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Second Stage Autoradiographic Amplification of Developed Underexposed Tri X Emulsion Images

David Dempster

ORIGINAL

SECOND STAGE AUTORADIOGRAPHIC AMPLIFICATION OF DEVELOPED UNDEREXPOSED TRI X EMULSION IMAGES

by

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B.S. Royal Military College of Canada

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MASTER'S THESIS

This is to certify that the Master's Thesis of David T. Dempster has been examined and approved by the thesis committee as satisfactory for the thesis requirement for the Master of Science degree

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SECOND STAGE AUTORADIOGRAPHIC

AMPLIFICATION OF DEVELOPED UNDERXPOSED

TRI X EMULSION IMAGES

by

David T. Dempster

Submitted to the Photographic Science and Instrumentation Division in partial fulfillment of the requirements for the Master of Science Degree at the Rochester Institute of Technology

ABSTRACT

A series of deliberately underexposed Kodak Film Type Tri-X negatives were first, conventionally developed, the image silver made radioactive with sulfur-35 thiourea, and by using an autoradiographic technique, the image recovered on X-ray film. The resolution and characteristic curve parameters of the final image compared to those of the original donor image were determined by varying the secondary exposure time (contact time between radioactivated film and x-ray emulsion), type of x-ray films and exposure levels.

The Tri-X Pan emulsion donor image was amplified using Kodak "NMC", "MA" and "RP" X-ray films as receivers. "NMC" was slightly preferable to "MA", both much more effective then "RP". Amplified images showed speed increases of up to twenty-nine times the original and significant increases in low contrast resolution were observed for donor targets imaged at 3% to 6% normal exposure.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation for the invaluable guidance and support provided by Ms. Askins and Dr. Owunwanne throughout the project. In addition Mr. J. F. Carson provided considerable assistance on several aspects of the experiment.

The author also wishes to thank Strong Memorial Hospital, Department of Radiology (Division of Nuclear Medicine) for allowing the use of their facilities. In conclusion the author wishes to thank Ms. J. Korman, without whose typing skill this thesis could not have been produced.

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INTRODUCTION

Photographic films store information by the production in the emulsion matrix of clearly visible deposits of silver metal; this information is being retrieved generally, by the transmission of visible light through the matrix. The density of the image silver must be considerably higher than the density of the background (base plus fog). Presently, image-grain densities of $10^7 - 10^9$ per cm^2 are required (owing to the necessary small size of Ag grains of approximately 1 μm diameter). Information is, without doubt, stored on considerably fewer grains; however, visibility requires sufficient exposure to make a larger number of gains developable.

NOTE: High quality printing may have a dot structure of only 10^4 ink spots per cm^2.

The above requirement, plus the low detective quantum efficiency (DQE) of even the best photographic films limit considerably the sensitivity or speed of photographic films.

NOTE: An ideal photon counter would have a DQE of 100%. The best films are about 1% (Kodak Astronomical Type IIIa is exceptional with a DQE of about 2%).

Another limitation is imposed by the requirement that the emulsion be transparent. This has tied photographic emulsions to clear water-permeable materials such as gelatine and polyvinyl alcohols. The technology of modern fast films is dependent largely on the addition to the silver halide emulsion of traces of sensitizing agents such as organic dyes, and compounds of sulphur, of gold, thallium and lead. The transparency requirement limits the choices of prospective sensitizing compounds as they must not affect the transparency of the film during or after processing.[1]

Some recent gains in photographic speed have been realized by sensitization of the film before exposure. Methods used included vacuum outgassing[2], baking in a vacuum (or inert atmosphere) and exposure to a hydrogen atmosphere[3]. However, as stated by Dainty and Shaw in Image Science,

> In the sensitivity sense, a high DQE low speed process is fundamentally superior as a first stage compared with a low DQE high speed process, so long as second stage amplification is possible . . . It is true that conventional silver halide processes which employ 10^9 amplification have normal speed ratings and produce a visible image at the camera stage. However there is no fundamental need for this. If the exposure has been recorded in the first stage with optimum DQE then as long as the first "image" can be sensed (chemically, physically, electronically, etc.), amplified, processed, etc. to produce a final visible print, the real limits of ultimate sensitivity will be attained[4].

The technique of autoradiography is a development which may have the potential for expanding the limits of photographic sensitivity by using a two-stage image amplification process.

BACKGROUND

The technique of autoradiography requires that a low exposure, thus low density, image be made radioactive, then placed in close contact with a second emulsion. The radioactive emissions can then produce sufficient exposure in the second emulsion so that initially stored, yet non-apparent, information can be recovered visually after conventional development of the second emulsion.

There have been three general methods for making the initial silver image radioactive as described in a report of the Australian Atomic Energy Commission authored by M. Thackray.[1]

A. Nuclear Reaction

This involves exposing the image silver to a neutron flux. Only reactions with neutrons are feasible as no other reaction induces sufficient radioactivity without destroying the emulsion. The important reactions are:

$^{107}Ag\ (n,\gamma) \rightarrow {}^{108}Ag$ $(t_{1/2}\ 2.4\ min)$

$^{109}Ag\ (n,\gamma) \rightarrow {}^{110}Ag^{m}$ $(t_{1/2}\ 253\ days)$

Irradiating the low-exposed image with 7×10^{12} neutrons $cm^{-2}\ s^{-1}$ for 5 minutes, followed by a cooling period of two minutes and an autoradiographic exposure of ten seconds gives dense heavily fogged results. Process times are very short for control purposes.

The long half-life of ^{110m}Ag requires very long autoradiographic exposures, which is inconvenient from a time point of view, and the initial photograph may become damaged by radiolytic decomposition of gelatine and film base.

B. Radiotoning

This is a process by which the image silver is made to react chemically with a radioactive material so that the silver grains become coated with or are replaced by a radioactive compound. Toning with radioactive elements of the sulphur group (sulphur, selelium, tellurium, and polonium) is most convenient, and procedures have been developed utilizing suplhur - 35, promethium - 147, cadmium - 115m, iron - 55, nickel - 63, mercury - 203, silver - 110, gold - 195, polonium - 210, uranium - 233, americium - 241, and californium - 252.

The processes are, for the most part, chemically complex, often involving resolution losses in each of the numerous steps.

C. Silver Isotope Exchange

This technique involves exchange of, for example, silver nitrate labelled with silver 110m with the emulsion silver. The reaction is slow and the gamma ray emissions are inconvenient. However, the technique has been used to produce autoradiographic amplification.

The above-mentioned techniques have not been extensively used for a number of reasons; the first of these is the inconvenience of the complex chemical procedures required, or the specialized nuclear equipment necessary to make the silver radioactive. Safety hazards are a problem and the long time required is inconvenient. Significant problems were found with respect to heavy fogging, in that activation methods produce radioactivity in the emulsion, apart from that produced on the image, in that radioactive particles are precipitated in the emulsion or that labelled chemicals react with impurities in the emulsion.

A method of radioactivating low density images with thiourea S^{35} (H_2 $NCSNH_2$) has been invented by Barbara Askins, which offers considerable advantages over previous techniques of radioactivating.

According to the designer, advantages of this system of radioactivating include:

A. The process is simple, could be automated, but in any event, could be set up easily in any photographic facility.

B. Problems with fogging lowering the DQE of the process have been markedly decreased as:

  (1) There are no colloidal compounds formed in the solution or gelatin. Thus it is not necessary to attempt to remove activity from the process (thus also removing activity from the image).

  (2) Thiourea S^{35} reacts preferentially with image silver to minimize base plus fog.

  (3) pH of the solution does not have to be carefully controlled; also, the hazard of $H_2 S^{35}$ gas evolving from acidic solutions is avoided as all solutions are neutral or basic. Furthermore, pH of the solution can be varied in the process.

  (4) The chemistry itself is simple (only two or three stock solutions are necessary), stable, and does not require specialized, thus inconvenient, storage conditions.

  (5) Sulphur-35 is a pure beta emitter requiring no special protection. Thus there is no gamma radiation as health hazard or to fog nearby emulsions. The half-life of 88 days is long enough for convenient used, and short enough to ease disposal problems.

THEORY

A basic aqueous solution of thiourea-35 ($H_2NCS^{35}NH_2$) will react preferentially with developed silver in the emulsion. Sulphur - 35 is a pure beta emitter. The mechanism of the reaction is not, according to process designer, Askins, completely understood as yet, however, the result of the reaction is that a portion of the silver is converted to radioactive silver sulphide (Ag_2S^{35}).

An activated negative can be contacted to an emulsion, such as a type "RP" X-ray film to produce a latent image on the second film. The result can be conventionally developed to produce a readable image.

The process itself contains a large number of parameters which will affect the final result. It is suggested that the pH of the activating solution is very important as the higher the pH, the higher the activity level of the image silver. The allowable pH of the activating solution is limited in that strongly alkaline solutions will damage the emulsion. The density produced by this intensification process depends on the radioactivity of the film, the contact time of donor to receiver film and characteristics of the receiver film. The radioactivity of the film depends on: the pH of the activating solution, the concentration of thiourea S^{35}, the age of the thiourea S^{35} ($t_{1/2}$ = 88 days), the activation time, the type of film activated, the temperature and the type of agitation.

Theoretically some amplification should be possible between any pair of emulsion types. The initial level of base fog and the rate of which it increases with contact time is a very important parameter of the donor and receiver emulsions.

PROCEDURE

In keeping with the object of this investigation, the experiment proceeded in two phases. First, studies were carried out to show the viability of the process and the feasibility of its use in a small facility, and to indicate areas worth detailed investigation in the second phase of the experiment. The high cost of activating film was an important limit on the amount of possible data.

The procedure will be described below in three parts: the prepatory phase, procedures carried out prior to the first activation; the "A" phase, experiments conducted to explore the feasibility of this process and use in small, possibly isolated photo facilities; and the "B" phase, experiments conducted investigating three receivers at various contact times, attempting to hold other parameters constant. Equipment is listed in Appendix A.

The prepatory procedure included calculations of the exposure levels, the exposure and the processing of the Tri-X film. Images consisted of resolution targets and step wedges imaged at 12.5%, 6.25% and 3% of normal (or 100%).

The Hasselblad camera shutter speed was verified using the oscilloscope time base. To minimize reciprocity effects, a shutter speed of 1/4 sec. was used, as the shutter of the Kodak 101 Sensitometer used to expose the step wedge is 1/5 sec. The f/stop of the camera was held f/5.6 to avoid resolution variations due to change in stop. Light level for the normal (or 100%) exposure was determined by exposures made by inserting the calculated neutral density filters between the target and the camera. All exposed images were processed in the RIT Versomat processor, according to instructions posted on the machine, and using the standard Versomat chemistry.

The activating procedure is that during which some of the photographic silver is converted to radioactive silver sulphide. This procedure consists of the pretreatment, the activation and the posttreatment steps. Stock solutions required were: a thiourea stock solution, prepared by dissolving 5 millicuries of thiourea-S^{35} in 25 ml of distilled water, and a 1 molar sodium hydroxide solution.

The pretreatment procedure consisted of affixing the donor film, emulsion side out, inside the Chromega Color Processing Drum. The film was then agitated in 100 ml solutions of first distilled water for two minutes, of 50% F-5 fixer for five minutes, two baths of distilled water for one minute each, a bath of 20% methanol then 50% methanol for five minutes each, then four five minute baths in distilled water. This completed the pretreatment procedures. The activating solution, consisting of 25 ml. of stock NaOH, 25 ml of stock thiourea solution and 50 ml of distilled water was then added and agitation continued for thirty minutes. Precautions involved to ensure safe handling of the isotope are listed in Appendix B. The post activation procedure consisted of two baths in 100 ml of distilled water for 1 minute, each followed by 1 bath in 20% and 50% methanol, then 4 baths in distilled water, all of the last 6 baths lasting five minutes.

"A" phase consisted primarily of contacting activated Tri-X Pan Film with type "RP", "MA" and "NMC" medical X-ray films. An experiment was carried out to ensure that receivers were non-radioactive and thus would not contaminate the X OMAT automatic processor, which was then used to process all medical X-ray films used as receivers. A short contact time series was run with each of the receiver films as a preliminary to the more intensive study to be carried out in Phase "B". A preliminary set of resolution tests were made for a contact time series. To investigate the possibility of reducing activation time two series were run whereby the activation time was varied. Data from this phase indicated the areas of investigation for the next experimental phase.

The "B" phase of the experiment consisted of activating step wedges and resolution targets imaged on the Tri-X film. The activated film was then contacted in replicated time series from 5 minutes to 10 hours with three receiver films to generate characteristic curves and system resolution data. All receiver films were processed in the same time period (1/2 hour) in the X OMAT processer. The TD 504 and resolution microscope were utilized to generate data points.

NOTE: All density readings in this experiment were normalized, that is, base plus fog was set equal to zero.

SOURCES OF ERROR

There were a large number of possible sources of error in this experiment, both in the number and amount of measuring, and in the large number of parameters which, it is hypothesized, could cause variations in the results. Naturally every effort was made to identify and minimize sources of error.

First, the experimenter carried out a self-training program on all aspects of the experiment, asking for and receiving, briefings when required. This included practicing operations such as camera function and loading (with the 70mm back) dishwashing lessons from Ms. Askins, Versamat and X OMAT operation, running the activation process itself, using the liquid scintillation counter and resolution microscope, and reading resolution targets. For resolution target reading, the manual Standardized Assessment and Expression of Tribar Resolution was re-read and the practice chapter done three times.

Specific steps taken during the experiment to limit error include:

Preparatory

- All Tri-X film came from the same emulsion number of new film.
- All film was exposed in the same day using one sensitometer and one camera.
- All camera images were made with exactly the same lighting, with the camera in the same position.
- The neutral density filter packs were the same for both camera and sensitometer.
- The exposure time of sensitometer (1/5 sec.) was matched to camera (1/4 sec.) to minimize reciprocity effect.

- The camera f/stop remained constant for all images.
- The exposed film strips were all processed in random order in the same forty-five minute period with the Versamat, about one one hour after the control strip indicated that the machine was operating within normal limits.
- A step tablet was imaged on each film strip. This was measured at the front and end of the strip to indicate that the Versamat was processing uniformly.

A and B Phase

- For each sub experiment, the film was activated at the same time unless otherwise noted.
- Density and resolution readings were done at the same time for each sub experiment. The density was periodically verified at zero. The resolution illumination and magnification were kept constant.
- All readings for B phase were replicated.

A quantitative assessment of error is attached in Appendix C.

RESULTS

A. "A" Phase

It is possible to carry out this procedure in a small photographic facility. The facility used to carry out the activating consisted of an area in a Nuclear Medicine laboratory with floor space approximately 1 by 2 meters. A fume hood where the procedure was run (with an area of .6m x 1.0m), counter space (about .6m x 1.2m) with a sink dispensing distilled water, and a small amount of counter space in the darkroom (to load cassettes) were sufficient.

Experiments in "A" phase consisted, of determining that the process was working, of showing that the projected study to be carried out in "B Phase" was feasible, and that it should produce interesting results. A number of avenues were explored which indicated the following:

- pH of activating solution remained constant at 12.
- "NMC" is slightly better than "MA" as a receiver; both are markedly superior to "RP".

This assessment of "better" is based on a subjective view of produced images, comparison of characteristic curve parameters for specific contact times, i.e. the contrast index, range of density, the density of low numbered steps, and the speed. At this point in the experiment, a contact time of 2 hours from a characteristic curve point of view appeared the best of those studied as seen Figure 2.

- No discernible radioactivity is passed from donor to receiver, thus the receivers can be machine processed without contaminating the machine. This was examined by contacting film to the recently

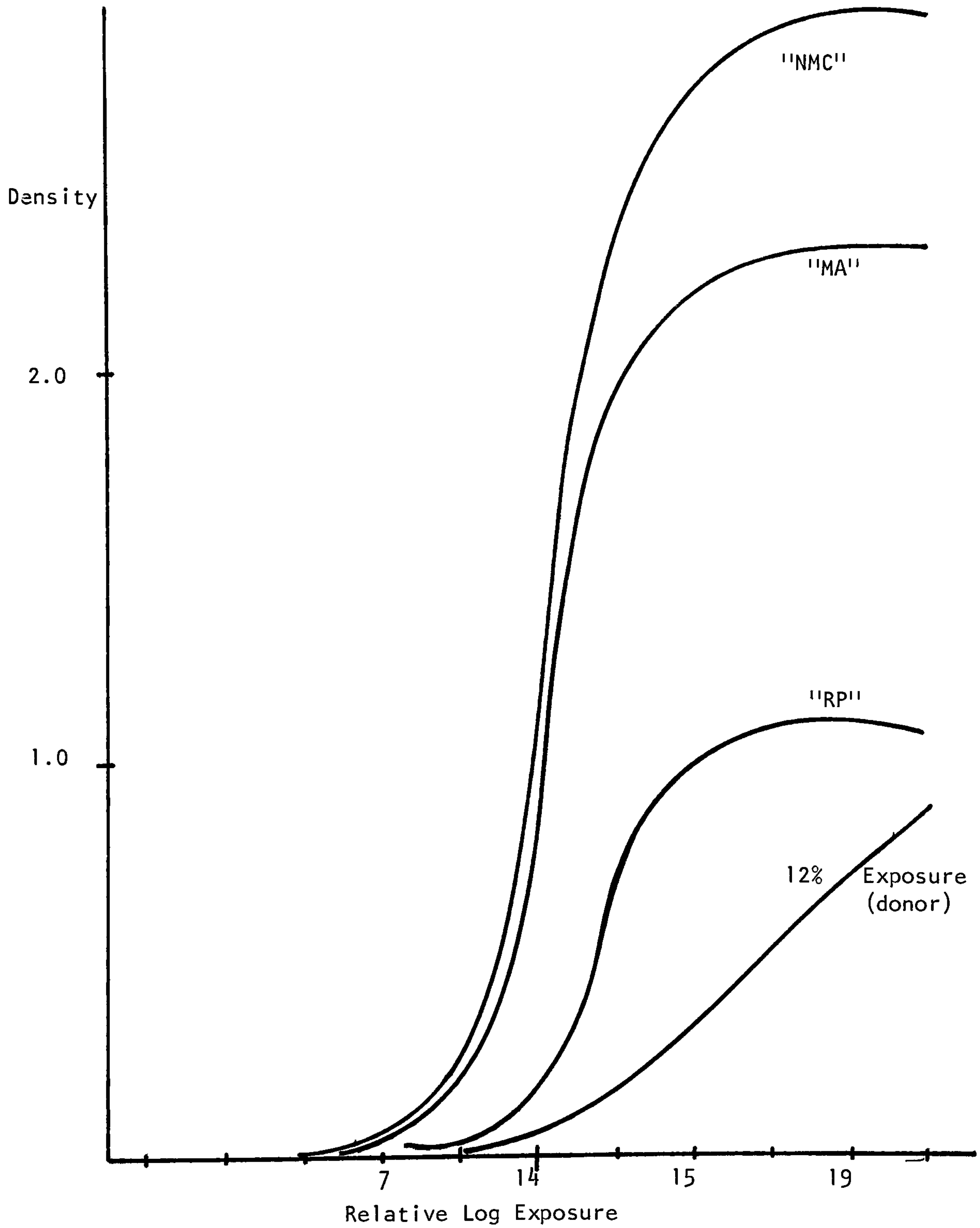


Figure 1. Characteristic Curves for Various Films at Fixed Contact times (CT = 2 HRS)

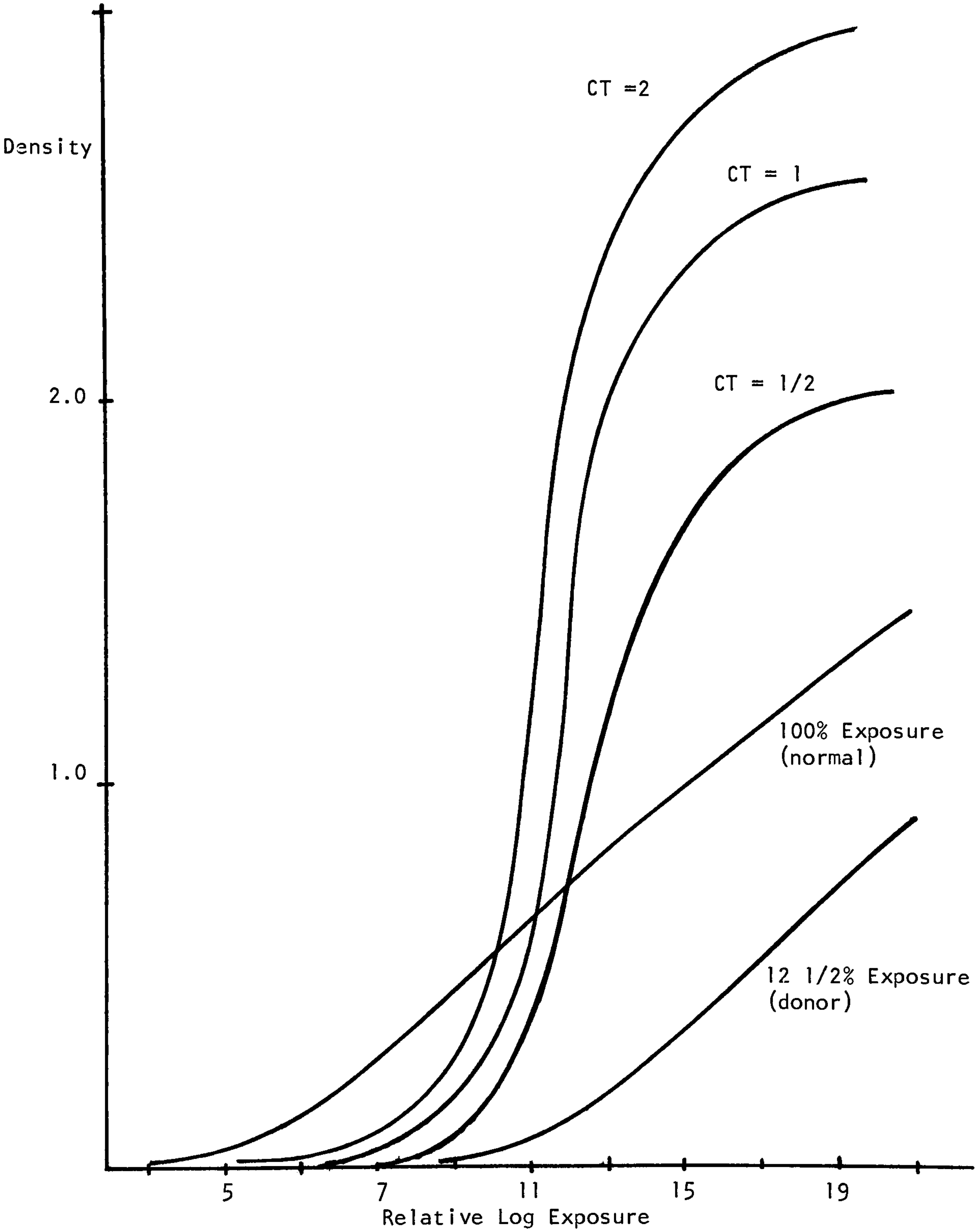


Figure 2: Characteristic Curves for a Given Receiver Film (NMR) with Varied Contact Times (CT in hours)

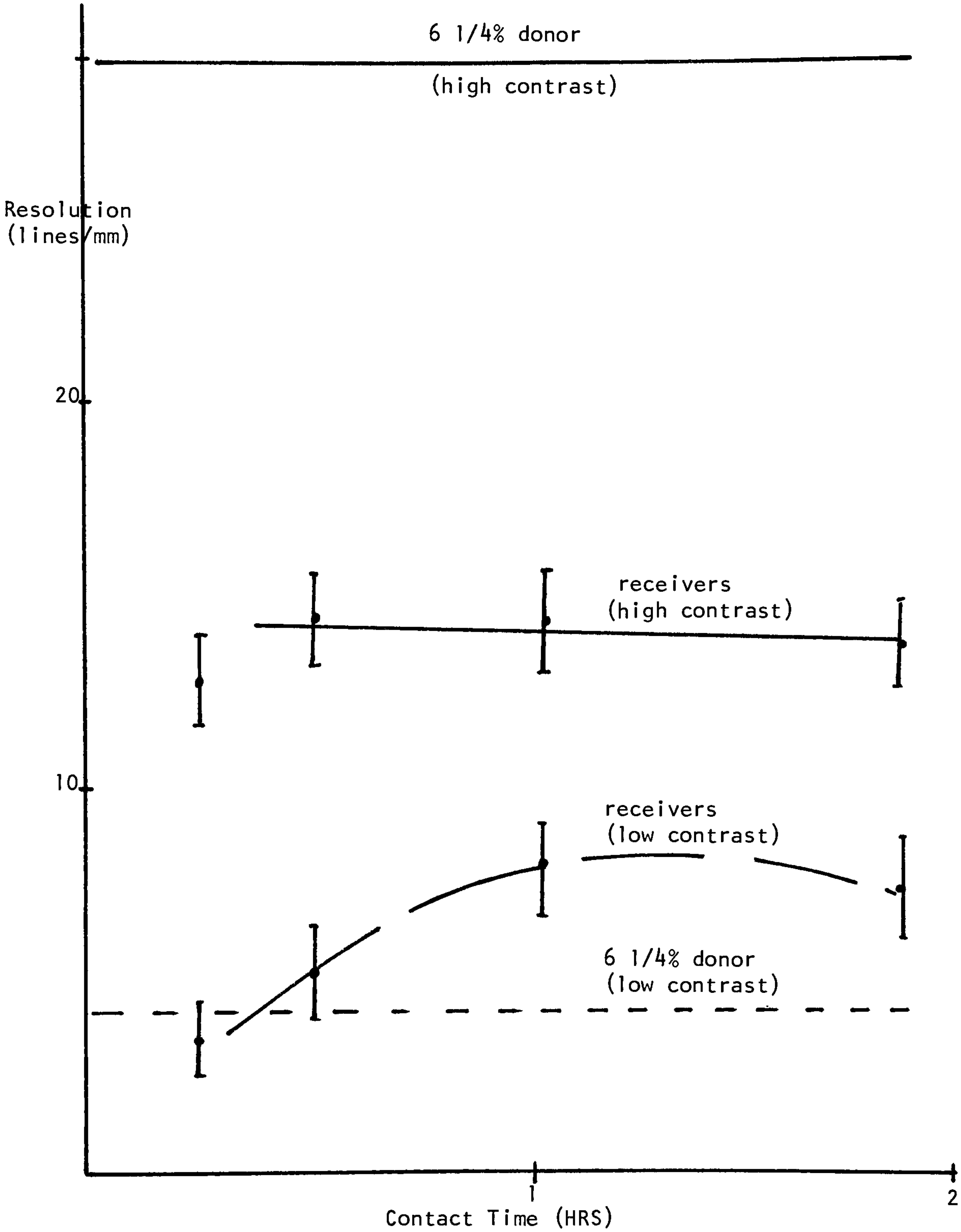


Figure 3. Resolution of a 6 1/4% Donor Compared to "NMC" receivers Resolution as a Function of Contact Time.

contacted receiver to see if any radiation developed on the second also by running unexposed sheets of NMC film before and after processing receivers to see if any density is developed. None was observed.

- Contacting "NMC" film with the back to the donor, produced, after 3 hours contact time, an image very similar to that of a 2 minute contacted film. Thus, some radiation had penetrated the backing to the emulsion, but very little. No double image was observed with the double sided "MA" or "RP" film, thus it is not felt that the back-side emulsion affected resolution measurements.
- Attempting to activate "RP" 8 x 10 sheet image of 2% and 20% exposure produced activity in the film which manifested itself as fairly constant density on contacting, but no discernible image.
- All X-ray film are high contrast emulsions thus it is unlikely that the 100% TRIX exposure with its comparatively low contrast index can be duplicated.
- Contact times from 2 minutes and greater produce images with the maximum size of the characteristic curve peaking about 1 1/2 hours to 2 hours contact time, then falling as the base fog increases.
- An attempt was made to activate "RP" film with "used" activator solution, however, no activity could be discerned on contacting this to another emulsion. The age of the solution was approximately two weeks. This reuse possibility was not explored further than the two sheets being activated the same day with the same age solution.

A series of curves was produced by varying the activation time, then replicated to see if decreasing this time could be justified. The results indicated that fifteen minutes activation time gives results very close to that of 30 minutes, although the 30 minutes activation did amplify one lower step. Thus I decided to retain the 30 minute activation time. Appendix D details the experiment.

Data with the liquid scintillation counter indicated that for about 30 square inches of film, after 30 minutes activation, more than half of the activation for the thiourea had left the solution. Appendix E details this data.

Lo'dose X-ray films of 6.25% and 2% were activated and contacted with "NMC" film to produce an amplified image of a hand. It would doubtless require a number of amplified images and subjective assessment by a number of doctors to establish how acceptable the image is, however, there is no question that significant detail, not available in the original, was brought out.

"B" Phase

For "B" phase, the three chosen receiver emulsions were contacted to activated Tri-X emulsions exposed to 3%, 6.25% and 12.5% of normal exposure. Density characteristic curves for donor/receiver combinations are drawn in Figures 4 to 12. Curves for density, fog and speed calculations are seen in Figures 13 to 16. Quantitative results are presented in Tables 1 to 3.

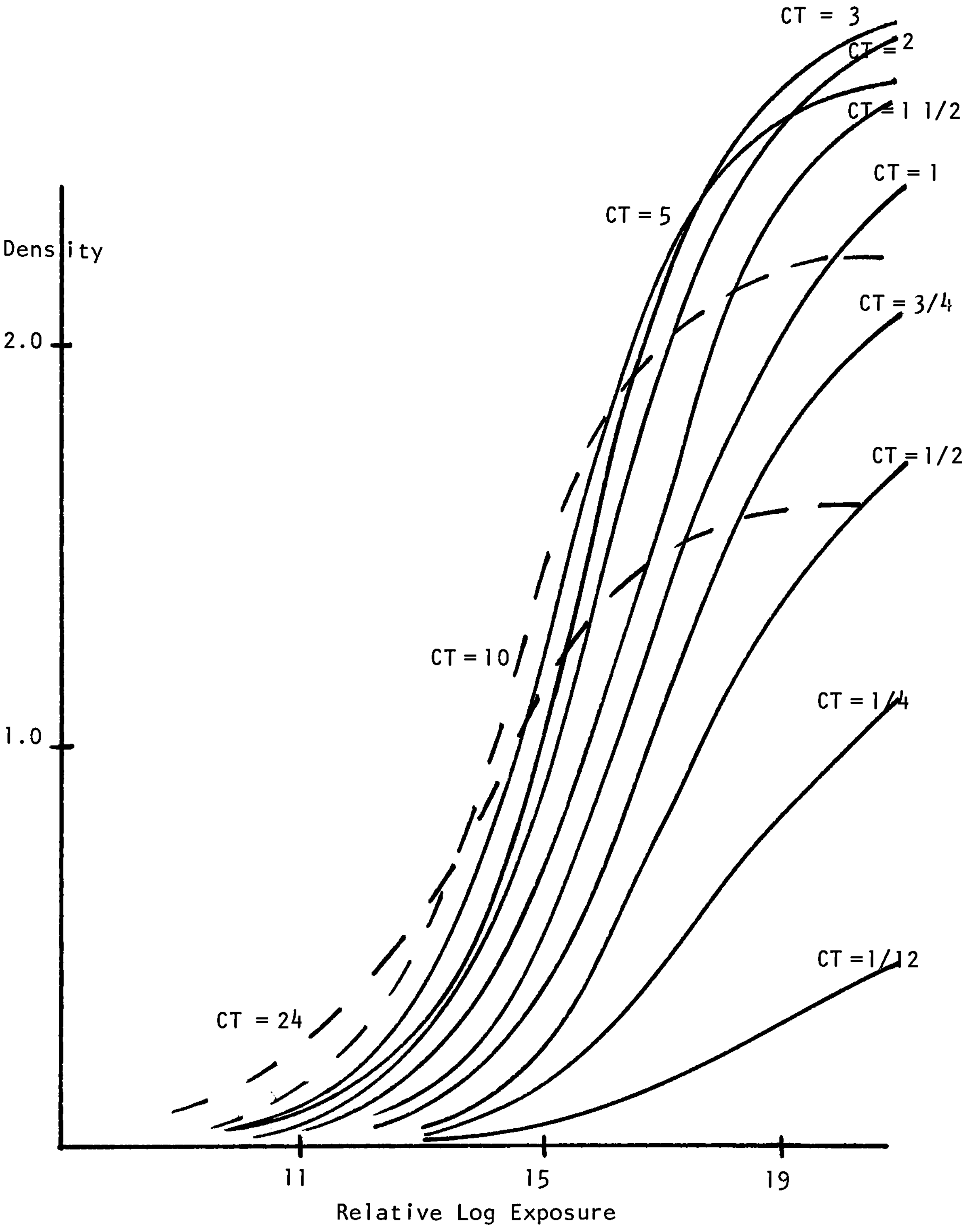


Figure 4. Characteristic Curves 3 1/4% Donor Contacted to "NMC" Receivers at Varied Contact Times.

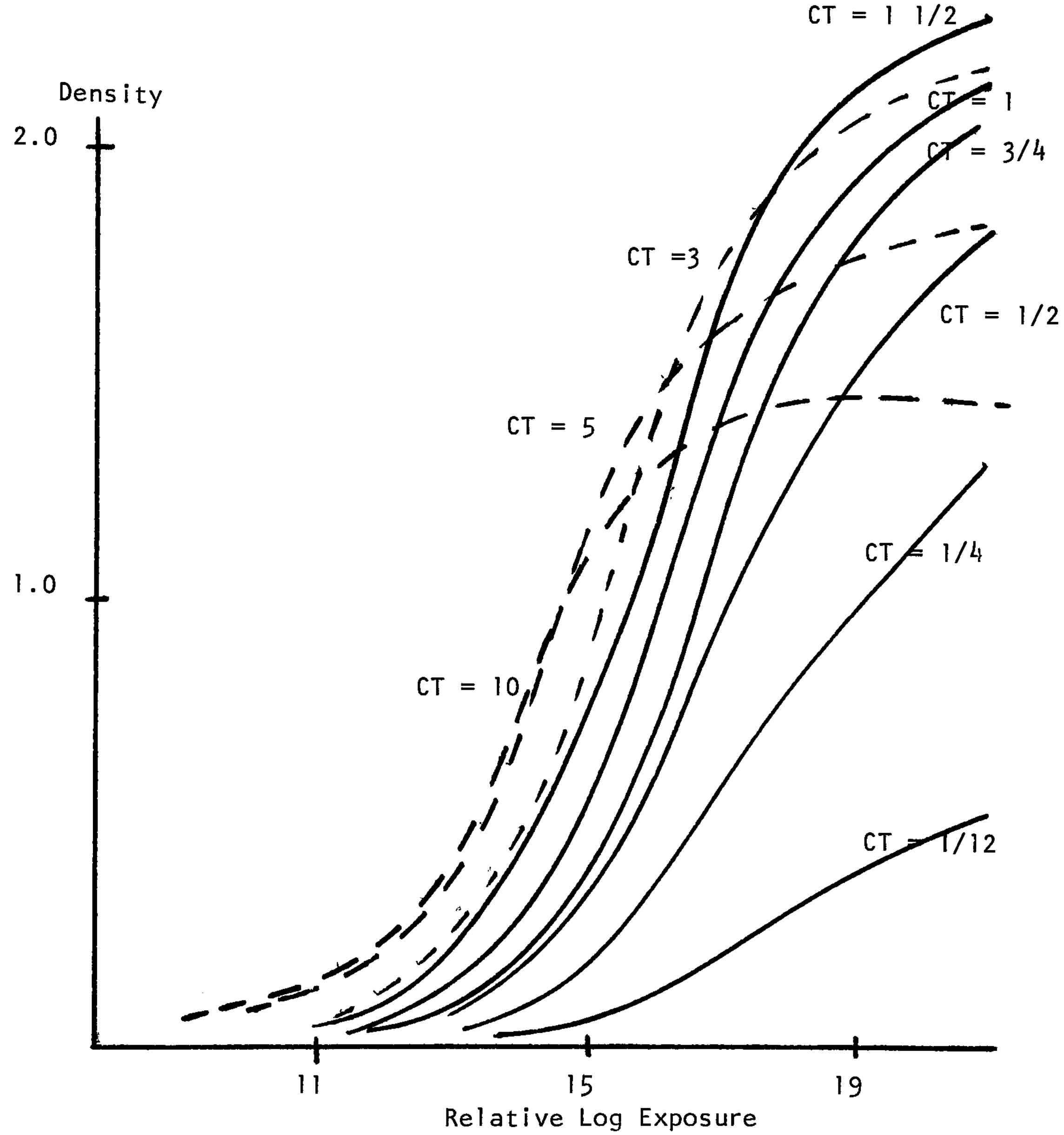


Figure 5. Characteristic Curves 3% Donor Contacted To "MA" Receivers at Varied Contact Times.

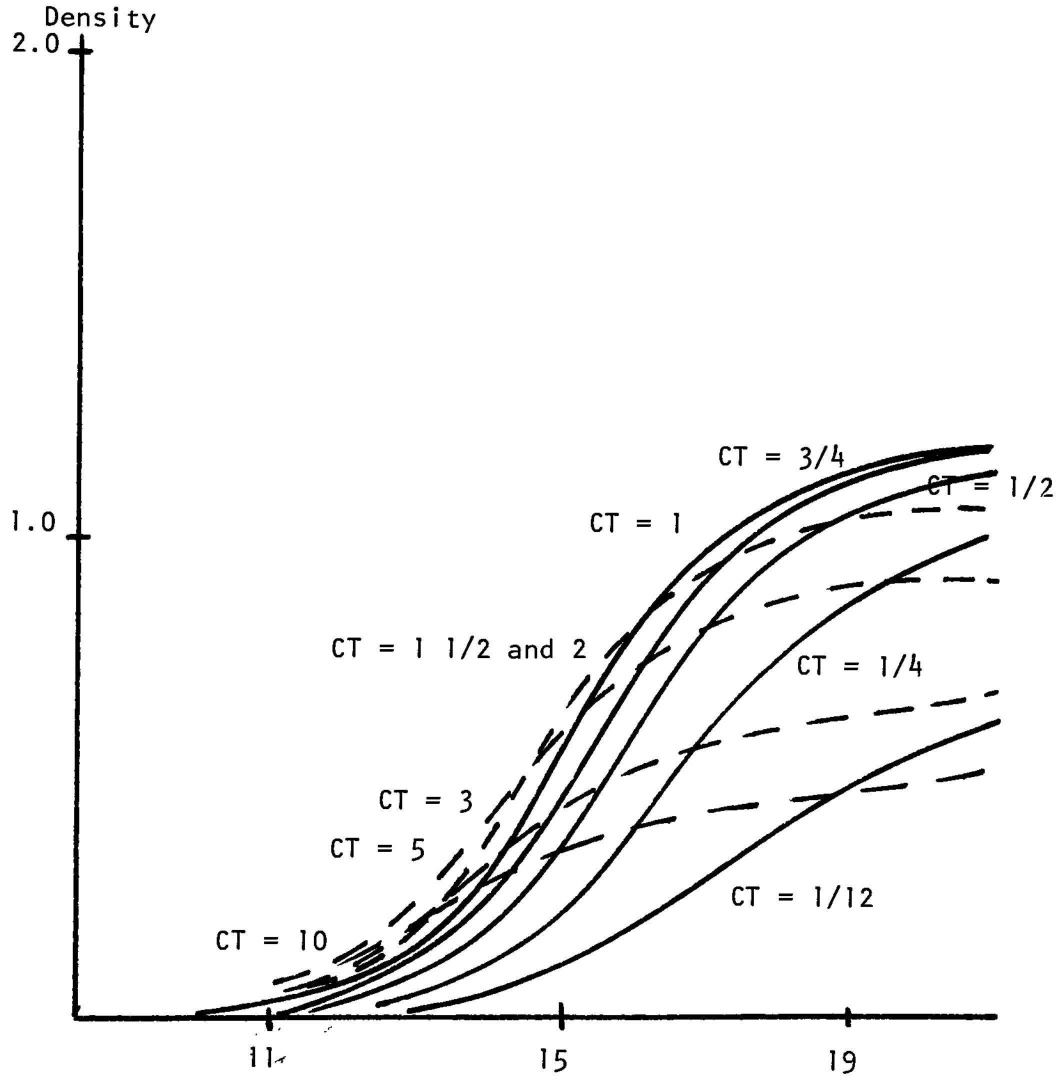


Figure 6. Characteristic Curves 3% Donor Contacted to "RP" Receivers at Varied Contact Times.

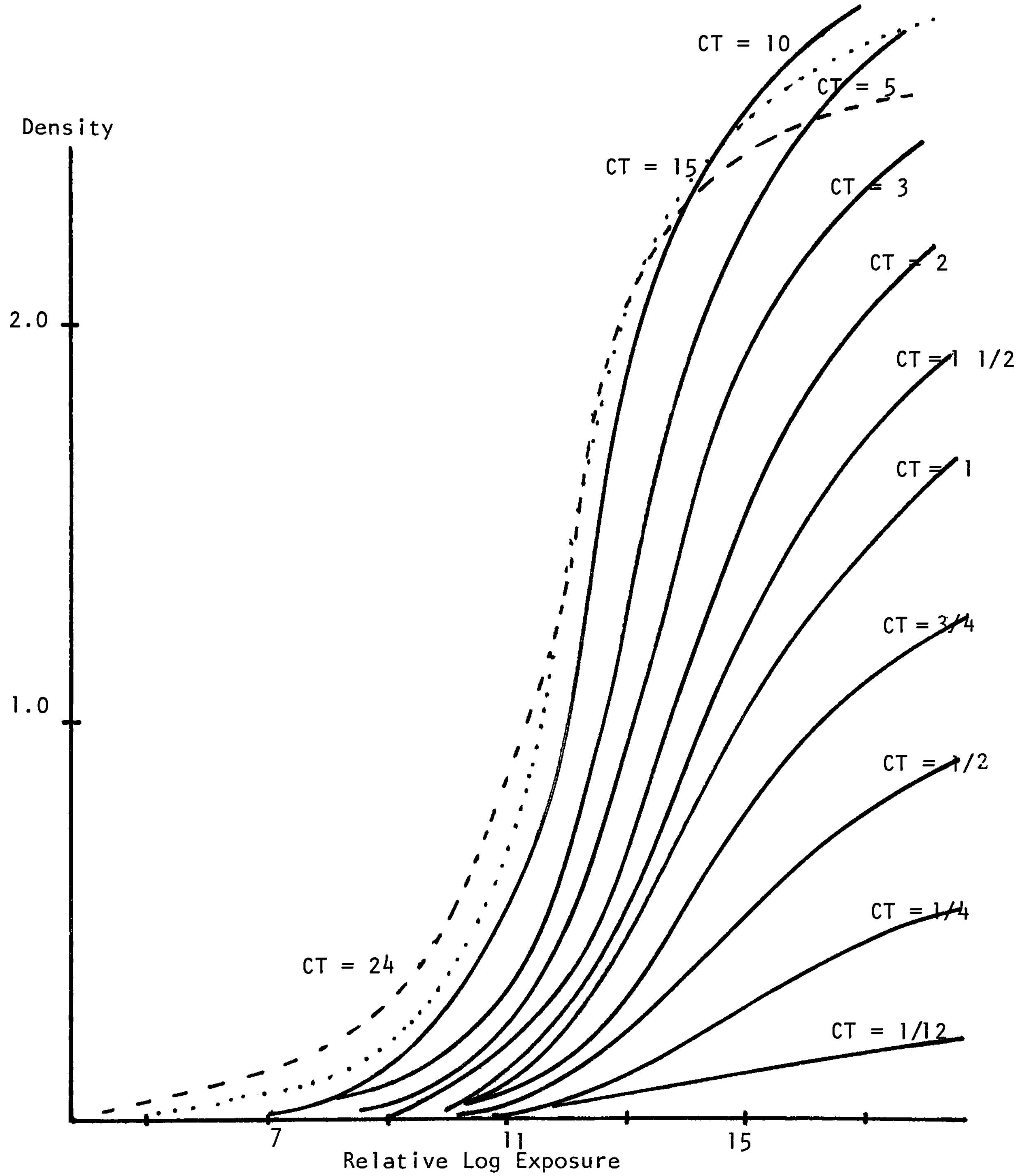


Figure 7. Characteristic Curves 6 1/4% Donor Contacted to "NMC" Receivers at Varied Contact Times.

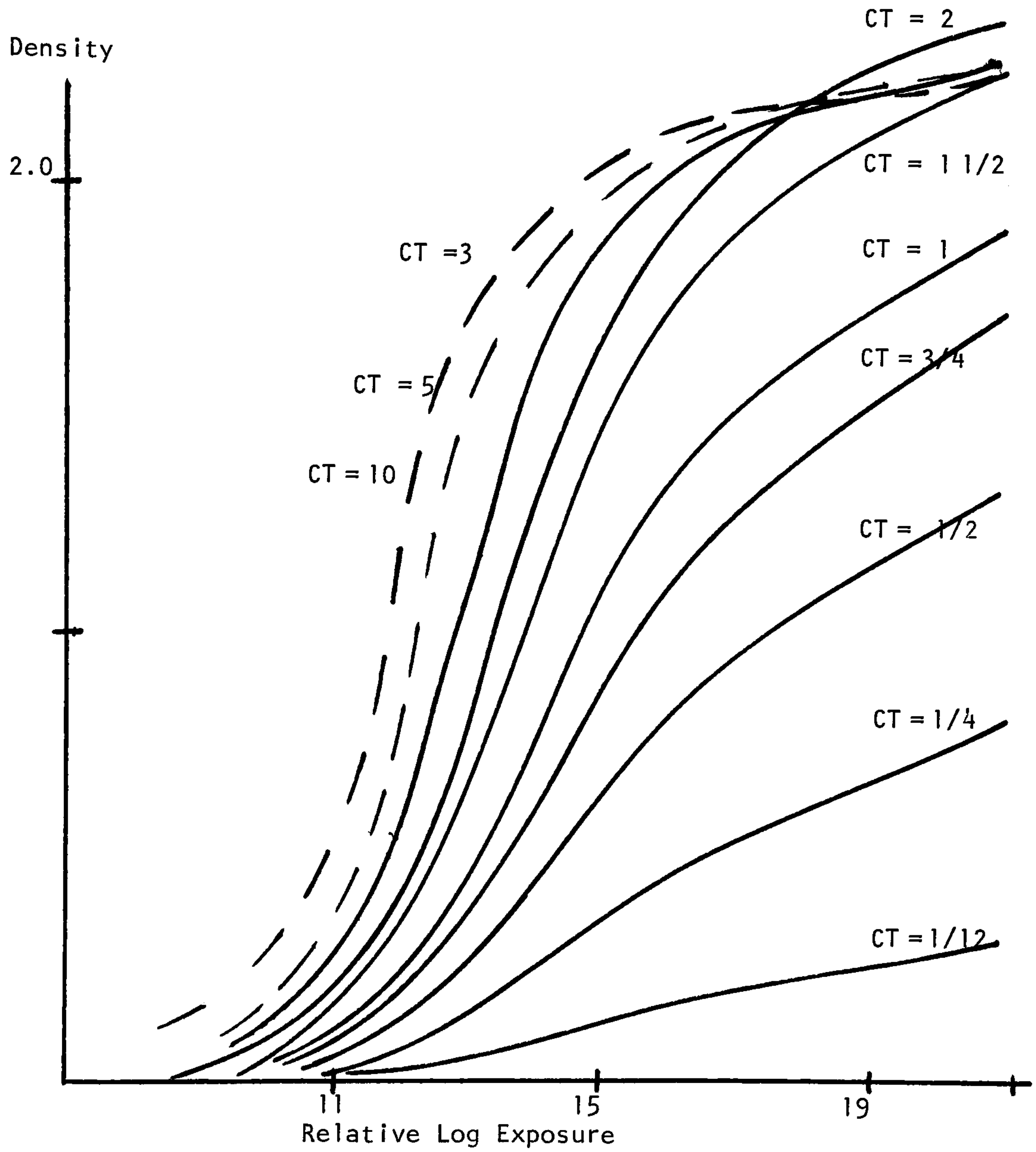


Figure 8. Characteristics Curves 6 1/4% Donor Contacted to "MA" Receivers at Varied Contact Times.

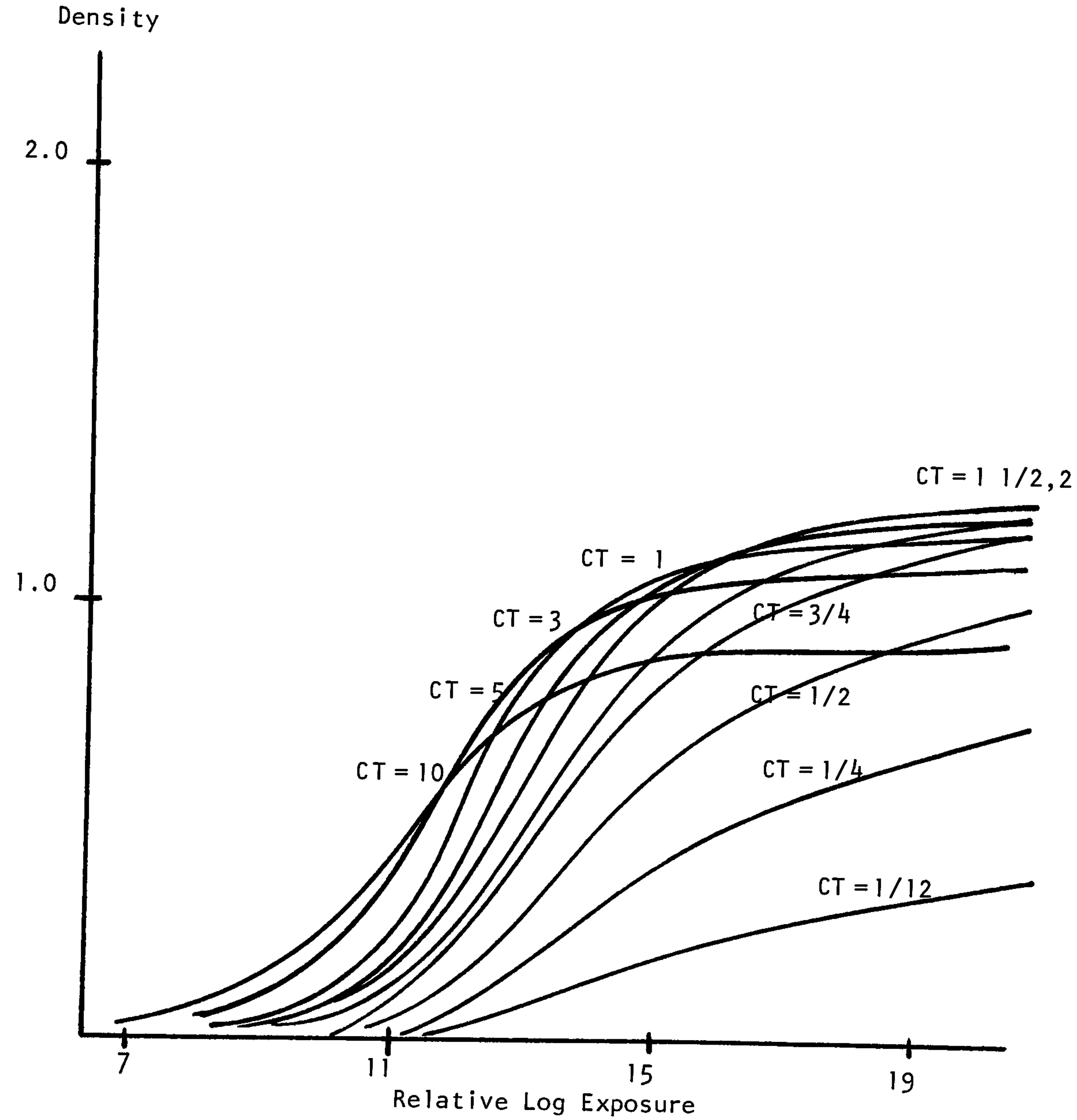


Figure 9. Characteristic Curves 6 1/4% Donor Contacted to "RP" Receivers at Varied Contact Times.

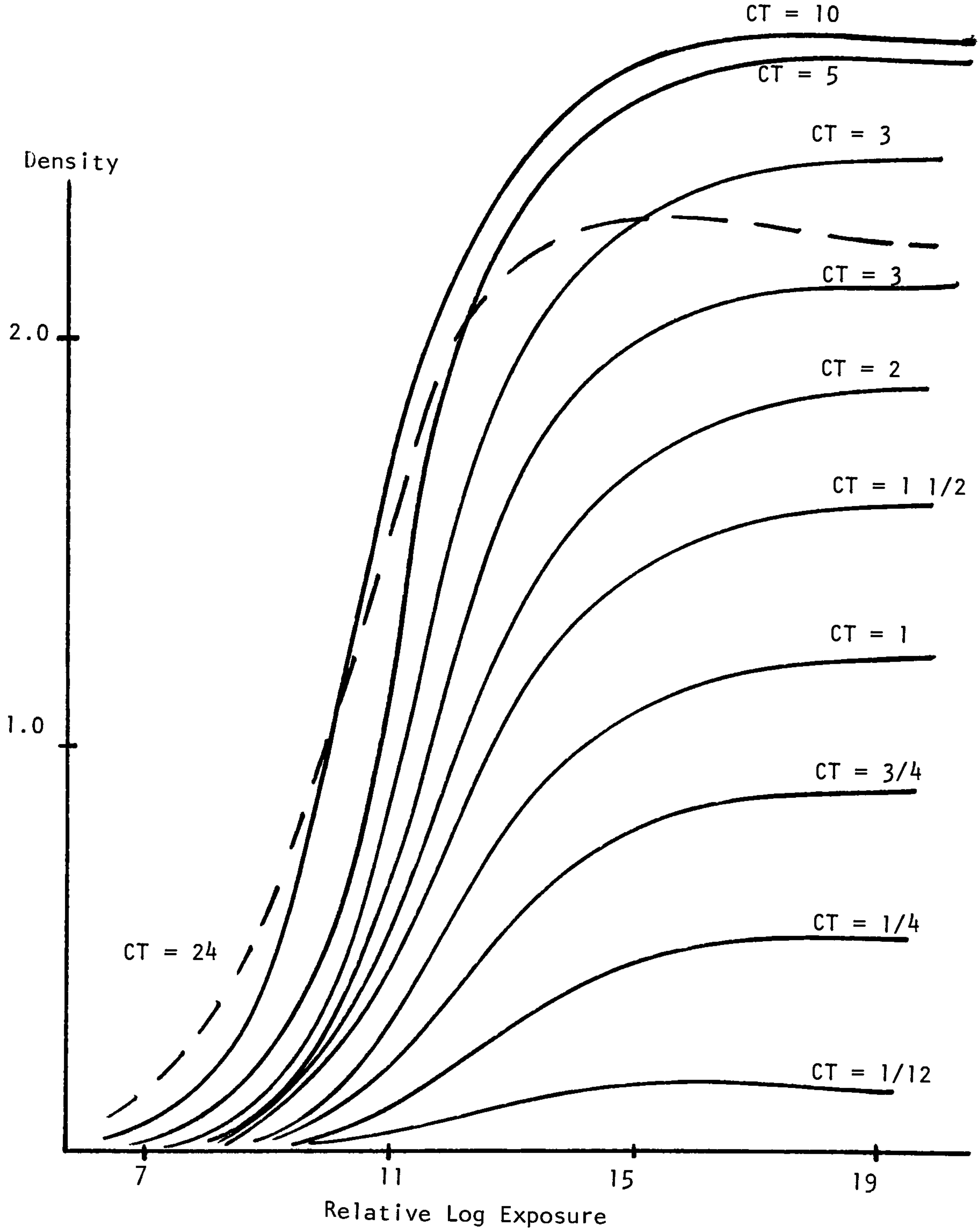


Figure 10. Characteristic Curves 12 1/2% Donor Contacted to "NMC" Receivers at Varied Contact Times.

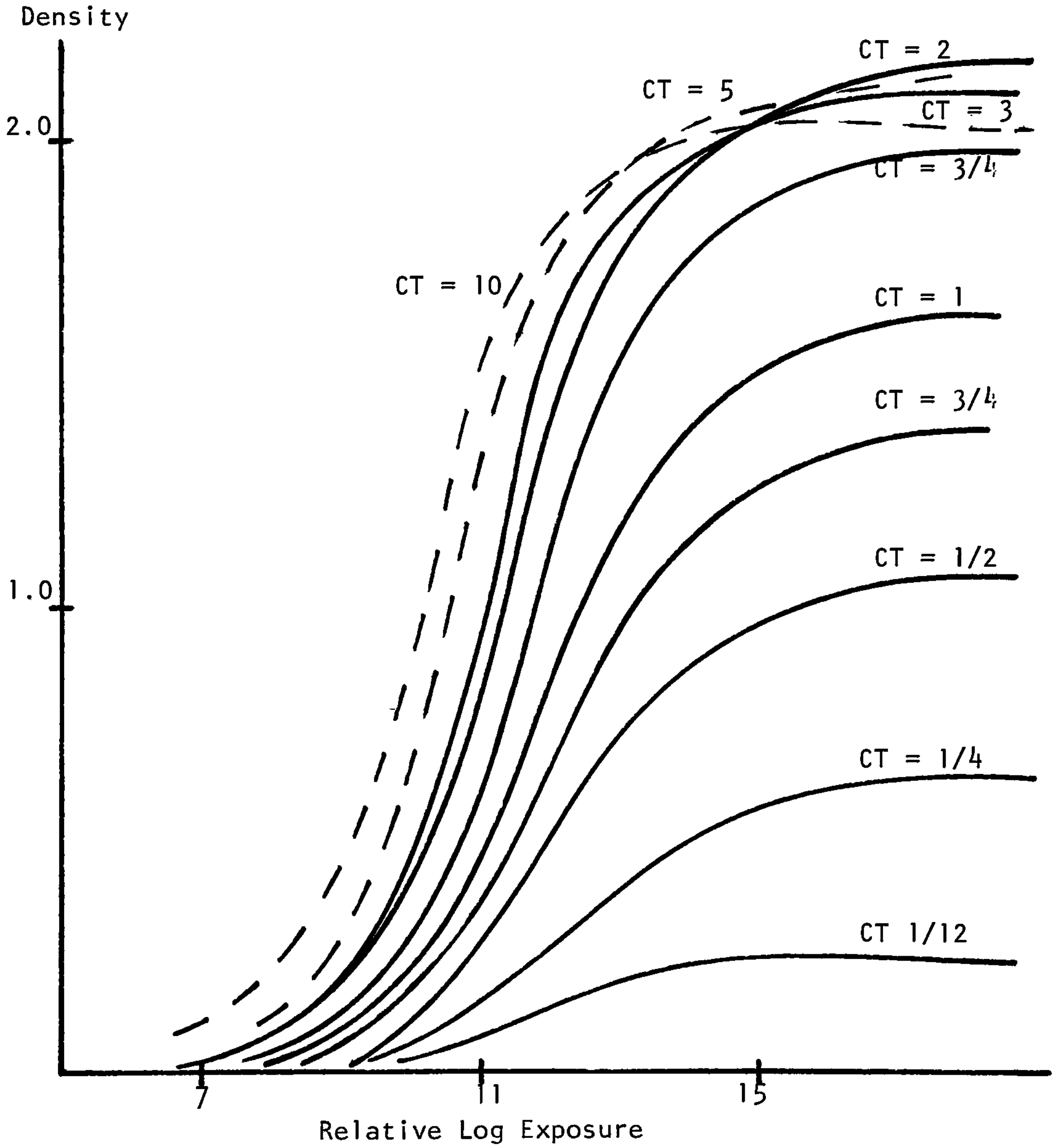


Figure 11. Characteristic Curves 12 1/2% Donor Contacted to "MA" Receivers at Varied Contact Times.

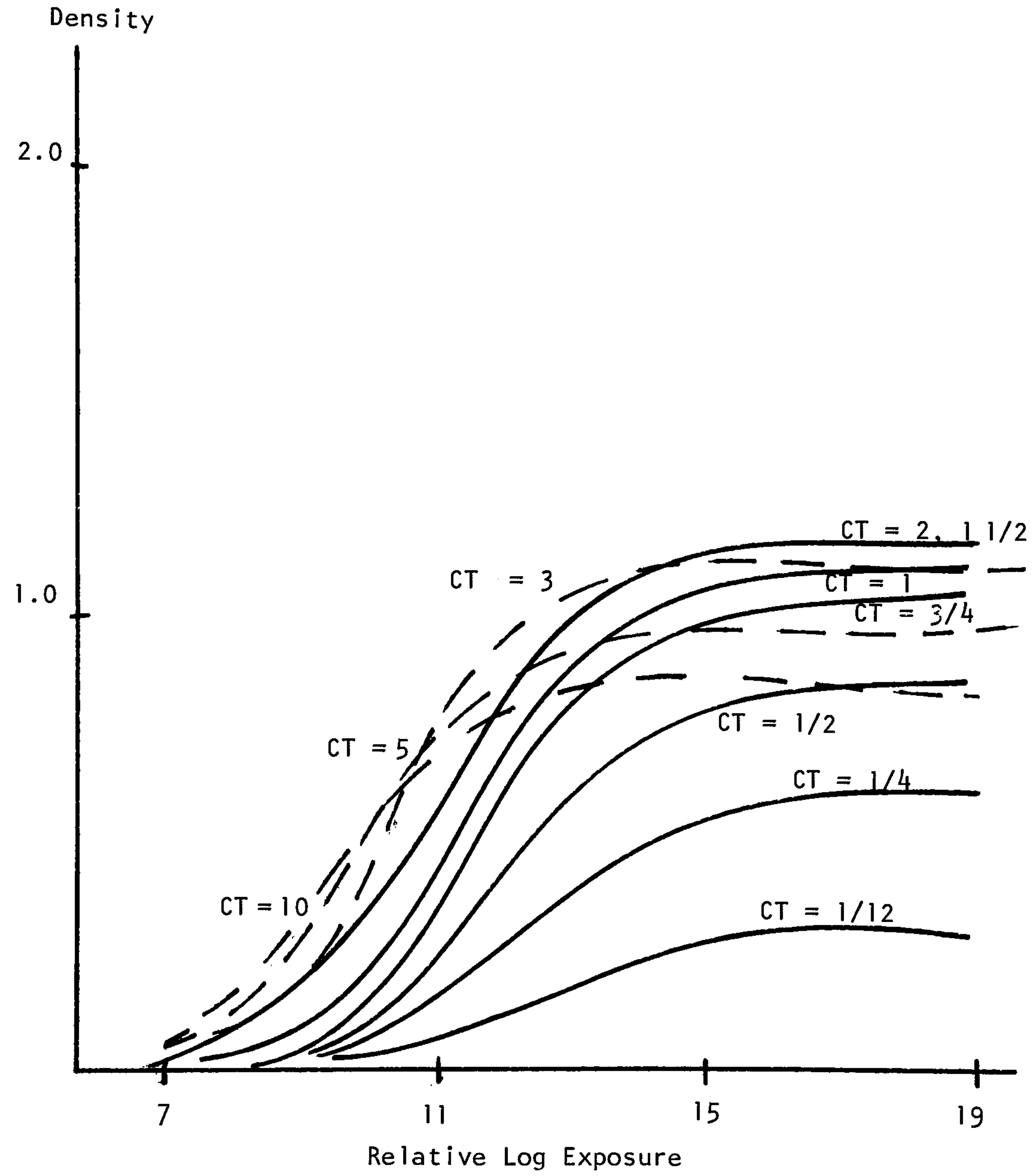


Figure 12. Characteristic Curves 12 1/2% Donor Contacted to "RP" Receivers at Varied Contact Times.

TABLE 1: Base Fog/Contrast Index/Δ Density

	Contact Time (HRS)	1/12	1/4	1/2	3/4	1	1 1/2	2	3	5	10	15	24	TRI X
12 1/2%	NMC	.08 .25 .18	.085 .67 .31	.105 1.2 .9	.12 1.8 1.2	.16 2.2 1.6	.16 2.7 1.8	.21 3.3 2.1	.275 3.8 2.6	.4 5.0 2.7	.79 4.8 2.7	1.79 4.5 2.7	1.2 4.2 2.2	.36 .58 .9
	MA	.305 .42 .2	.325 .8 .6	.355 1.52 1.1	.37 2.0 1.4	.395 2.5 1.6	.435 3.2 2.0	.49 3.5 2.2	.585 4.0 2.2	.755 3.8 2.1	.98 3.6 2.0	-	-	
	RP	.585 .4 .3	.595 .8 .6	.635 1.26 .9	.66 1.68 1.1	.68 1.8 1.1	.75 2.2 1.2	.76 3.0 1.2	.90 2.5 1.1	1.045 2.2 1.0	1.20 1.5 .8	-	-	
6 1/4%	NMC	.07 .26 .3	.08 .57 .7	.09 .99 1.1	.10 1.48 1.5	.115 1.82 1.9	.15 2.2 2.2	.18 2.8 2.5	.23 3.4 2.75	.33 4.5 2.94	.595 4.6 2.9	.70 3.6 2.6	.94 2.9 2.3	.36 .58 .7
	MA	.31 .24 .3	.32 .68 .8	.34 1.23 1.3	.36 1.54 1.7	.375 2.3 1.9	.43 2.5 2.3	.465 2.9 2.4	.51 3.3 2.3	.64 4.3 3.2	.82 3.8 2.2	-	-	
	RP	.58 .31 .4	.585 .74 .8	.61 1.14 1.0	.64 1.36 1.2	.65 1.6 1.2	.72 1.84 1.3	.73 2.2 1.2	.85 2.2 1.2	.93 1.9 1.1	1.14 1.32 .9	-	-	
3%	NMC	.09 .56 .2	.105 1.17 1.1	.145 2 1.7	.19 2.6 2.1	.245 3.0 2.4	.31 3.2 2.6	.41 3.6 2.8	.545 4.0 2.8	.815 4.0 2.65	1.375 3.5 2.2	1.54 3.0 2.0	1.98 1.9 1.6	.36 .58 .4
	MA	.325 .31 .4	.36 .74 .8	.425 1.14 1.0	.48 1.36 1.2	.54 1.6 1.2	.64 1.84 1.3	.74 2.2 1.2	.87 2.2 1.2	1.14 1.9 1.1	1.60 1.32 .9	-	-	
•	RP	.605 .64 .6	.64 1.31 1.0	.70 1.52 1.1	.77 1.63 1.2	.805 1.86 1.2	.94 1.64 1.1	.96 1.64 1.1	1.19 1.2 .9	1.46 .9 .7	1.64 .54 .5	-	-	
100%														.36 .58 1.4

TABLE 2: Resolution (Lines/mm.) High Contrast/Low Contrast

	Contact Time (HRS)	1/12	1/4	1/2	3/4	1	1 1/2	2	3	5	10
12.5% Donor [28.8 / 9.1]	NMC	9.1 -	14.4 2.0	16.2 4.0	14.4 4.5	14.4 4.5	14.4 4.5	12.8 4.0	10.2 2.0	4.0 -	- -
	MA	6.4 -	12.8 4.0	14.4 4.0	11.4 4.0	11.4 4.0	11.4 4.0	9.1 2.9	9.1 2.0	5.1 -	- -
	RP	6.4 -	8.1 2.0	11.4 3.2	10.2 2.9	7.2 2.0	7.2 1.3	5.1 1.1	4.0 -	2.0 -	- -
6.25% Donor [28.8 / 4.5]	NMC	9.1 -	12.8 2.0	14.4 4.5	14.4 4.5	16.2 5.1	14.4 6.4	12.8 8.1	11.4 8.1	8.1 3.6	2.9 -
	MA	7.2 -	14.4 4.0	14.4 4.5	11.4 4.5	11.4 4.0	12.8 4.5	10.2 4.0	10.2 4.5	7.2 2.0	- -
	RP	9.1 -	9.1 2.0	11.4 2.9	11.4 4.0	9.1 4.0	9.1 2.0	8.1 2.0	6.4 2.0	4.0 -	- -
3% Donor [28.8 / 0]	NMC	9.1 -	12.8 -	14.4 1.8	16.2 4.0	16.2 4.5	16.2 5.1	16.2 6.4	18.1 5.7	12.8 4.5	7.2 2.0
	MA	7.2 -	12.8 -	16.2 2.0	16.2 4.0	16.2 5.1	16.2 4.5	16.2 4.0	14.4 4.0	11.4 4.0	0 -
	RP	6.4 -	10.2 -	11.4 1.1	14.4 2.0	12.8 2.3	11.4 2.0	11.4 2.0	9.1 2.0	7.2 2.0	- -

TABLE 3: Speed Increase Receiver/Donor at .1 over Base Fog/ .6 over Base Fog

	Contact Time (HRS)	1/12	1/4	1/2	3/4	1	1 1/2	2	3	5	10	15	24
12%	NMC	1.6 -	1.7 -	1.9 5.0	2.1 7.2	2.8 9.8	2.9 10.7	3.0 12.0	3.1 13.2	3.8 15.8	4.5 20.9	5.0 21.9	5.8 22.9
	MA	1.1 1.9	1.6 2.1	2.0 6.5	2.4 8.1	2.7 9.8	3.0 11.5	3.4 13.2	3.6 14.4	4.0 17.4	5.2 20.9		
	RP	1.1 -	1.5 1.7	2.0 5.5	2.3 7.9	2.8 10.7	3.7 11.0	2.0 11.7	3.5 14.4	3.9 15.1	4.5 14.8		
6%	NMC	.7 -	1.4 .8	2.0 4.6	2.6 7.1	2.8 9.3	3.1 10.5	4.2 11.8	5.1 15.2	5.9 17.0	7.1 22.4	15.8 24.6	11.0 28.9
	MA	.9 -	1.8 2.0	2.5 6.0	2.8 8.0	3.2 9.6	3.4 12.0	4.5 13.5	4.7 15.9	5.6 19.5	7.2 23.0		
	RP	1.3 -	1.9 2.0	2.3 5.9	3.1 8.7	3.5 9.8	4.1 11.5	4.3 12.6	4.5 14.8	7.1 17.4	7.4 16.6		
3%	NMC	1.2 -	2.2 4.6	2.7 7.8	3.7 9.6	4.1 11.2	5.1 12.3	5.9 15.5	7.1 16.6	7.9 18.2	9.6 21.9	11.7 24.0	14.8 23.4
	MA	1.5 -	2.5 5.9	3.5 8.9	3.8 10.0	4.4 11.8	5.0 14.8	6.5 15.5	7.8 16.2	10.5 19.1	11.2 20.0		
	RP	1.8 1.6	2.6 5.9	3.5 8.5	4.2 9.8	4.7 11.2	5.5 12.6	5.9 12.6	6.5 12.6	5.1 3.5	5.9 -		

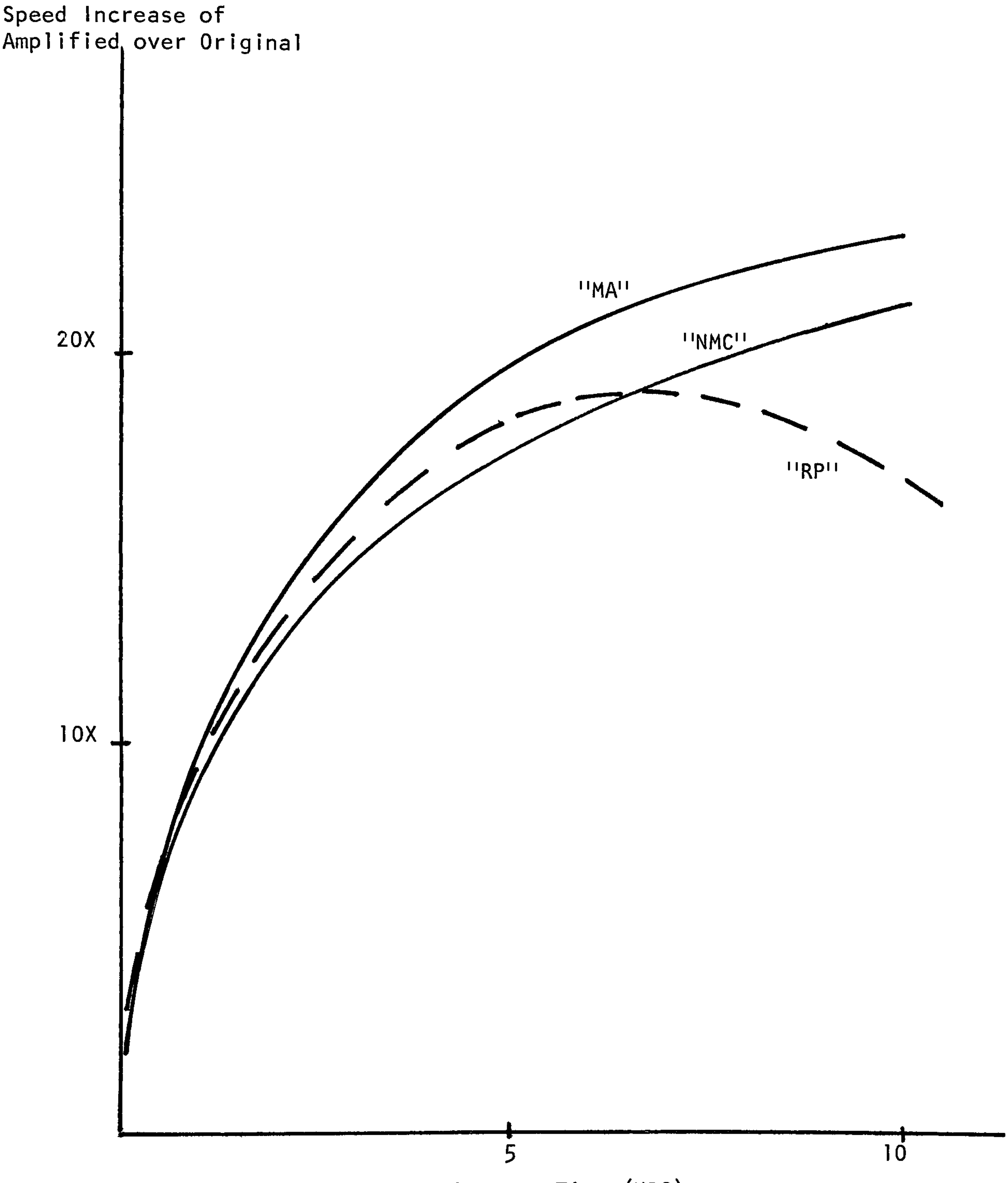


Figure 13. 6 1/4% Donor - Speed Increase vs. Contact Time.

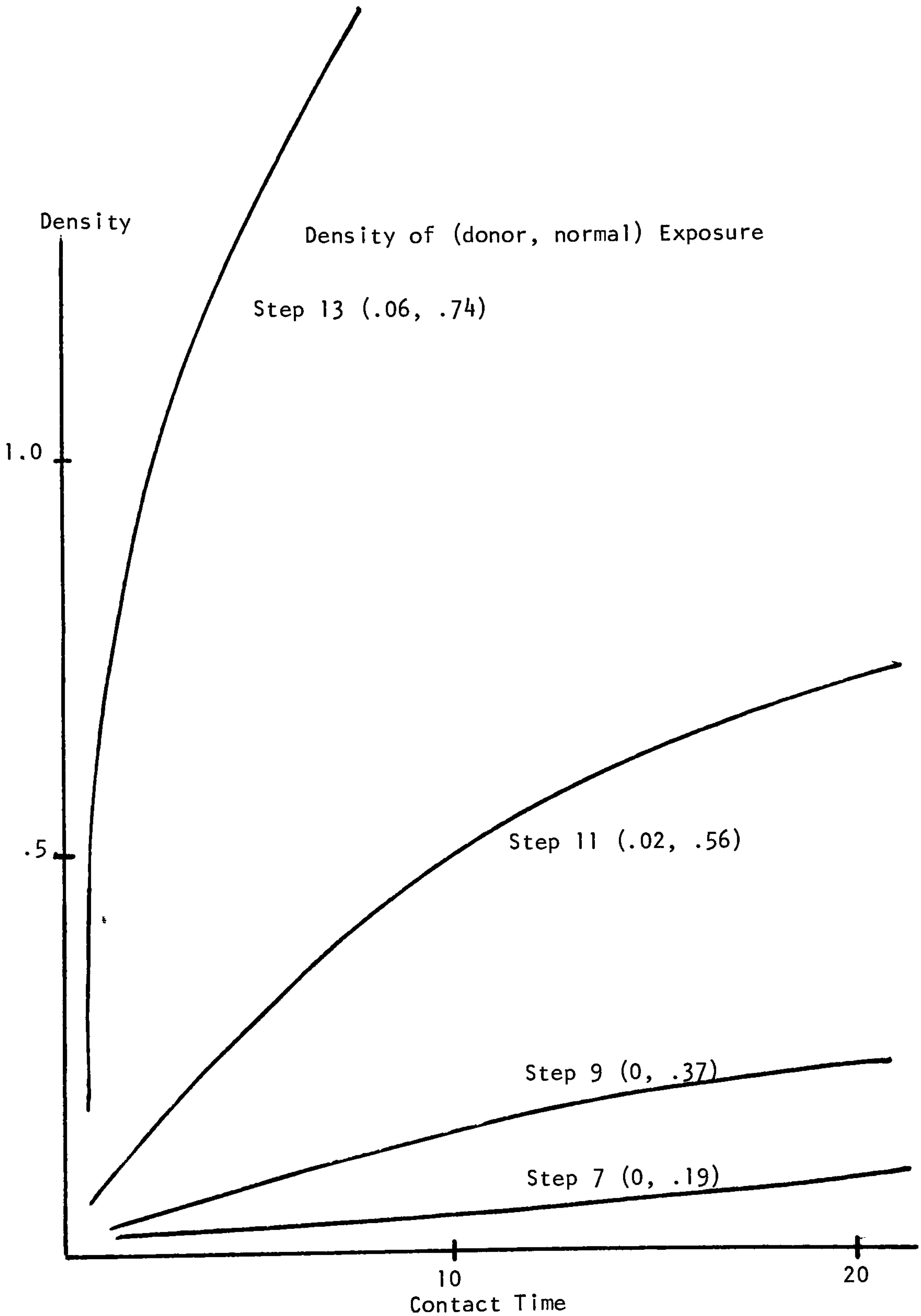


Figure 15. Density vs. Contact Time for Specific Amplified Steps (6 1/4% Donor - "NMC" Receiver).

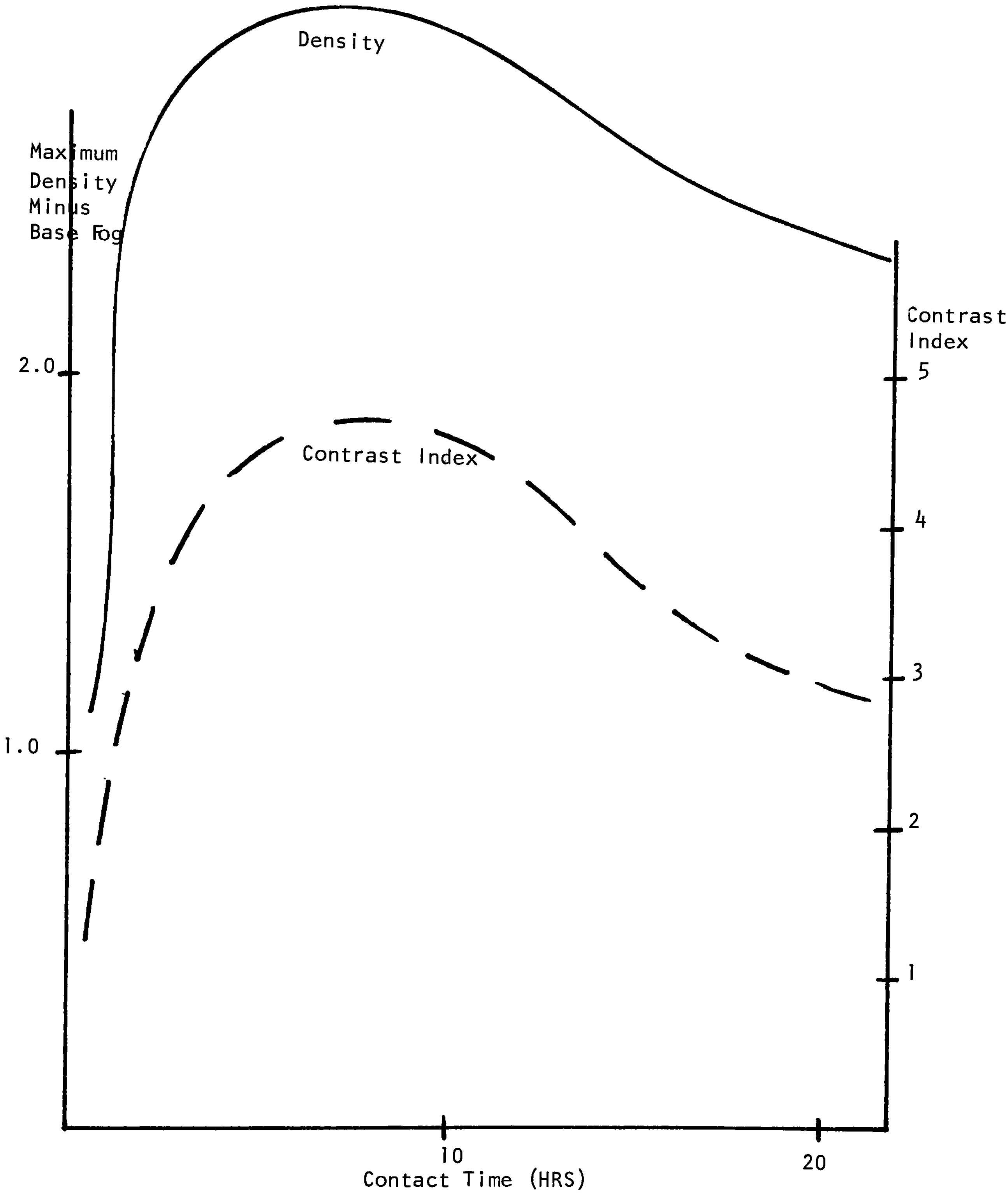


Figure 14. 6 1/4% Donor - Change in Density/Contrast Index Versus Contact Time

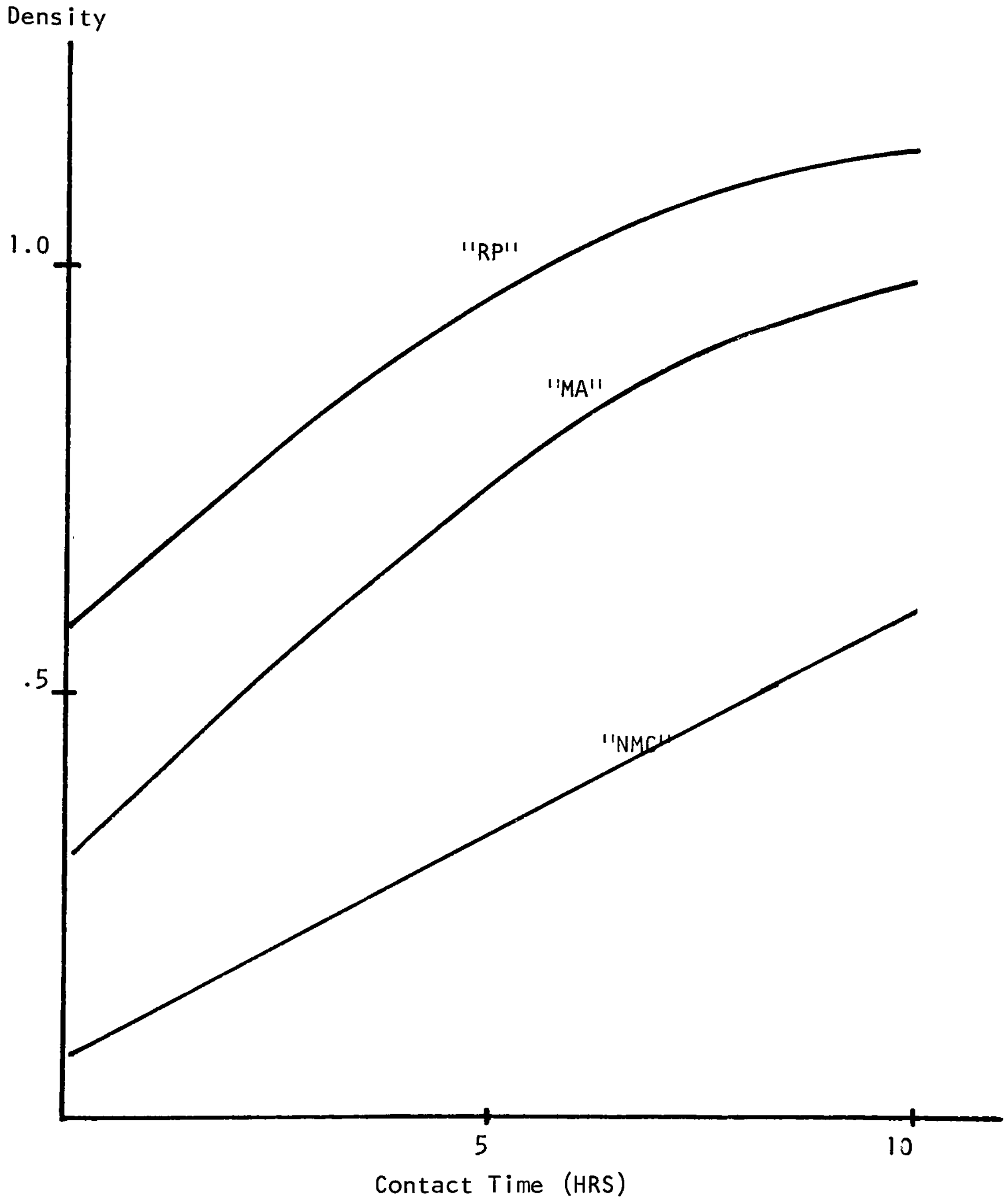


Figure 16. Base Fog of 6 1/4% Donor vs. Contact Time.

The following tables summarize the data from "best" point of view, as determined in "B" phase. A "Best", contact time range was determined subjectively, by observing and comparing the amplified images on a light table with fixed illumination.

TABLE 4: Subjective Assessment of "Best" Image

Film Type	Contact Time (HRS)	Mean
NMC	1/3 - 3	1 3/4
MA	1/2 - 1 1/2	1
RP	1/2 - 1	3/4

The "NMC" film was the easiest to view as its base plus fog level was the lowest thus the image was observed against a fairly clear background. After three hours contact time the information is still present (as seen from the characteristic curve, Figure 4) but the images were dark and the triads could not be discerned well. Increasing the background illumination would shift "best" contact time.

The following tables delineate quantitative "best" values determined for resolution and sensitometric data.

Table 5 shows a listing of contact times for "best" curves; "best" curves here are defined as those which have highest change in density and contrast index values.

TABLE 5: Contact Time for "Best" Curves

	12.5%	6.25%	3%	Mean
NMC	10	5	2-3	6 HRS
MA	2-3	2	1.5	2 HRS
RP	1.5 - 2	1 1/2	1 - 1.75	1.7 HRS

This table, when compared to Table 4, indicates that the "Best" quantitative curves have longer contact times than those found to be most desirable subjectively at the illumination level of the light table.

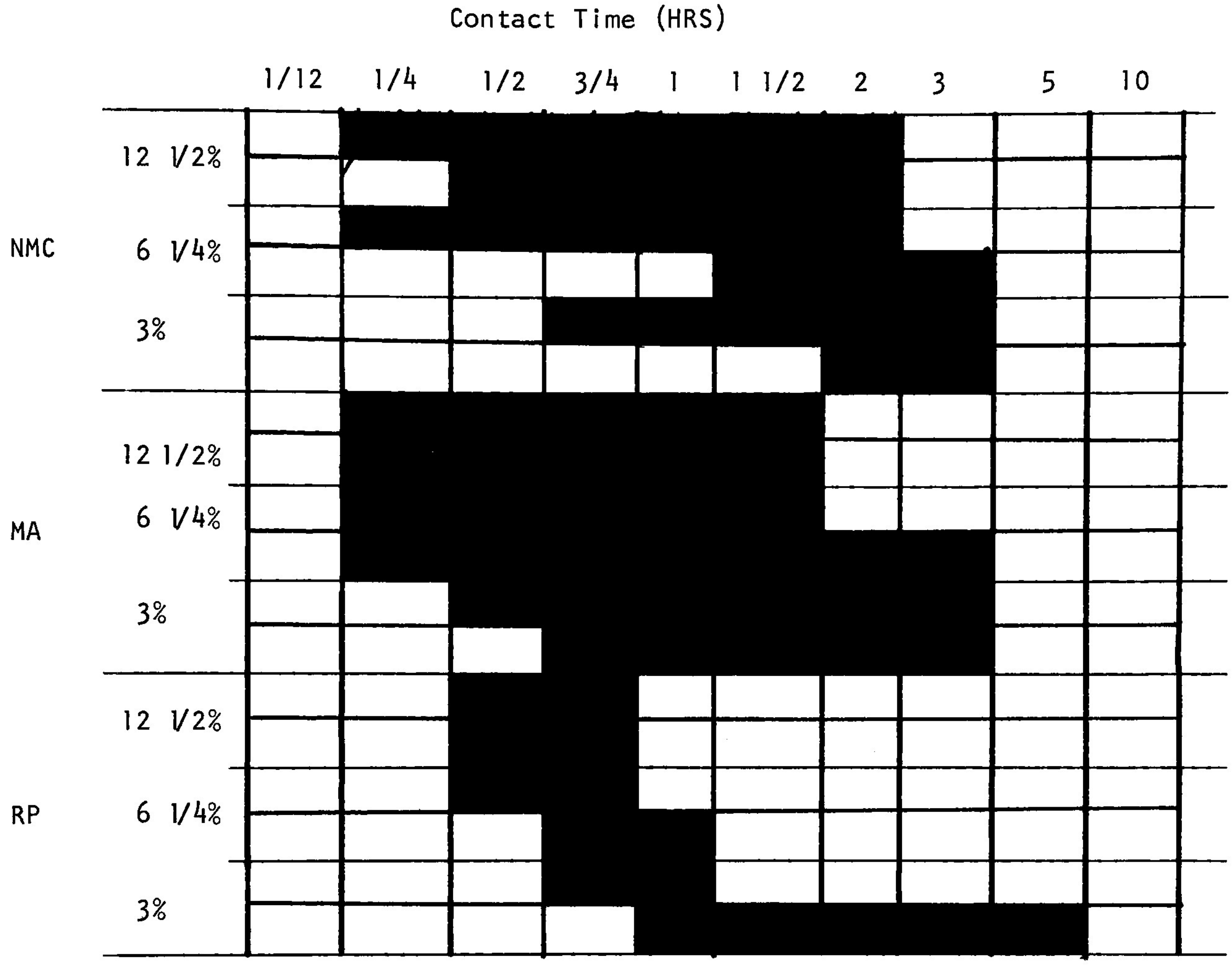
The base fog values for the range of "Best" characteristic curve as listed in Table 5, were averaged for each film type to see if comparisons could be made between "Best" curve and the base fog level.

TABLE 6: Base Fog of the "Best" Characteristic Curves (from point of view of ΔD and Contrast Index)

Film Type	Mean Base Fog	Std Dev.
NMC	.57	.11
MA	.57	.10
RP	.75	.02

Resolution readings are tabulated in Table 7 and the range of best resolution noted in Table 7.

TABLE 7: Range of Best Resolution
High Contrast/Low Contrast



The initial resolution increases as contact time increases to a maximum value. Resolution stays relatively constant then drops off apparently not because of deterioration of the image (particularly for the low contrast resolution), but because the illumination is no longer strong enough to permit the triads to be discerned. The high contrast resolution is an indicator of degradation of resolution because of the intensification process. The low contrast resolution is an indicator of the effectiveness of the second stage amplification procedure in delineating information not discernable is the target.

The combination of increase in density and the contrast index, seen in Table 1, give a good indicator of the size and slope of the characteristic curve. The best characteristic curve from a point of view of the combination of high contrast, to emphasize difference in tone, and largest change in density, which indicates the range of density available, gives a "best" indication for the characteristic curve: Both contrast index and change density were seen to rise sharply (Table 1) then decrease as contact time was increased. Speed as listed in Table 3, continued to increase even after change density and contrast index had peaked, although the rate of increase slowed considerably. Note that the speed increases are much higher calculated at .6 over base fog than at .1, because the amplified characteristic curve is much higher contrast than the original.

Considering the three receivers used, "NMC" appeared to be marginally preferable to "MA" in most areas, although it required longer contact times for the same speed increase. It was subjectively preferable because of its low base fog levels and the characteristics of its Density/Log Exposure curves. Both were much superior to "RP".

It is difficult to specify a best contact time as one would choose this parameter in accordance with the requirements of the project. To amplify a continuous tone photograph, one would want a large change in density. However, if it were desirable to amplify a specific area, one might want to disregard the total image and contact the donor for extended time periods to amplify a specific area of image. For a 12% image for "NMC" receiver, for example, using a contact time of 10 hours gives a good overall amplification. However, to see a difference in step 5 and step 6, one would want to use a 24 hour contact time where the difference is .07 density units rather than 0 (for both at 10 hours contact time) even though the base fog level is 1.2, and the overall change in density has decreased 20% and contrast index has decreased 15%.

RECOMMENDATIONS

The study carried out for this thesis involved specific emulsions chosen for non-scientific reason, that is the donor emulsion is an emulsion of interest to the agency funding my studies. The receiver emulsions were chosen as being easily acquired in a relatively isolated environment but with a medical facility nearby.

From the process point of view, it would be of interest for further studies to optimize the donor and receiver emulsions possibly with a view to determining general characteristics of each. The microstructure and detective quantum efficiency of the emulsion is of interest. Process parameters such as the quantitative effect of changing pH, process temperature, activating time, type or number of baths, and variation of the activation temperature require study. In addition studies to determine the reusability of the activating solution, and the "process ability", or the susceptibility of this process to being handled by machine, would be of interest.

SUMMARY

The specific technique of radioactivating using thiourea S^{35} was evaluated and found to be easily carried out in any small photo facility assuming appropriate licensing has been arranged. Results obtained indicate that Tri-X Pan film is usable as a donor emulsion and that Kodak Type NMC film was the best receiver of the three intensively studied. This film gave a speed increase, calculated at a density of .6, of 21 times the original at 10 hours contact time and low contrast resolution increases over the original of 6.1 to 4.5 lines/mm.

The targets were not brought back to a 100% exposure, that is, showing the same characteristics as a 100% Tri-X exposure characteristic curve. This was not feasible as all the receiver emulsions were high contrast, as opposed to wide latitude and lower slope of the Tri-X Pan characteristic curve.

Significant increases in low contrast resolution and speed were observed for the amplified image as compared to the initial. The speed appeared to increase with a limit depending on the receiver film. Maximum speed increase was noted at twenty nine times that of the target.

There is considerable scope for further research in this area, particularly with respect to reducing activation times and optimizing the donor and receiver films.

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APPENDIX

APPENDIX A

APPARATUS AND MATERIALS

Small Darkroom - R-15 (RIT)

Chemical work area with fume hood.

Chromega Dual Action Agitator Color Processor Serial # 02 011184 sold by Omega Division of Berkey Marketing Division

Chromega Drum 11 8 x 40 Color Processor Cat No. 469-010

Liquid Scientillation Counter - Searle Delta 300 689 Liquid Scintillation System University of Rochester Serial #24750

Hasseblad 500C Camera Serial #UH128673, Lens-Zeiss planar lens 1:2.8 f - 80mm. Serial #NR SS70375

Oscilloscope Type 4S3 Serial #029046

MacBeth Transmission Densitometer Serial #2622A, RIT #-113368 with Standardizing Wedge #cc-02

Kodak Model 101 Sensitometer EK Serial #101872 RIT Serial #58740 with included step wedge and a inconel filter (ND-2.1)

Gossen light meter, Serial #7C65115 RIT serial 137173

Tripod, Sampson Quick Set RIT #62175

Two Studio Lights

Kodak Versamat Processor

Kodak Xomat Processor

Resolution Test Object (Low Contrast) RT-5-75

Resolution Test Object (High Contrast) RT-5-75, both produced by Graphic Arts Research, Rochester Institute of Technology, Rochester, New York.

Kodak Wratten Gelatin Filters:

No. 96 ND .97

No. 96 ND .4

No. 96 ND 1.00

No. 96 ND .5

8 x 10 Spring loaded WAFER rigid form cassettes, 9 x 10 inches, produced by Halsey X-ray Products, Inc. PAT NOS 2298587-2878389

Kodak Tti-X Pan Film 70mm Perfs Type 11

70mm Vinton F-95 core

TX t35 LOT NO 5063 267 32

Kodak "RP" Xomat Medicine X-ray film CAT 9752726

Kodak "NMC" nuclear medicine film CAT 124 5349

Kodak "X-OMAT MA" film

Thiourea S^{35}, New England Nuclear 025 7A3-30 8/4/78

Ph tester, Panpeha, pan pH; Carl Schleiche and Schull Co.,

NaOH

Methanol

Kodak F-5 FIXER, CAT 197 1920 KP 66251 A-1

Electronic balance, Sartorius, #4375

Eastman Kodak Company, Contrast Index Meter Model B.

APPENDIX B

Precautions required in the handling of the radioactive isotope were as follows:

The activating process was set up under a fume hood.

Rubber gloves were worn at all times when working with the thiourea S^{35}.

Glassware was be kept washed clean and rinsed with distilled water.

A geiger counter was used to monitor levels of radioactivity in the laboratory.

NOTE: Maximum range of the beta particles (.167 Mev Maximum energy) is approximately 25 cm in air, .02 cm in glass.

APPENDIX C

Quantitative calculations for error in measurements follows:

A. Density:

For density measurements the error was broken into two parts, one, determined from past experience with the TD 504 indicated that for a uniformly exposed and processed piece of film, a difference of .01 density units could be determined by taking measurements in different parts of the film from edge to center. As a result of taking the mean of two readings, I arbitrarily gave this error a value of ± .005 density units. The other error, a compound of all other factors, was considered to vary with density level. Mean values for error, from a density of .1 to 2.5, were determined by taking the ± value for five levels, samples of no less than eleven pairs were used to give a mean value for error.

TABLE 8: Error in Density Readings

Density Level	Number of Pairs	Mean Error in Density Units	% Error		
			± .005	± Other	Total Error
.1	20	.005	5%	0%	5%
.5	24	.008	1%	.5%	1.5%
1.0	19	.009	.5%	.4%	.9%
1.5	12	.011	.3%	.4%	.7%
2.0	13	.010	.3%	.3%	.6%
2.5	11	.0125	.2%	.3%	.5%

An F test for variance was carried out and while this test is admittedly insensitive, it did verify that no difference in variances of the upper and lower readings were noted within 95% confidence limits.

B. Speed Increase

Error in speed calculation, that is the error in the times increase in speed was determined by drawing the calculated variation in density readings on the graphs, determining the speed increases of the mean and plus and minus values, then determining a percent error.

The calculated mean from fourteen data sets of three speed calculation gave a mean error of 4.5% with a standard deviation of .07%.

Contrast Index

The error in measurements made with the contrast index template was determined, by the size and type of the gradations, to be an error of 3%.

To determine the error in the contrast index readings, a line through the straight line portion of the curve were drawn, see Figure 10, one through the mean AB, and two others through the extreme A_1B_2 and A_2B_1. The contrast index for ten data sets were calculated and this error added to the error in the contrast index meter. This error was determined to be 5%, thus total error for the contrast index measurements is given as 8%.

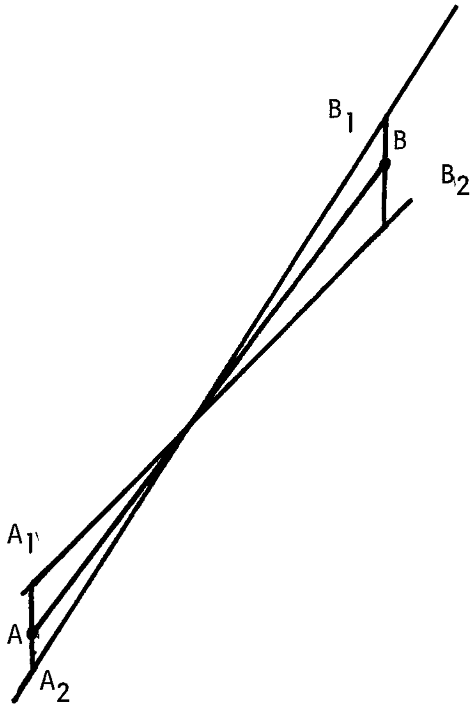

Figure 19: Contrast Index Error Determination

APPENDIX D

ACTIVATION SERIES

The thiourea activation process was run as specified except that at intervals of 2, 5, 10, 15, 22 1/2 minutes a step tablet was removed and stored in distilled water. After thirty minutes all tables were reinserted and the process completed. After contacting the wedges to NMC, sensitometric data was taken to determine the effects of shortening activation time. See Figures 17 and 18.

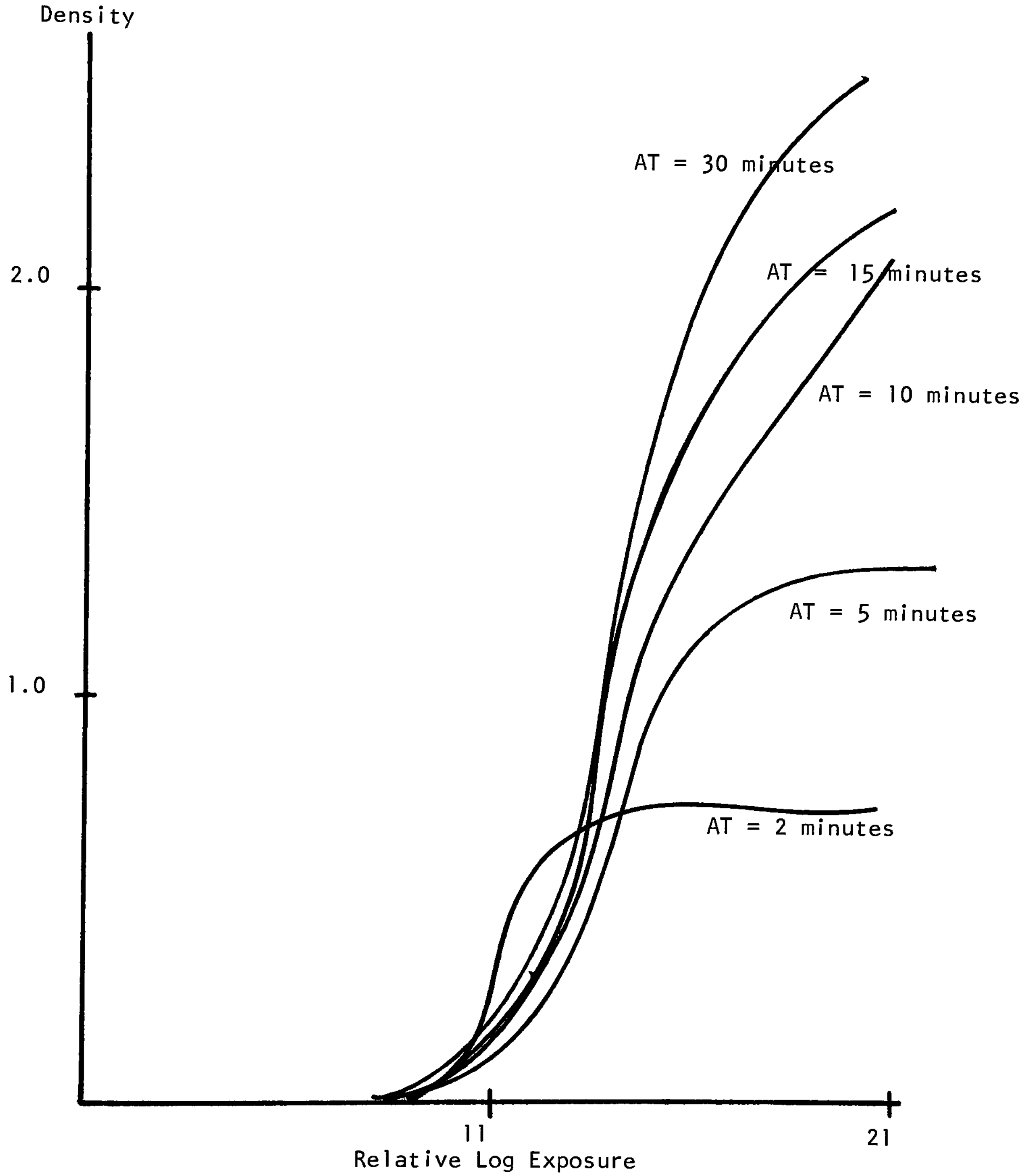

Figure 17. Characteristic Curves for Activation Time (A.T.) series with "NME" Receiver, Contact Time of 2 hours.

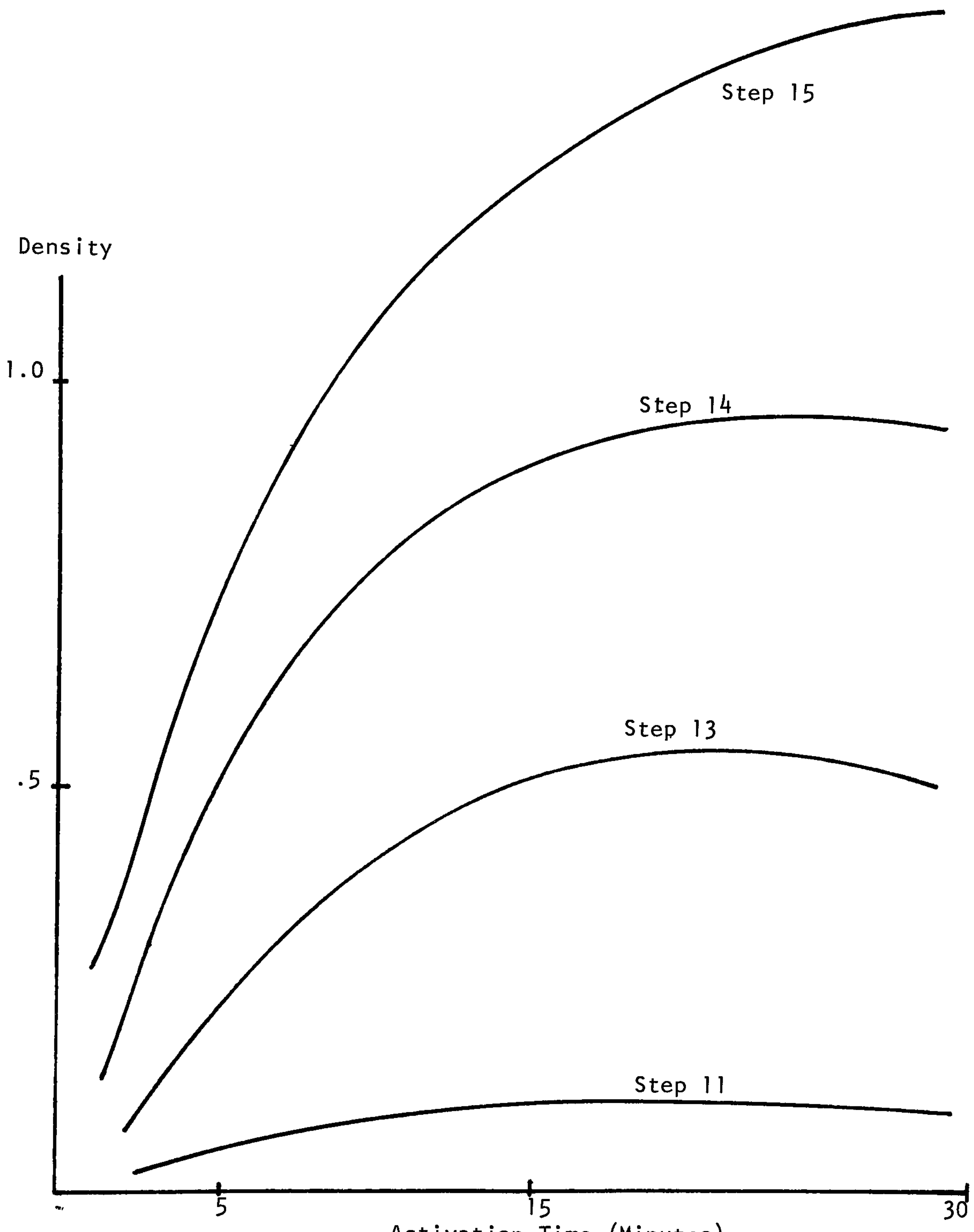

Figure 18. Density versus Activation Time for Specific Steps with NMC Receivers and a Contact Time of 2 hours.

APPENDIX

LIQUID SCINTILLATION DATA

Approximately one cc of activation solution was taken at the beginning and after the thirty minute activation period. This was added to 9 cc of fluorescent cocktail and the results fed through the liquid scintillation counter.

	Before		After	
Reading	cpm	eff	cpm	eff
1. t = 1 minute	66889	.785	31010	. 78
2. t = 5 minutes	67142	.775	31803	.765
3. t = 5 minutes	69093	.765	32405	.765

	Bottle wt Empty	Bottle wt Full	Activator wt
Before	9.39061	10.41349	1.02208
After	9.42537	10.47010	1.04473

$$\% \text{ activator remaining} - \frac{\text{final}}{\text{initial}} \times 100\%$$

Sample	Remaining
1	45.7%
2	47.0%
3	45.9%
	Mean 46.2%
	Standard deviation .7%

$$\text{Area} = \frac{3 \times (7 \times 14)}{(2.54)^2} + 3(5 \times 1)$$

Area of Tri-X emulsion = 60 square inches $\pm$ 5%