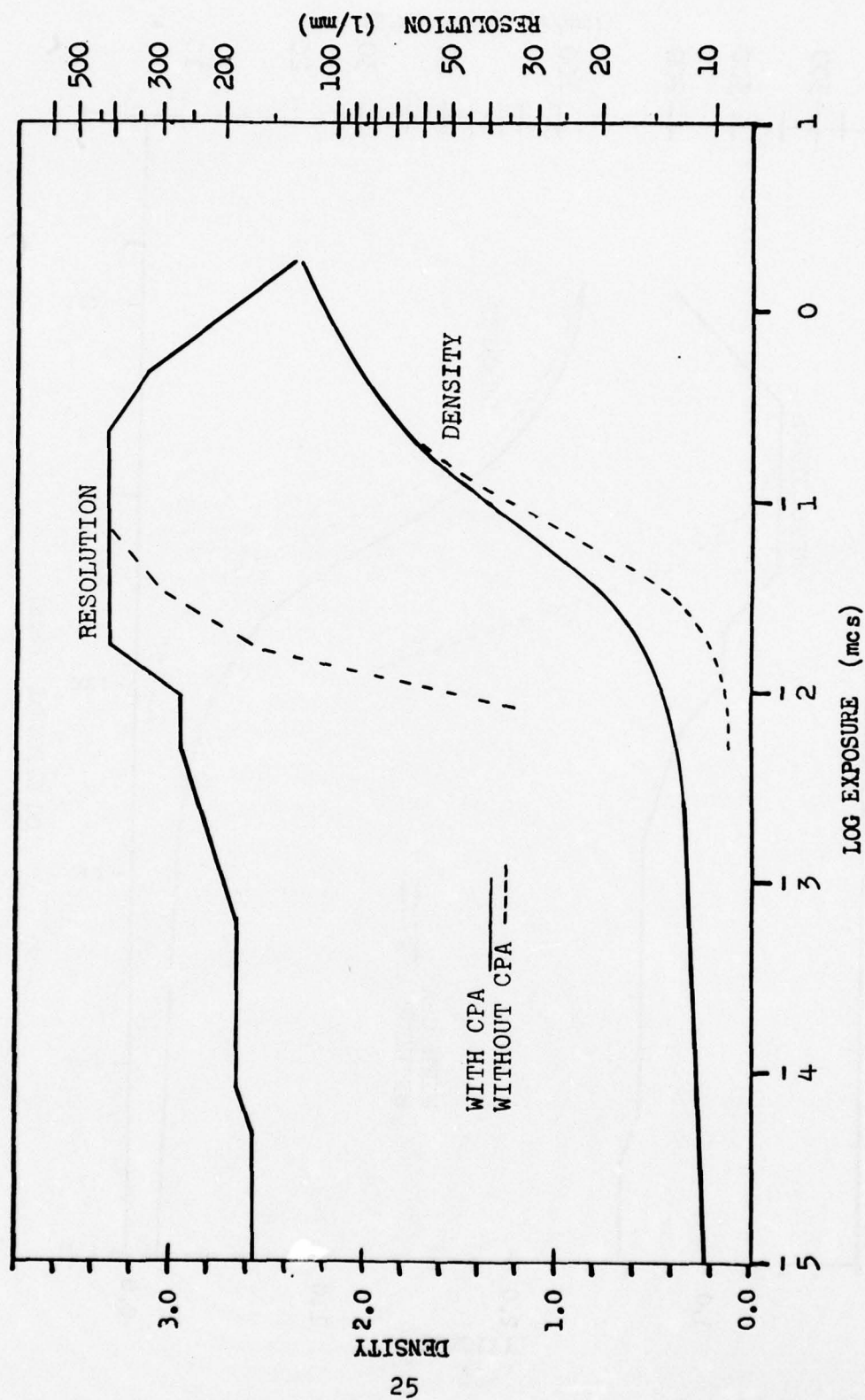


FIGURE 8, 3414 FILM, CPA-1 DEVELOPER, 14 MINUTES @ 68°F, I.A.

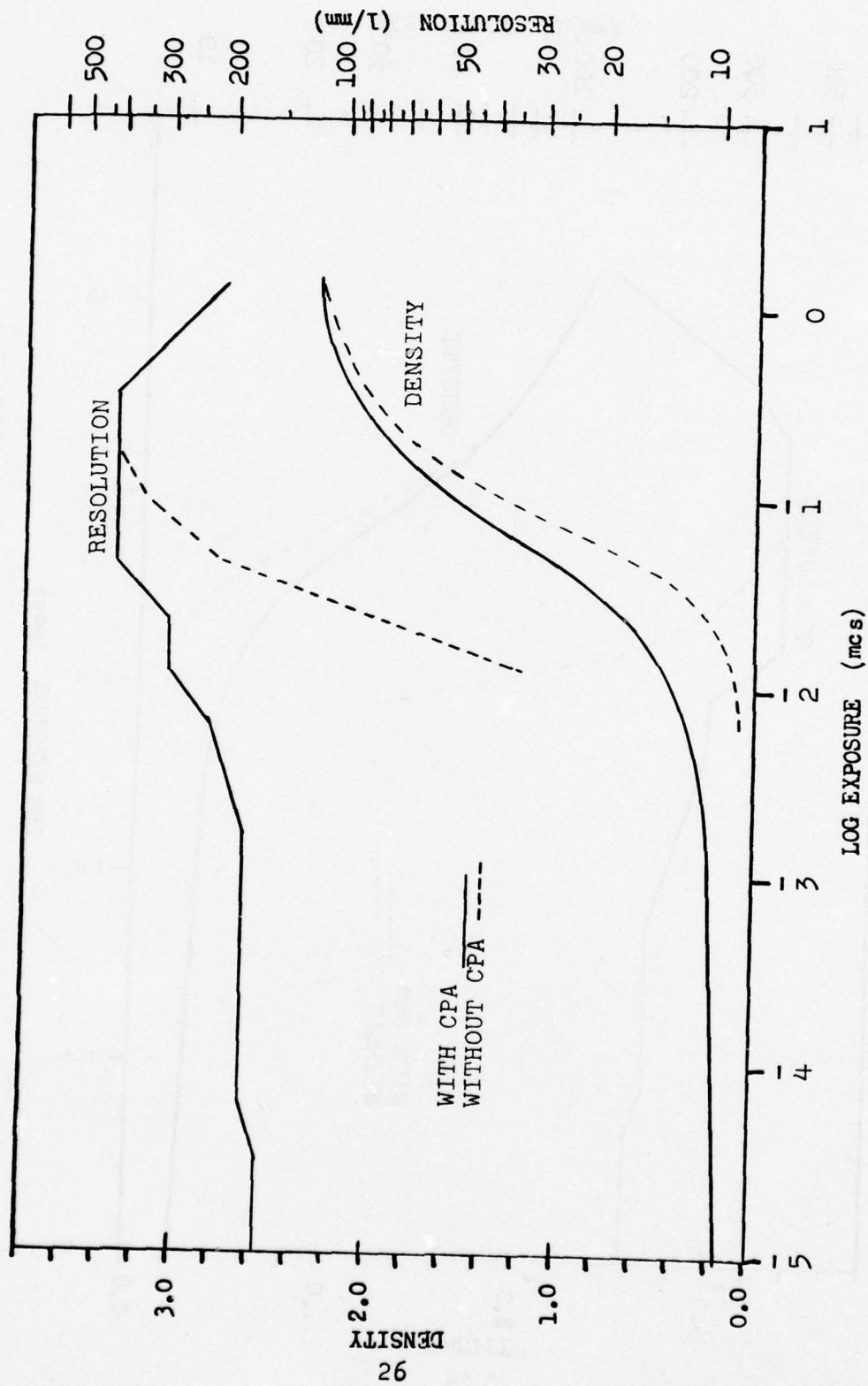


FIGURE 9, 3414 FILM, D-19 DEVELOPER, 8 MINUTES @ 68°F, I.A.

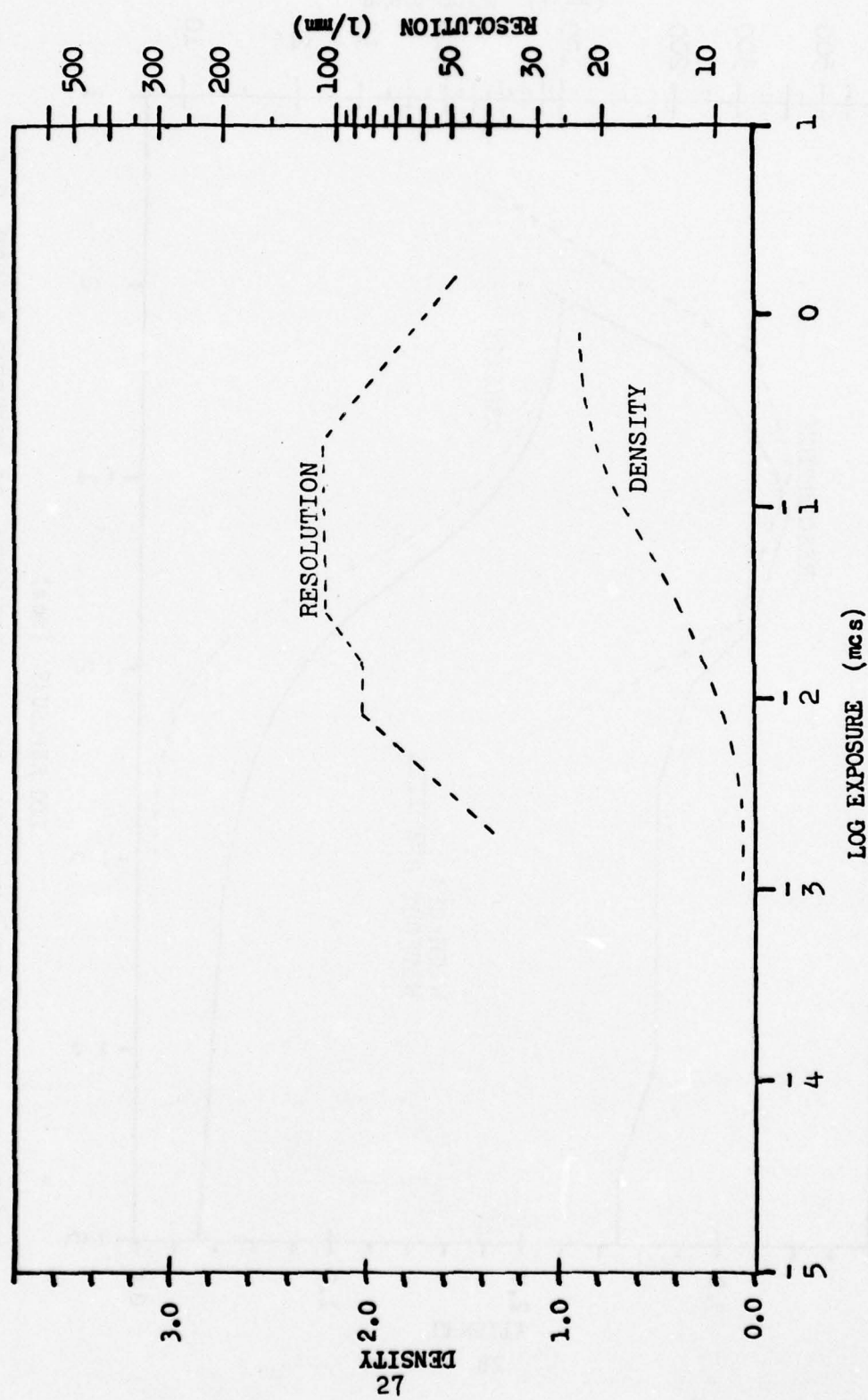


FIGURE 10, H & W VTE PAN FILM, H & W 4.5 CONTROL DEVELOPER, 9 MINUTES @ 68°F, I.A.

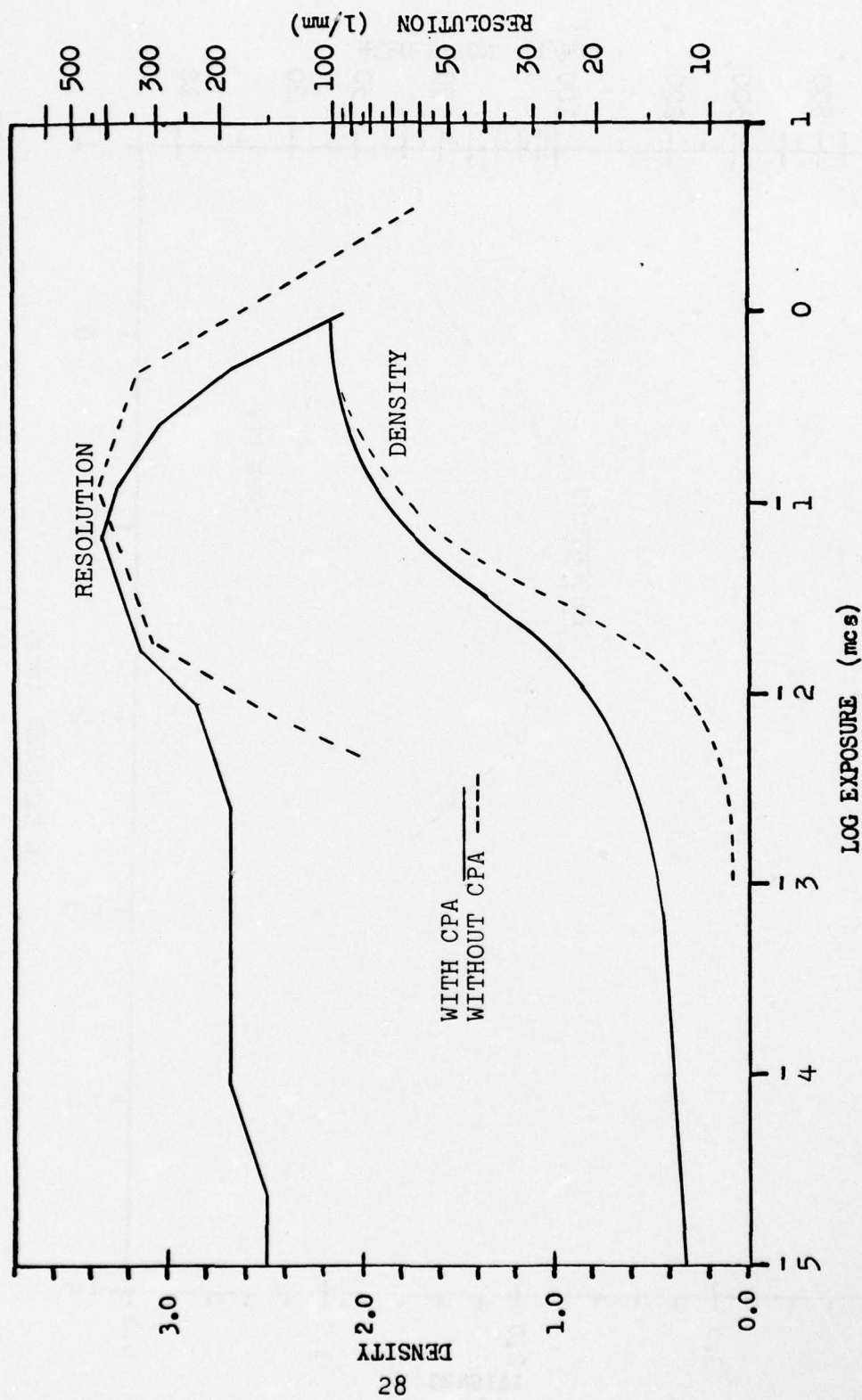


FIGURE 11, H & W VTE PAN FILM, CPA-1 DEVELOPER, 15 MINUTES @ 68°F, C.A.

D. 200⁺ lnp/mm FILM SYSTEMS

During the course of this effort, a search was made for other film systems that could improve the resolution capabilities within various speed classes. Two films that we thought might be high resolution substitutes for Kodak's PLUS-X (E.I. 125) when used in conjunction with CPA aided exposure were Kodak 3400 Aerial and 5060 Recordak AHU Documentation films.

Tests were initiated on 3400 using the recommended D-19 developer. Our best results were obtained at 90°F with a five minute development time using constant agitation. This provided a control speed of 50 and CPA speed of 400. Peak resolution was just slightly over 200 lnp/mm. The gamma in both control and CPA exposures remained above 2.0, a level that is too high for general continuous tone ground photography. These results are summarized in Table 4. Figure 12 shows the sensitometric and resolution curves for the best 3400/D-19 film-developer combination.

Although the resolution characteristics were poorer than we had expected, we decided to conduct additional tests with 3400 using our CPA-1 developer. Test rolls were prepared by exposing the 3400 film with control and varying levels of CPA-aided exposures on our sensitometer. Processing in CPA-1 developer was carried out at 90°F with continuous agitation for times ranging from 10 to 30 minutes. Best results were obtained at 20 minutes. The control speed was increased from 50 to 160 with D-19. The CPA speed did not increase in a similar fashion, but actually decreased about one-third f-stop from that provided by D-19 development. Peak resolution and resolution latitude at 200 lnp/mm were improved slightly with CPA-1, but the latitude at 100 lnp/mm with CPA was about half that provided by D-19 processing. Gamma was also increased to 2.8 (and above) which is undesirable. The test results for the 20 minute CPA-1 processing are summarized in Table 4 and the curves shown in Figure 13.

It was concluded that while 3400 may have application to some specific applications in ground based photography, its high gamma limits its usefulness in general and is therefore not recommended. Further testing with this film was cancelled.

Experiments with Kodak 5060 were initiated using the recommended D-19 developer at temperatures from 68 to 90°F and processing times ranging from 5 to 20 minutes. The best results were obtained at 90°F for 15 minutes with constant agitation. A control speed of 20 was increased to 160 by CPA aided exposure. Peak resolution was 228 lnp/mm in each case. Resolution latitude at 200 lnp/mm was 4.6 stops for the control and 6.3 stops with CPA. These results are summarized in Table 4 and the curves shown in Figure 14. Further testing with this film was abandoned because better speed and resolution characteristics were already available through the use of CPA on Kodak 5069 or 3414 films.

FILM	DEVELOPER	CPA EXPOSURE mcs	BASE DENSITY	SPEED ¹ @ 0.1 ABOVE FOG	GAMMA	MAX RES lnp/mm	RES LATITUDE	
							@ 100 lnp/mm STOPS	@ 200 lnp/mm STOPS
3400	CPA-1 20 Minutes 90°F C.A.	none	0.32	160	3.0	228	4	2
		6.3 x 10 ⁻³	0.44	320	2.8	203	4.2	.3
3400	D-19 5 Minutes 90°F C.A.	none	0.20	50	2.6	181	4.3	-
		1.58 x 10 ⁻²	0.33	400	2.2	203	8.5	.3
5060	D-19 15 Minutes 90°F C.A.	none	0.18	20	2.25	228	---	4.6
		4.0 x 10 ⁻²	0.26	160	1.10	228	---	6.3

¹ It is recommended that these film speeds be used ONLY as trial settings in determining the correct exposure index for a particular application. See Section V A.

TABLE 4, KODAK 3400 and 5060 TEST RESULTS

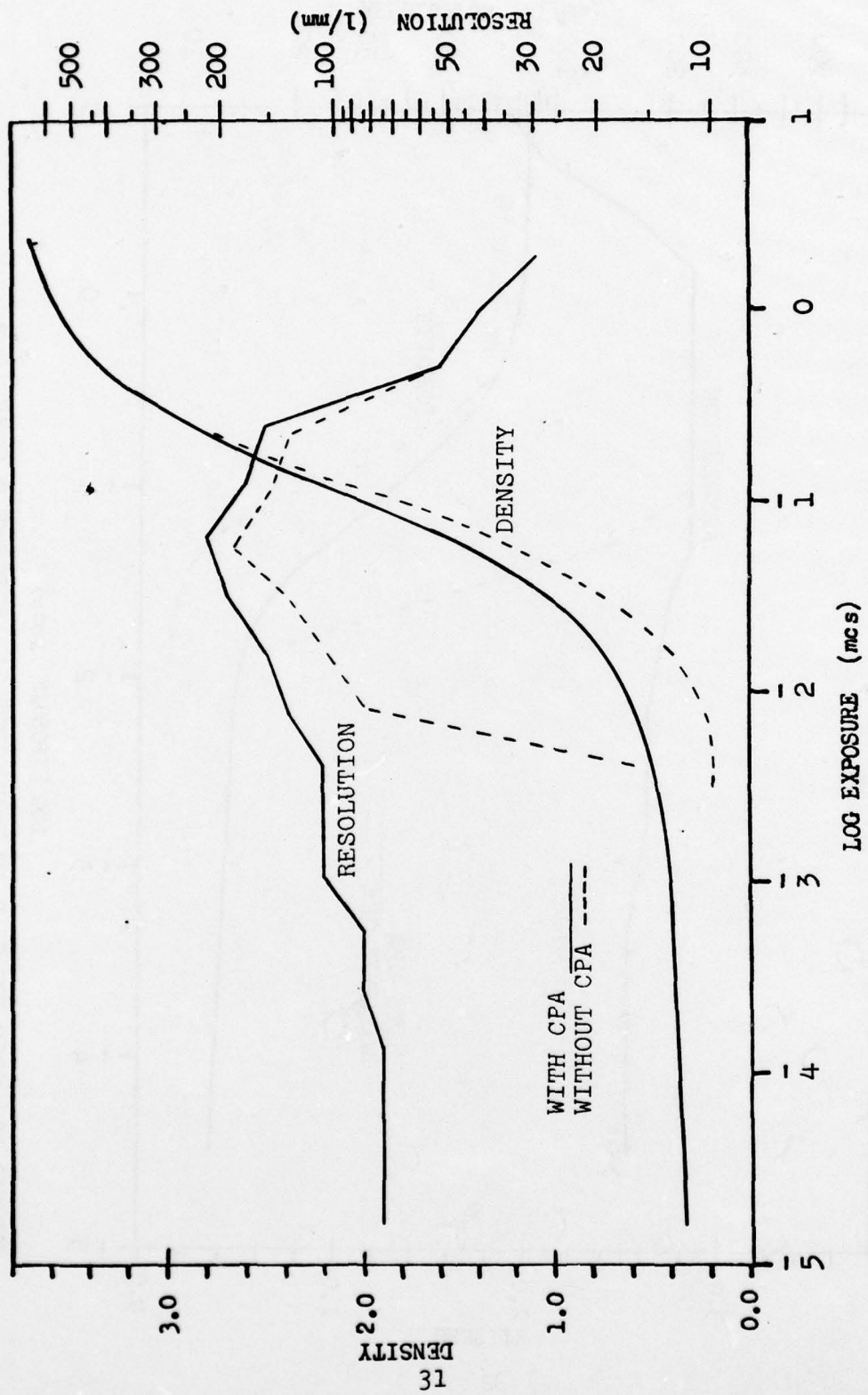


FIGURE 12, KODAK 3400 FILM, D-19 DEVELOPER, 5 MINUTES @ 90°F, C.A.

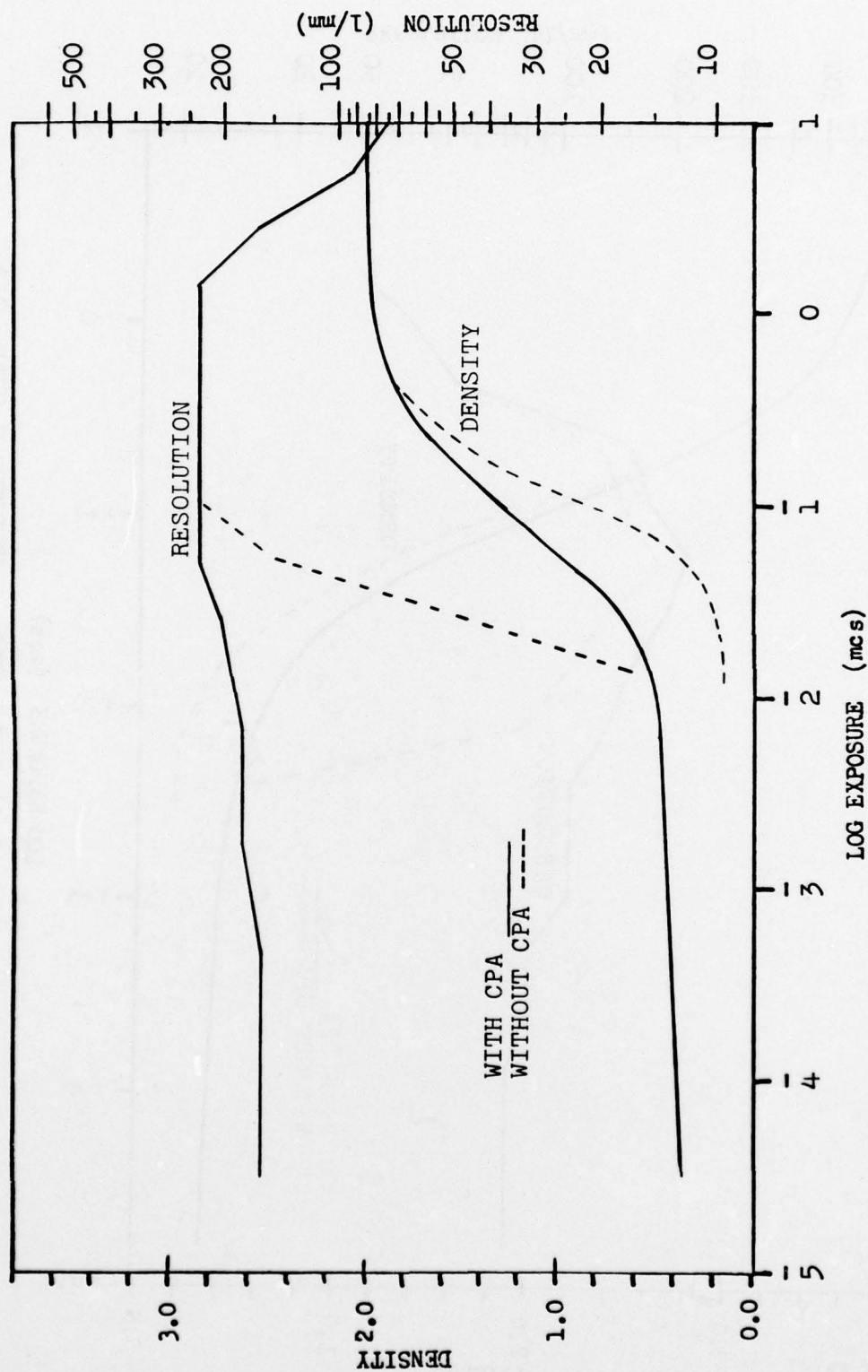


FIGURE 13, 5060 FILM, D-19 DEVELOPER, 15 MINUTES @ 90°F, C.A.

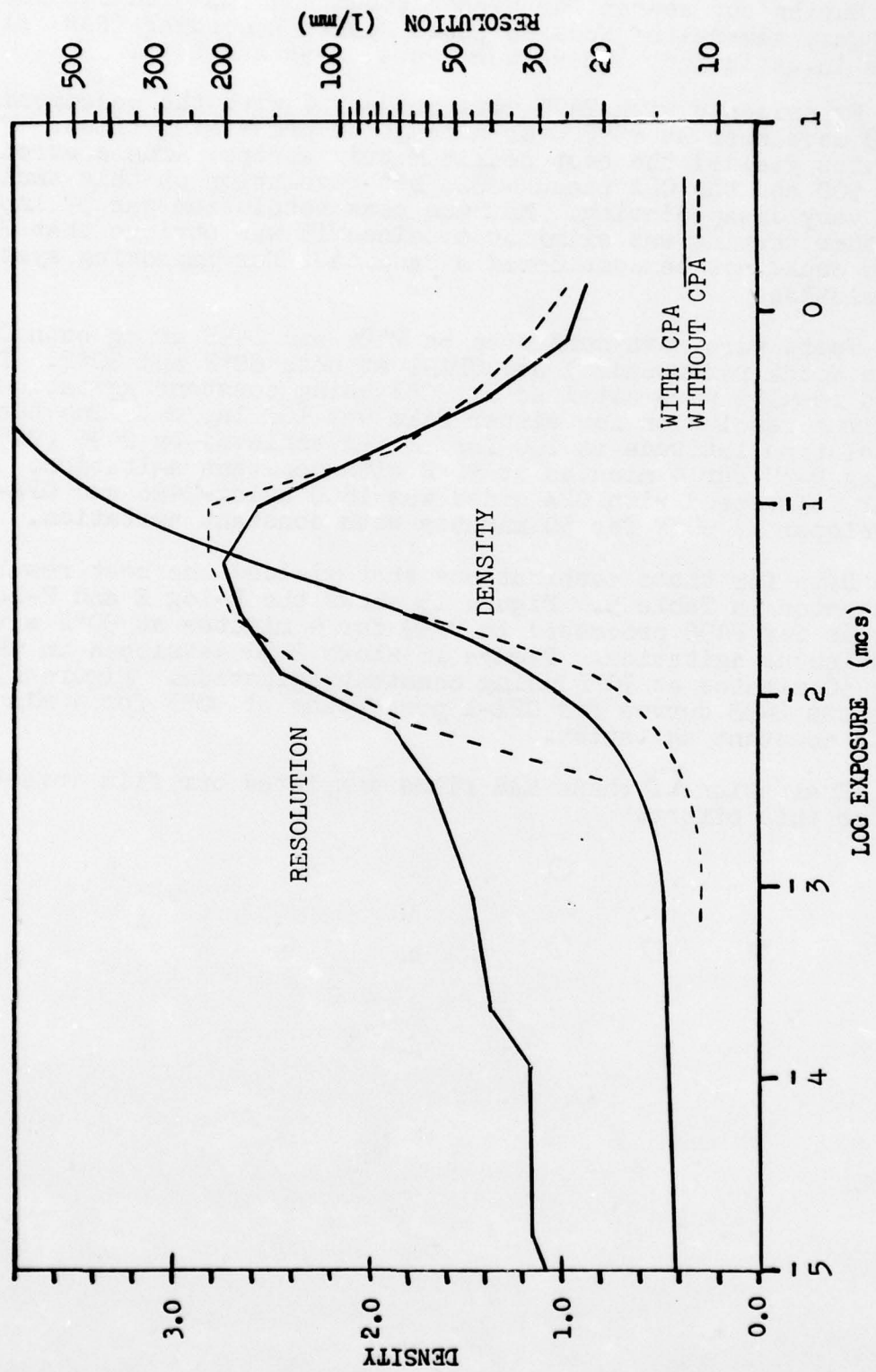


FIGURE 14, KODAK 3400 FILM, CPA-1 DEVELOPER, 20 MINUTES @ 90°F, C.A.

E. 100⁺ lnp/mm FILM SYSTEMS

During our search for higher speed and improved resolution systems, several of Kodak's Rapid Access Recording (RAR) films were investigated. These were 2479, 2496 and 2498.

Experiments with 2479 were conducted with the recommended D-19 developer at 85°F over a range of processing times. Five minutes yielded the best sensitometric strips. The control speed was 500 and the CPA speed 4000, but resolution on this emulsion was very disappointing. Maximum peak resolution was 57 lnp/mm. Further testing was eliminated, since it was obvious that 2479 film could not be considered a candidate for improving system resolution.

Tests were next conducted on 2496 and 2498 using both D-19 (the Kodak recommended) and CPA-1 at both 68°F and 90°F. The best results were attained at 90°F using constant agitation. The maximum resolution for either film was 161 lnp/mm. The best resolution latitude at 100 lnp/mm was achieved by 2496 (9.5 stops) using D-19 for 4 minutes at 90°F with constant agitation. The best film speed with CPA added was 1600 using 2496 and CPA-1 developer at 90°F for 30 minutes with constant agitation.

Data for those combinations that yielded the best results is presented in Table 5. Figure 15 shows the D-log E and R-log E curves for 2496 processed in D-19 for 4 minutes at 90°F with continuous agitation. Figure 16 shows 2496 developed in CPA-1 for 30 minutes at 90°F using constant agitation. Figure 17 depicts 2498 curves for CPA-1 processing at 90°F for 4 minutes with constant agitation.

Evaluation of these RAR films completed our film investigations under this effort.

FILM	DEVELOPER	CPA EXPOSURE mcs	BASE DENSITY	SPEED ¹ @ 0.1 ABOVE FOG	GAMMA	MAX RES lmp/mm	RES LATITUDE @ 100 lmp/mm STOPS
2496	D-19, 4 Min 90°F	none	0.16	250	2.4	144	3.5
2496	D-19, 4 Min 90°F	3.8×10^{-3}	0.30	1000	1.9	161	9.5
2496	CPA-1, 30 Min 90°F	none	0.32	200	1.9	144	2.7
2496	CPA-1, 30 Min 90°F	4.0×10^{-3}	0.38	1600	1.45	144	4.0
2498	CPA-1, 4 Min 90°F	none	0.21	400	1.2	144	3.7
2498	CPA-1, 4 Min 90°F	2.0×10^{-3}	0.32	1000	0.9	161	5.7

¹ It is recommended that these film speeds be used ONLY as trial settings in determining the correct exposure index for a particular application. See Section V A.

TABLE 5, 2496 and 2498 FILM TEST RESULTS

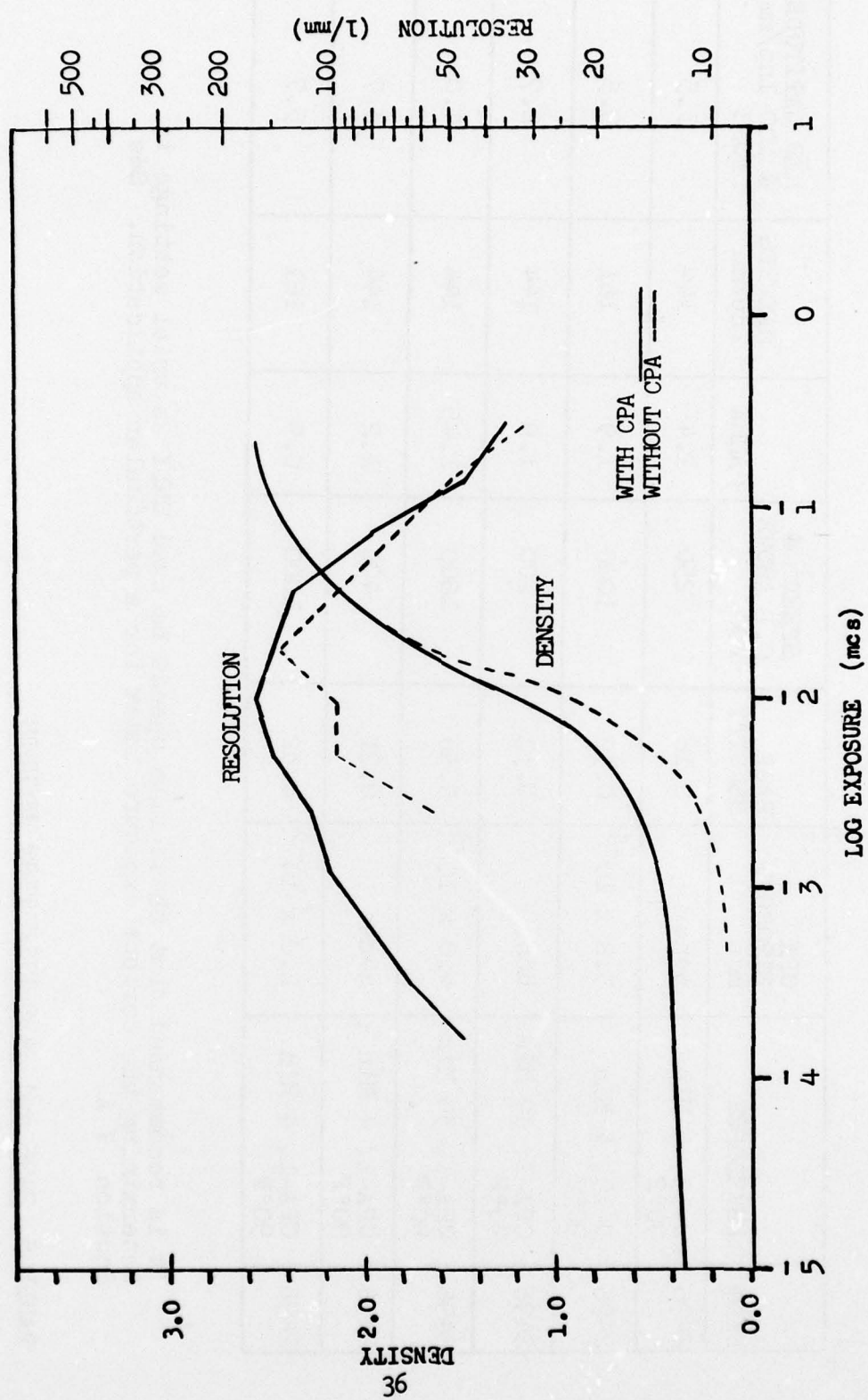


FIGURE 15, 2496 FILM, D-19 DEVELOPER, 4 MINUTES @ 90°F, C.A.

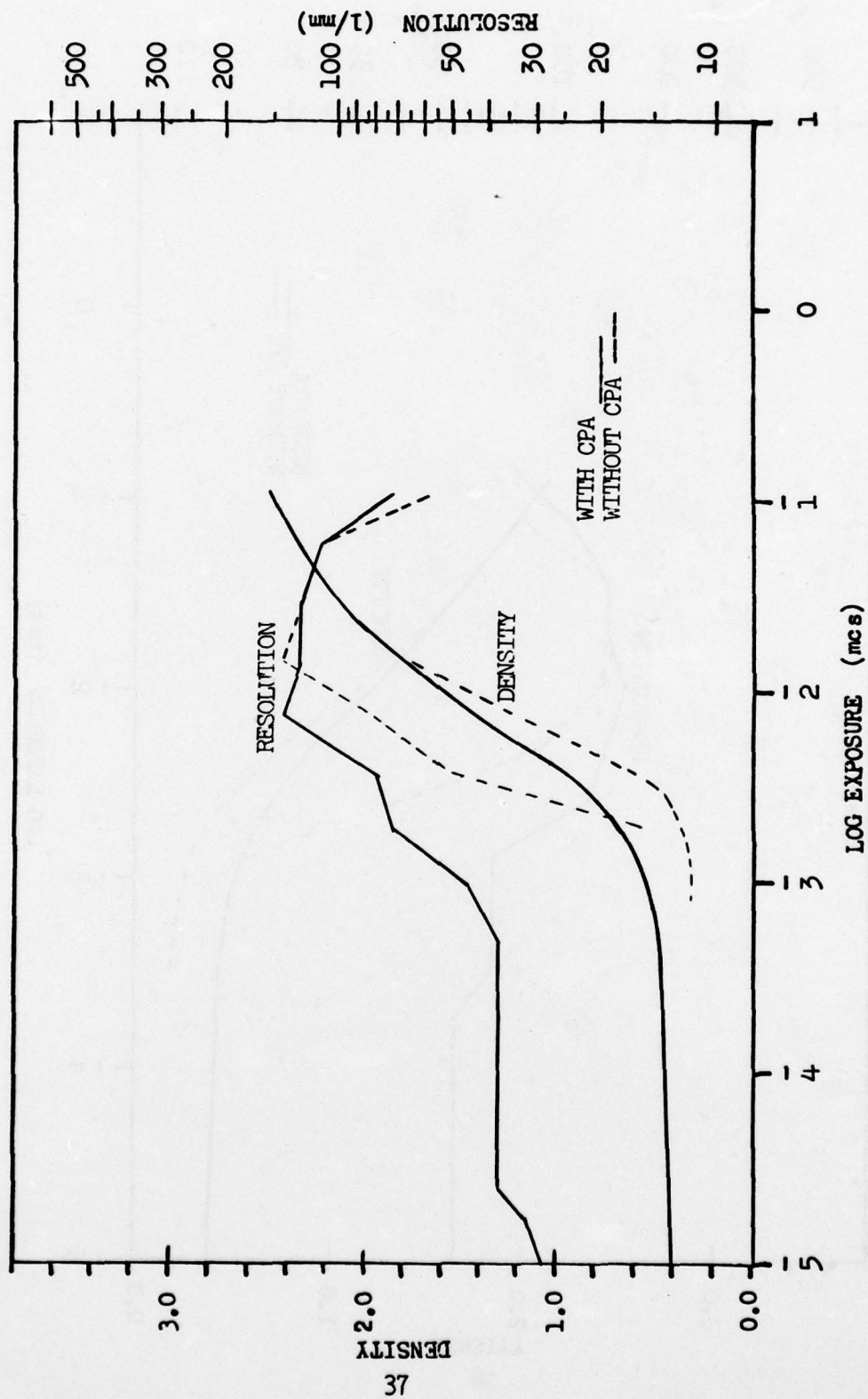


FIGURE 16, 2496 FILM, CPA-1 DEVELOPER, 30 MINUTES @ 90°F, C.A.

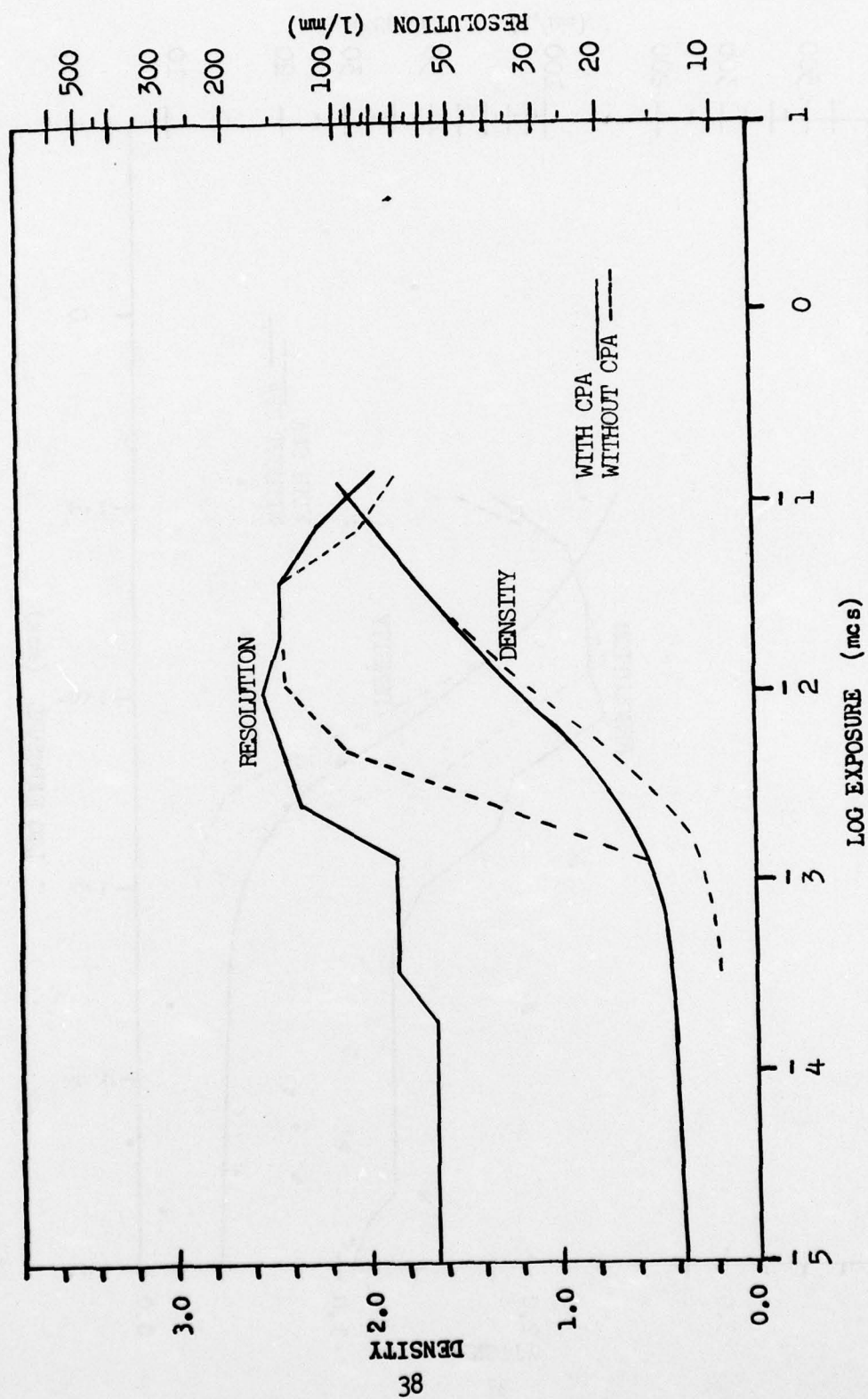


FIGURE 17, 2498 FILM, CPA-1 DEVELOPER, 4 MINUTES @ 90°F, C.A.

F. PHOTOMETRIC AND MISCELLANEOUS RESULTS

Before an engineering change was processed, deleting from the effort the requirement for investigating methods of incorporating CPA into 35mm cameras, some time was spent in developing a new measurement system for determining the intensity of CPA lamps installed in such cameras. A breadboard system was devised wherein a photomultiplier tube was used as the primary detector. It had the necessary gain required to monitor the low CPA lamp intensities existing with fast films at slow shutter speeds. Used in conjunction with neutral density filters, it also provided the dynamic range to measure the bright light levels required for slower, higher resolution materials. Tests of the system with available CPA cameras proved its effectiveness in making these measurements. Advised of the impending engineering change, no further effort was devoted to this area of endeavor.

In order to accommodate a wider range of resolution on our resolution/log E graphs, a new scale was derived. Since we wanted to cover a range of resolution from 10 lnp/mm to 500 lnp/mm, some form of exponential or log scale had to be devised. The final version, which is utilized in the figures that are included in this report, facilitates curve plotting and is quite amenable to interpretation. It also helps put significant changes in resolution in proper perspective, i.e. a 1 lnp/mm change at the 10 lnp/mm level has the same magnitude as a 10 lnp/mm change at the 100 lnp/mm level. Although not shown in the figures included in this report, our normal plot paper has an eighth inch grid. Each square on our resolution plot represents a sixth root of two change in resolution, thus it conforms exactly to the steps of resolution that we observe on the reticle recorded on the film. One no longer has to interpolate between lines to plot the resolution data. The report scale of resolution is conveniently labeled in units of ten or hundreds to facilitate interpretation.

VI

CONCLUSIONS AND RECOMMENDATIONS

It can be concluded that by substituting new films and processing methods, the Concurrent Photon Amplification technique can be employed to double system resolution and increase film speed over existing black-and-white film systems that use conventional films and processing techniques. A significant increase is also obtained in resolution latitude, i.e. the ability to maintain a particular level of resolution over a wide range of exposures.

Since CPA increases the exposure latitude of film systems that it is employed with, film not originally intended for continuous tone photography can be successfully adapted for this use by utilizing CPA. Additional flexibility can be obtained by appropriate choice of processing methods.

It is recommended that new research be conducted to investigate post processing enhancement of these high resolution film systems using chemical or autoradiographic techniques that now exist. The chemical enhancement conducted under a previous Air Force contract worked very successfully for coarser grained films such as TRI-X, PAN-X, 2475 and High Speed Infrared, and could offer the same gains with the CPA high resolution film systems. Autoradiographic enhancement techniques have already shown great promise with some of the finer grain films used for the high resolution CPA study. A combination of CPA, to increase the number of image silver grains produced during the original camera exposure, and autoradiography to enhance the contrast of the details recorded in the shadows of the CPA negative, has the potential of producing black-and-white film systems with maximized speed and resolution characteristics. The possibility of combining all three techniques, i.e. CPA high resolution film systems with post processing chemical enhancement followed by application of autoradiographic methods, should not be overlooked.

METRIC SYSTEM

BASE UNITS:

Quantity	Unit	SI Symbol	Formula
length	metre	m	...
mass	kilogram	kg	...
time	second	s	...
electric current	ampere	A	...
thermodynamic temperature	kelvin	K	...
amount of substance	mole	mol	...
luminous intensity	candela	cd	...

SUPPLEMENTARY UNITS:

plane angle	radian	rad	...
solid angle	steradian	sr	...

DERIVED UNITS:

Acceleration	metre per second squared	...	m/s
activity (of a radioactive source)	disintegration per second	...	(disintegration)/s
angular acceleration	radian per second squared	...	rad/s
angular velocity	radian per second	...	rad/s
area	square metre	...	m
density	kilogram per cubic metre	...	kg/m
electric capacitance	farad	F	A ² /V
electrical conductance	siemens	S	A/V
electric field strength	volt per metre	...	V/m
electric inductance	henry	H	V ² /A
electric potential difference	volt	V	W/A
electric resistance	ohm	...	V/A
electromotive force	volt	V	W/A
energy	joule	J	N·m
entropy	joule per kelvin	...	J/K
force	newton	N	kg·m/s
frequency	hertz	Hz	(cycle)/s
illuminance	lux	lx	lm/m
luminance	candela per square metre	...	cd/m
luminous flux	lumen	lm	cd·sr
magnetic field strength	ampere per metre	...	A/m
magnetic flux	weber	Wb	V·s
magnetic flux density	tesla	T	Wb/m
magnetomotive force	ampere	A	...
power	watt	W	J/s
pressure	pascal	Pa	N/m
quantity of electricity	coulomb	C	A·s
quantity of heat	joule	J	N·m
radiant intensity	watt per steradian	...	W/sr
specific heat	joule per kilogram-kelvin	...	J/kg·K
stress	pascal	Pa	N/m
thermal conductivity	watt per metre-kelvin	...	W/m·K
velocity	metre per second	...	m/s
viscosity, dynamic	pascal-second	...	Pa·s
viscosity, kinematic	square metre per second	...	m ² /s
voltage	volt	V	W/A
volume	cubic metre	...	m
wavenumber	reciprocal metre	...	(wave)/m
work	joule	J	N·m

SI PREFIXES:

Multiplication Factors	Prefix	SI Symbol
1 000 000 000 000 = 10 ¹²	tera	T
1 000 000 000 = 10 ⁹	giga	G
1 000 000 = 10 ⁶	mega	M
1 000 = 10 ³	kilo	k
100 = 10 ²	hecto*	h
10 = 10 ¹	deka*	da
0.1 = 10 ⁻¹	deci*	d
0.01 = 10 ⁻²	centi*	c
0.001 = 10 ⁻³	milli	m
0.000 001 = 10 ⁻⁶	micro	μ
0.000 000 001 = 10 ⁻⁹	nano	n
0.000 000 000 001 = 10 ⁻¹²	pico	p
0.000 000 000 000 001 = 10 ⁻¹⁵	femto	f
0.000 000 000 000 000 001 = 10 ⁻¹⁸	atto	a

* To be avoided where possible.

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RADC plans and conducts research, exploratory and advanced development programs in command, control, and communications (C³) activities, and in the C³ areas of information sciences and intelligence. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.

