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Processing Corrections for Skylab Photographic Imagery *

Improperly exposed or filtered aerial imagery may be salvaged in the laboratory, saving the expense of additional flights to reacquire that imagery.

ABSTRACT: *Camera filters were inadvertently omitted from the six-channel multispectral photographic camera (S190A) during the exposure of the first roll of film from each channel on the final manned Skylab mission. Each of the films was overexposed and degraded as a result of the filter omissions. Explained are the techniques used by the NASA/JSC Photographic Technology Division to evaluate and process those films. These or similar techniques can be used in other photographic multispectral remote sensing applications in which black-and-white infrared and panchromatic or color infrared film are degraded due to loss of filtration or to overexposure. Results prove that data may be salvaged after camera exposure errors are made thus saving the expense of reacquiring data.*

BACKGROUND

EARTH RESOURCES data gathering was a major program of the NASA Skylab missions. The Earth Resources Experiments Package (EREP) provided data to investigators in the areas of agriculture, forestry, hydrology, geology, oceanography, geography, meteorology, and ecology.

One important part of EREP was the multispectral photographic camera (S190A) designed to provide precise six-channel multispectral 70mm film records from a space platform. Six matched f/2.8, six-inch focal length lenses with a 21.2° field-of-view covered an area of about an 88 nautical mile square (7744 square nautical miles) per frame during the three manned Skylab missions.[3] The nominal photographic parameters for the multispectral camera are given in Table 1.

The spectral sensitivity curves for the films are shown in Figure 1 and the filter transmission curves are shown in Figure 2.

On the final Skylab mission the multispectral camera system recorded over 15,000 frames of Earth Resources imagery.

During the exposure of the first set of S190A films on the final manned Skylab mission, the six camera filters were inadvertently omitted from the multispectral camera. During this period of late November to early December 1973, a series of 10 EREP passes were made over 15 states in the United States, Venezuela, Brazil, Puerto Rico, Central America, the Gulf of Mexico, the Caribbean Sea and other sites. A total of about four hundred 70mm frames was exposed in each of the channels or a total of 2400 frames of valuable data from S190A was improperly exposed.

The NASA/JSC Photographic Technology Division (PTD) was assigned the responsibility of salvaging the data from these ten

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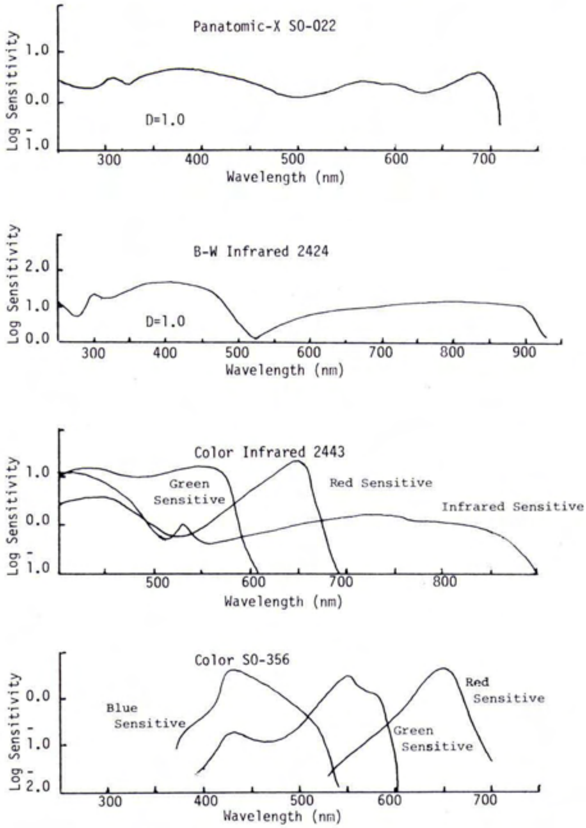

FIG. 1. S190A film spectral sensitivities.

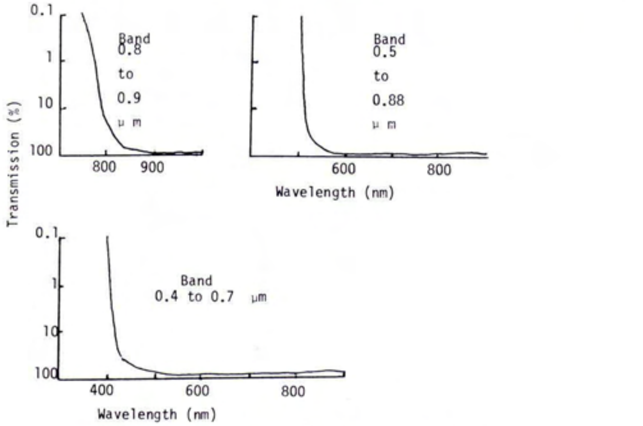

FIG. 2. S190A filter transmissions.

TABLE 1. NOMINAL PHOTOGRAPHIC PARAMETERS.

FILM (all on 4.0 mil base)	Spectral Sensitivity with filter (μm)
Kodak Infrared Aerographic Film 2424	0.7 to 0.8
Kodak Infrared Aerographic Film 2424	0.8 to 0.9
Kodak Aerochrome Infrared Film 2443	0.5 to 0.88
Kodak High-Definition Ektachrome Film SO-356	0.4 to 0.7
Kodak Panatomic-X Aerial Film SO-022	0.6 to 0.7
Kodak Panatomic-X Aerial Film SO-022	0.5 to 0.6

EREP passes. PTD already was responsible for processing S190A original films and duplicating them for national and international distribution.

The techniques used to salvage the multispectral camera data have applications in other programs that use these films in which the possibility of exposure without the assigned filter always exists. The S190A films and filters are commonly used for applications like remote sensing from aircraft. They also have routine photographic applications. The salvaging techniques and their derivations are described here for potential applications with these and other films.

DEFINITION OF THE PROBLEM

Each of the six films was degraded in varying amounts, the extent of which required precise definition prior to any decision regarding the handling of the film. Two steps were taken.

- Sensitometric definition of the problem.
- High altitude simulation of the S190A imagery.

SENSITOMETRIC DEFINITION

Exposures were made on each of the films with and without filters to simulate the S190A system using the I-B Precision Sen-

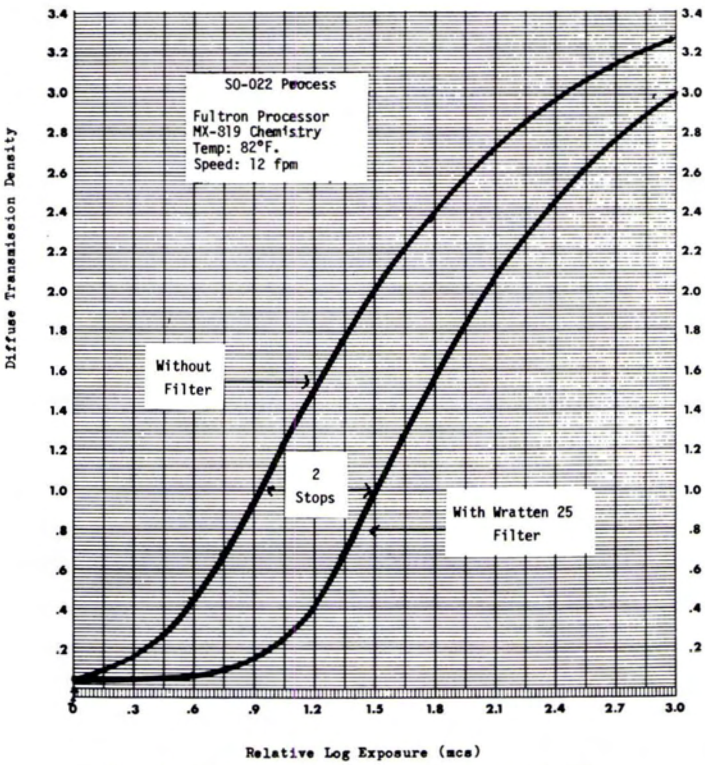

FIG. 3. Kodak Panatomic-X Aerial Film SO-022.

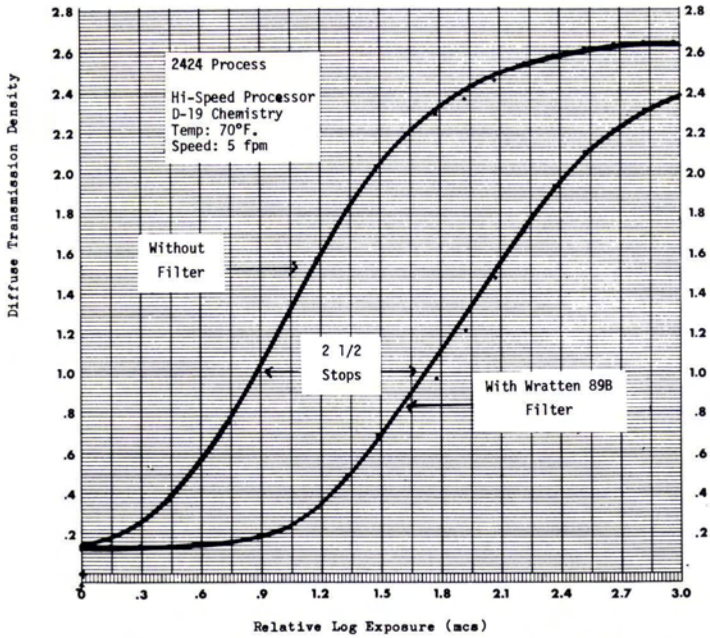

Fig. 4. Kodak Infrared Aerographic Film 2424.

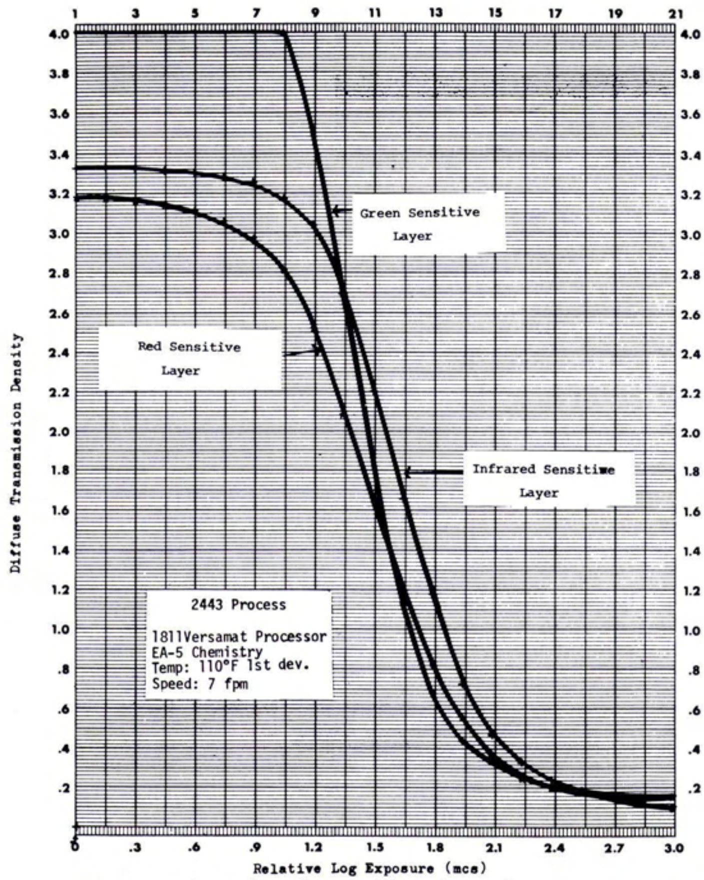

Fig. 5. Color Infrared 2443, filtered, tricolor curve.

TABLE 2. SPEED SHIFTS AND COLOR BALANCE.

Film	Wratten Simulation Filter	Overexposure with No Filter
SO-022	25	2 Stops
2424	89B	2½ stops
2443	12	1 stop (visual)
SO-356	2A	None

TABLE 3. OVEREXPOSURES FOR FILM 2443.

Layer	Overexposure
Infrared sensitive (cyan dye)	1¾ stop
Red sensitive (magenta dye)	½ stop
Green sensitive (yellow dye)	1 stop

sitometer routinely operated by PTD. It was found that each of the films except SO-356 was overexposed to some degree, and the color infrared film type 2443 suffered a gross change in color balance. Figures 3 through 6 show the sensitometric curves which resulted. Table 2 shows the effective speed shifts and color balance without a camera filter at density 1.0.

In the case of the black-and-white films, two to three stops (four to eight times) in film speed had to be lost in the chemical process without excessive subject contrast loss.

In the case of the color infrared film, 2443, each of the three layers (infrared sensitive, red sensitive, and green sensitive) were overexposed but at varying degrees. Table 3 gives these overexposures for 2443 (Figures 5 and 6) as measured at a density of 1.0. The challenge was to design a chemical process, adjusted to cause a loss in effective film speed without sacrifice of subject contrast, to compensate for the varying overexposure in each layer.

HIGH ALTITUDE SIMULATION

A second consideration in developing an understanding of the problem was to simulate as closely as possible the actual imagery from the Skylab spacecraft. A multispectral simulation was accomplished using a NASA RB-57 aircraft flying at 60,000 feet over a variety of subjects: i.e., urban, agricultural, desert, and water. The camera system used was an aircraft mounted version of the S190A multispectral camera system.

The exposed films were processed normally and densitometric analyses performed to predict additional effects expected by actual subject variation. It was found that film type 2424 was an additional one-half stop overexposed for a total of three stops.

Additional tasks including the design of a I-B sensitometric filter pack and exposure combination to simulate the atmosphere and spacecraft optical system were accomplished. These simulations were used to make closely color-balanced sensitometric approximations of the Skylab imagery to permit laboratory testing

PROCEDURE

PTD photographic scientists, S190A program experts, data users, and outside consultants all played key roles in the decisions regarding salvage of the data from these Skylab films.

The approach decided upon after studying simulation data, conducting preliminary processing tests and reviewing data applications included:

- Process the high-definition color SO-356 to normal PTD standards. Use these results to further evaluate subject matter prior to processing the remainder of the films in the set.
- Process one roll of Panatomic-X SO-022 to lose the required effective film speed with minimal gamma loss.
- Process one roll of black-and-white infrared 2424 to lose the required effective film speed with minimal gamma loss.
- Process the color infrared 2443 to produce close-to-normal-appearing imagery.
- Reconstruct the color infrared 2443 imagery to permit user densitometric analysis.

These directives were carried out as discussed in the subsequent sections.

PROCESS HIGH-DEFINITION EKTACHROME FILM SO-356.

The absence of the filter from SO-356 caused no significant speed gain problem, and the film was considered normal for processing purposes. This role was used as reference against which test results were compared and actual subject characteristics were studied. For example, a density analysis of this roll was compared with SO-356 and 2443 rolls from other S190A data sets resulting in the conclusion that ½ stop less speed loss was required for the 2443 due to the subject matter.

Separations of the red and green layers from this roll were used as part of the color infrared 2443 reconstruction process.

PROCESS PANATOMIC-X AERIAL FILM SO-022

Tests in available PTD processing machines indicated that a speed loss com-

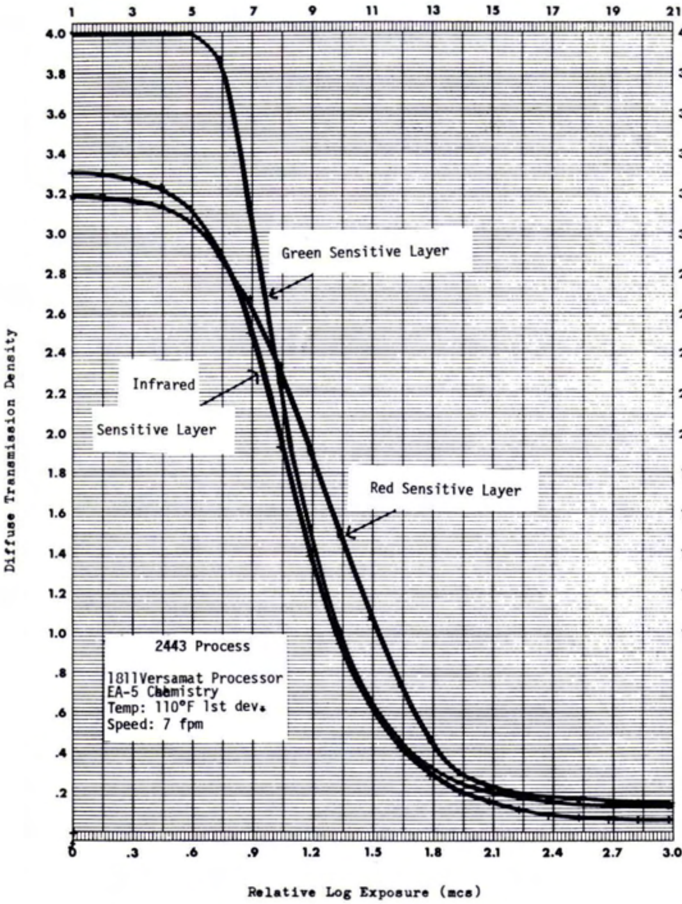

FIG. 6. Color Infrared 2443, no filter, tricolor curve.

pared to normal Skylab controls could be achieved by processing in the Kodak Versamat 11C-M. Normal control required processing in MX-819 chemistry in a Fultron processor. An additional speed loss for the required 2-stop loss was achieved by the additional of 1.45 grams per liter of Kodak Anti-Fog No. 6 to the MX-641 developer. Processing parameters of 8½ feet per minute at a temperature of 75°F through the modified developer resulted, as shown in Figure 7, in a density/exposure corrected image exhibiting the results of sensitivity of 0.4 to 0.7 μm subject reflectances.

PROCESS INFRARED AEROGRAPHIC FILM 2424[1]

When attempting to lose large amounts of film speed, the challenge is to maintain gamma. The speed change required for 2424, 3 stops, is significant and posed a severe problem.

The literature[1] revealed a developer formulation which resulted in a speed loss of 1½ stops yet maintained the gamma. Table 4 lists the formula named SD-42.

TABLE 4. DEVELOPER SD-42.

Water @ 125°F	500cc
Hydroquinone	20g
Sodium Sulfite (dessicated)	50g
Sodium Carbonate (monohydrated)	50g
Potassium Bromide	20g
Water to	1 liter

Additional testing centered around the use of either Kodak Anti-Fog No. 6 or sodium sulfite resulted in the addition of 50 grams per liter sodium sulfite to the SD-42 formula. Anti-Fog No. 6 resulted in unacceptably high granularity. A speed loss of 3 stops at a density of 1.0 was achieved as shown in Figure 8.

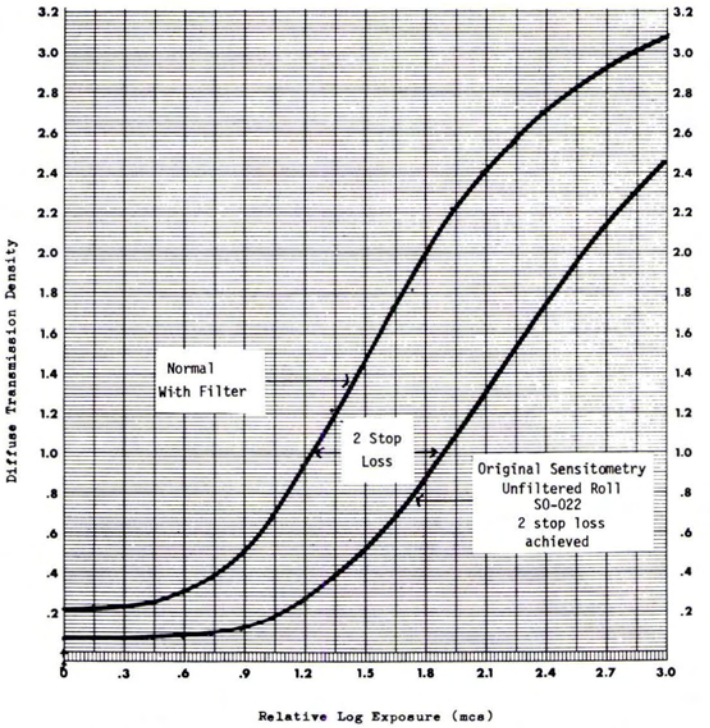

FIG. 7. Kodak Panatomic-X Aerial Film SO-022, S190A processing.

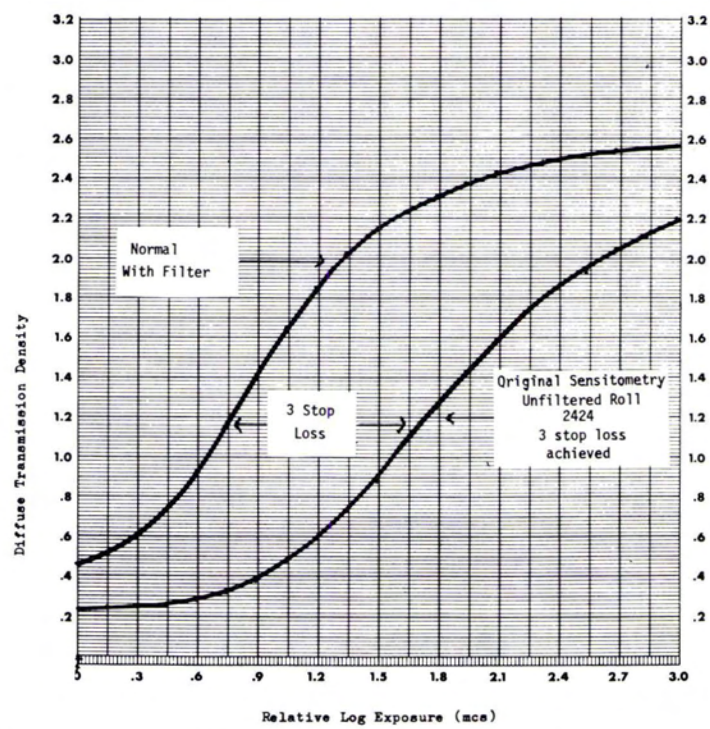

FIG. 8. Kodak Infrared Aerographic Film 2424, S190A processing.

PROCESS AEROCHROME INFRARED FILM 2443

The excessive contamination of all layers by unwanted blue light and the variation in effective speed gain layer-to-layer made this the most complex and difficult processing problem. Radiometric determinations of high accuracy from this data would be impossible because of varying and unknown blue to non-blue subject reflectance ratios within any given scene or frame. Because subjective color infrared reference is useful to investigators, particularly when differentiating water and vegetation, the decision was made to process the color infrared 2443 film to produce a close-to-normal-appearing image. This meant the results would appear sensitometrically correct but imagery would remain radiometrically incorrect.

NASA requested Eastman Kodak to recommend a modified EA-5 chemistry process for 2443 in a Kodak 1811 Color Versamat. PTD also conducted tests to study a modified process. A combination of the two produced imagery which will be useful for subjective analysis.

Using a Kodak 1811 Color Versamat and EA-5 chemistry, the following changes from a normal PTD 2443 control were made:

- A color developer pH of 11.05 instead of 11.60.
- MX-870 neutralizer was added to EA-5 neutralizer in a 1:1 ratio.
- The first developer temperature was lowered 10°F to 100°F.

Tricolor curves for a normal PTD Skylab 2443 control and for the nonfiltered roll of 2443 are shown in Figures 9 and 10.

Measured at a density of 1.0, the red and green layers were about ½ stop fast and the infrared layer was about 1 stop fast. The resulting imagery easily met the subjective criteria and its potential for water and vegetation discrimination was not sacrificed. As a matter of fact, the imagery appeared normal

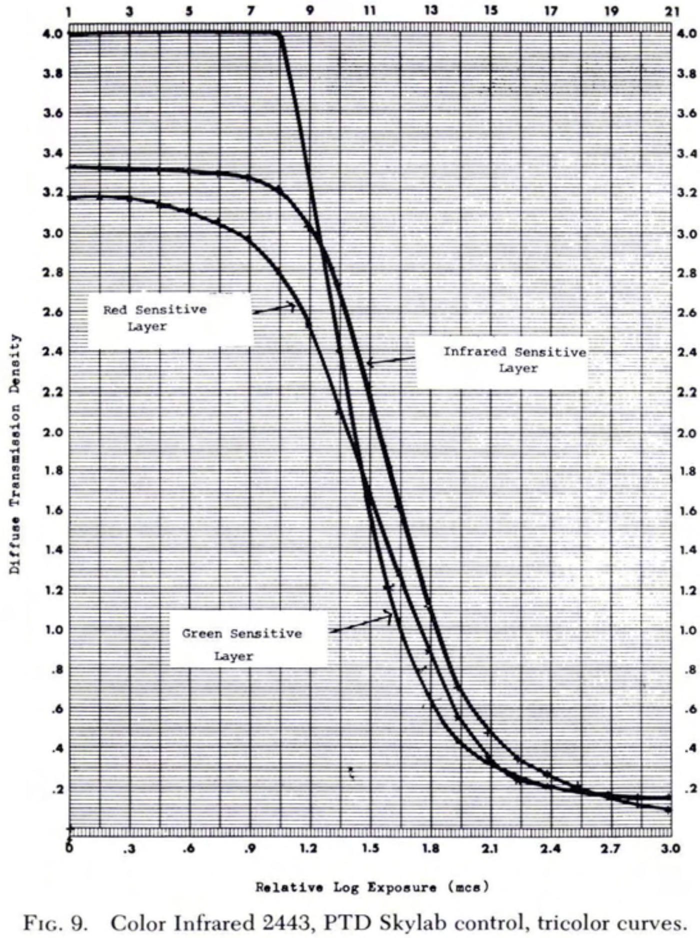

FIG. 9. Color Infrared 2443, PTD Skylab control, tricolor curves.

with the exception of color change in water areas. The extent of change in effective layer sensitivity resulting from the process may be observed by comparing Figures 6 and 10.

Reconstruction

The results achieved from the SO-356, SO-022, and 2424 were used to reconstruct and supply to investigators data which was otherwise unavailable from the 2443 imagery. Briefly, the red and green sensitive layers were reconstructed by separating the red and green layers from the correctly filtered roll of SO-356. The blue contaminated infrared sensitive layer from the unfiltered 2443 was also separated and made available for distribution to the scientific community. The infrared sensitive layer was reconstructed by overlaying or registering a positive from the SO-022 unfiltered roll (visible radiation sensitivity) and a negative from the 2424 unfiltered roll (visible plus infrared radiation sensitivity). The result was a negative image comparable to 2424 film exposed with an 89B filter.

The procedures used, too detailed to be included here, will be published at a future date.

Results

The imagery produced from the four processed rolls was such that it was useful for both analysis and reconstruction of severely degraded imagery. Density ranges in the imagery were comparable to those achieved when those same films were exposed with a filter and processed normally. The color infrared film imagery was "normal appearing" and could be used for subjective analysis.

Conclusions

Should a major problem occur during the acquisition of photographic multispectral, remote sensing or other data, and it is either

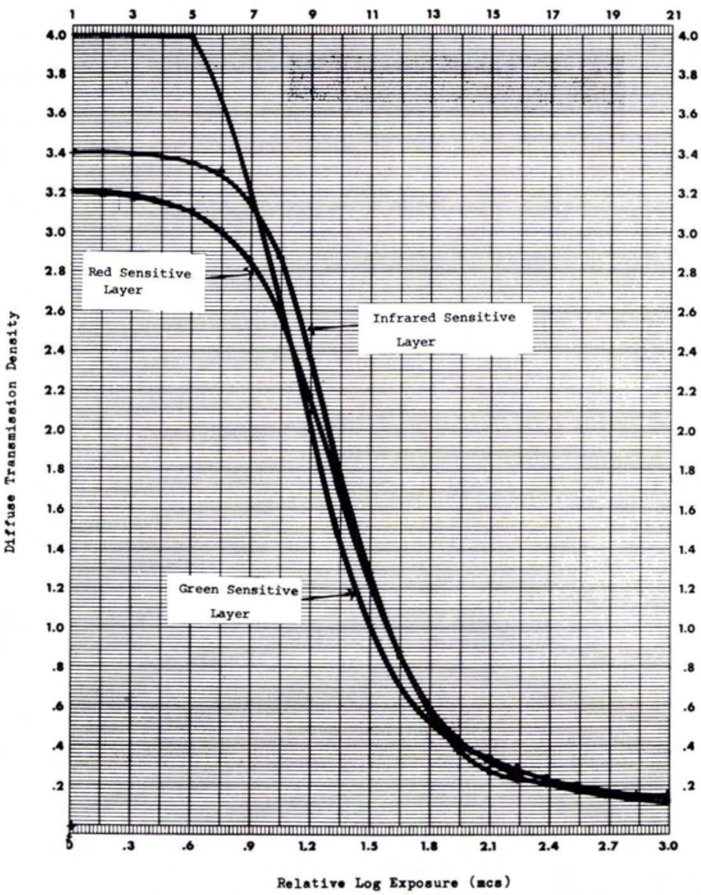

FIG. 10. Color Infrared 2443, unfiltered, tricolor curve, S190A original.

impossible or expensive to reacquire that data, an adequate salvaging job may be accomplished in the photographic laboratory. Omission of camera filters will cause an effective film speed gain and gross overexposure, but the speed may be compensated for and imagery salvaged in many cases. Significantly, a reasonable color balance salvaging may be accomplished with 2443 for subsequent use in subjective analysis. Reconstructions of missing imagery may be accomplished by using existing multispectral elements. Separations and negative-positive overlays were demonstrated as solutions to problems in this instance. Camera exposure errors due to overexposure may be corrected, within limits, in the photographic laboratory.

ACKNOWLEDGMENTS

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2. Exley, N. A. and Ives, C. E., "The Interrupted Processing Method of Compensating for Exposure Errors in Aerial Photography," *SPSE Journal*, Vol. 5, No. 2, March-April 1961.

3. "EREP Investigators' Information Book," MSC-07874, April 1973.

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