TOP SECRET
NO FOREIGN DISSEMINATION

[redacted]

Total No. of Pages 91
Copy No [redacted]

REPORT NO 6

KH-4B SYSTEM CAPABILITY

**Evaluation of SO-180 Film
For Use With The KH-4B System**

4 AUGUST 1969

Authors: [redacted]

Declassified and Released by the N R O

In Accordance with E. O. 12958

on NOV 26 1997

Itek OPTICAL SYSTEMS DIVISION
ITEK CORPORATION • 10 MAGUIRE ROAD • LEXINGTON, MASSACHUSETTS 02173

[redacted]

TOP SECRET
NO FOREIGN DISSEMINATION

HANDLE VIA
TALENT-KEYHOLE
CONTROL SYSTEM ONLY

CONTENTS

FIGURES

TABLES

1. SUMMARY

The fourth KH-4B system mission was launched on 7 August 1968. The primary objective of special engineering operations on this mission was the evaluation of SO-180 (Infrared Ektachrome) film, which this document reports. This SO-180 tag-on experiment constitutes the first operational KH-4 system photography with color material. Full loads of SO-180 film exposed in the main camera system on an experimental basis in 1967 from high-altitude aircraft had indicated significant potential application for satellite reconnaissance. Now, successful image acquisition and exploitation provides the community with documented experience on false color (color translation) reconnaissance from orbital altitudes. However, susceptibility to two photographic anomalies, differential loss of speed in the cyan layer and electrostatic discharge fogging, impeded demonstration of SO-180 film compatibility with the KH-4 system.

2. TEST DESCRIPTION

The FWD-looking camera (unit no. 309 with third generation Petzval lens I-205) was supplied with 15,200 feet of 3404 film plus 800 feet of SO-180 film as a tag-on. All of this 3404 film was exposed through a Wratten no. 25 filter in the primary position. Joining 3404 with SO-180 was an MCD actuator strip which was sensed by the material change detector (MCD) and automatically changed the filter to its alternate position.

In the alternate position was a Wratten no. 15 plus 0.9 IND combination filter. The Inconel neutral density (IND)* added to the yellow filter compensated for the (8×) higher speed of the SO-180 and thus permitted use of the same slits as required for the 3404 exposures. Although the full speed benefit of the SO-180 was not taken advantage of, this procedure was necessary to obtain correctly exposed color photography under the constraint of wide slits set for the prime mission material, 3404. During the final 38 revolutions of mission 1104, eight photographic passes were made with the SO-180 film, one over domestic territory (California) and seven over foreign areas.

Color photography began with frame 20 on rev 199 and ended with frame 31 on rev 236. The film was successfully recovered on August 22 in the "B" bucket during rev 244. A total of 306 frames were exposed on the SO-180. The maps of Figs. 2-1 and 2-2 reveal the ground tracks for the color coverage.

Processing of original SO-180 positives and production of duplicate SO-271 (Aerial Color Duplicating Film) positives were carried out at [redacted] In studying the resulting imagery, two anomalies with regard to system capability require attention. One is a cyan cast that varies in degree and extent over most of the frames. The other is a variety of red, pink, and white dendrites and corona fogging throughout most of the color imagery. Description, causal explanation, and consequent recommendations are products of this study.

All of the SO-180 exposures were accomplished in the stereo mode. With 3404 film and a Wratten no. 21 filter in the AFT-looking camera (unit no. 308 with second generation Petzval lens I-183), high resolution comparative coverage was obtained for most of the SO-180 frames, with the usual six-frame differential between the two cameras. Ground resolution on the 3404 imagery is, at its best, on the order of 6 feet, and the corresponding SO-180 ground resolution is on the order of 30 feet. However, this 5× poorer detail rendition on the color material does not preclude stereo analysis.

Intelligence targets (selected before the mission) of special interest for color translation photography were obscured by cloud cover, nullifying readout against specific requirements.

---

*Evaporation deposition of a thin layer of the alloy Inconel onto a Wratten filter produces a neutral density coating that exhibits some specular reflection but very little scattering.

A through-exposure sequence was programmed for the SO-180 image acquisition, but the results of this experiment were totally negated by cloud cover. However, despite the extensive cloud cover, the limited footage of tag-on, the cyan cast and the electrostatic discharge fogging, a sufficient amount of good imagery was acquired on the SO-180 film to support a reliable engineering evaluation and analysis of interpretability.

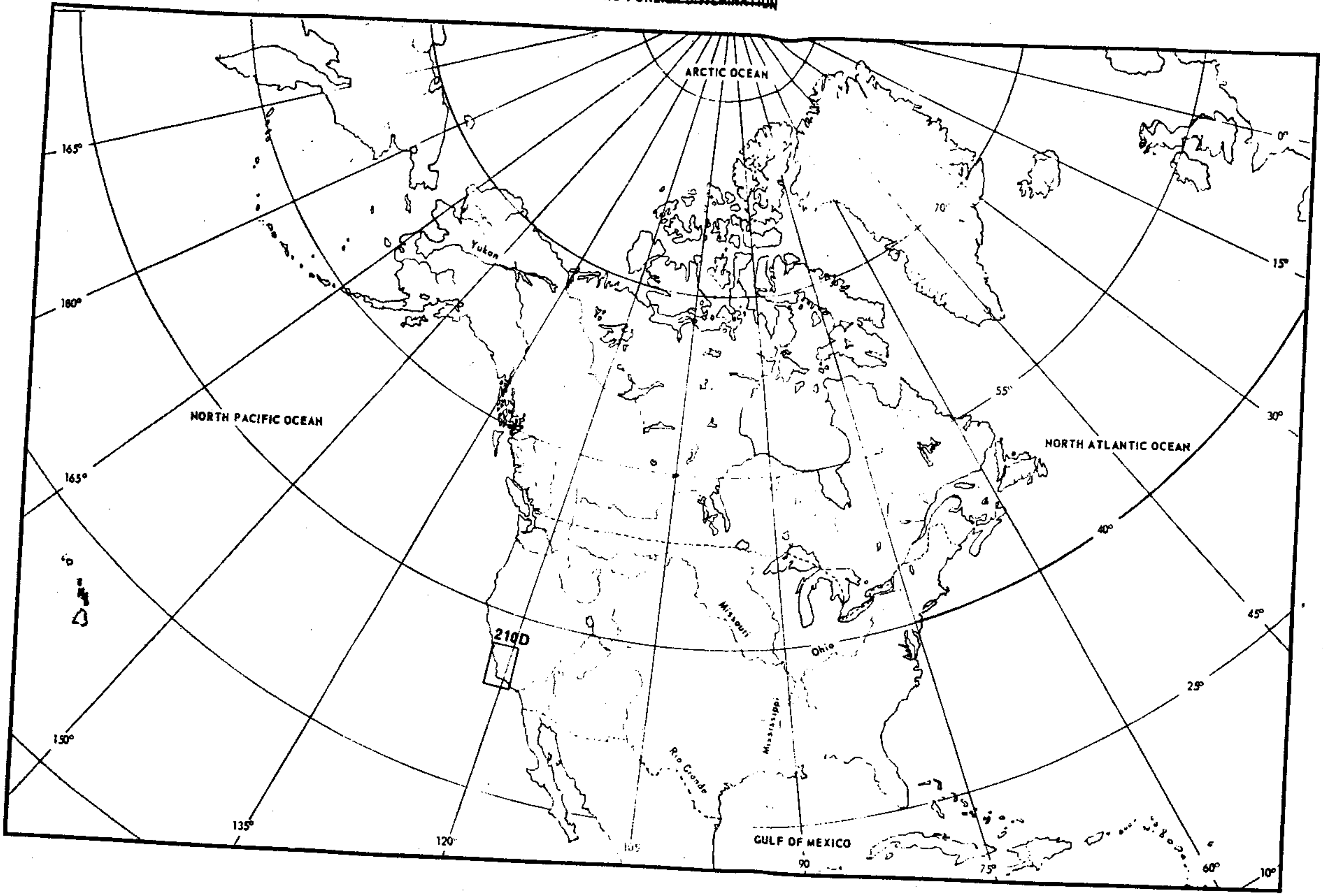


Fig. 2-1 — Mission 1104 SO-180 ground track over United States

[redacted]

[redacted]

TOP SECRET
~~NO FOREIGN DISSEMINATION~~

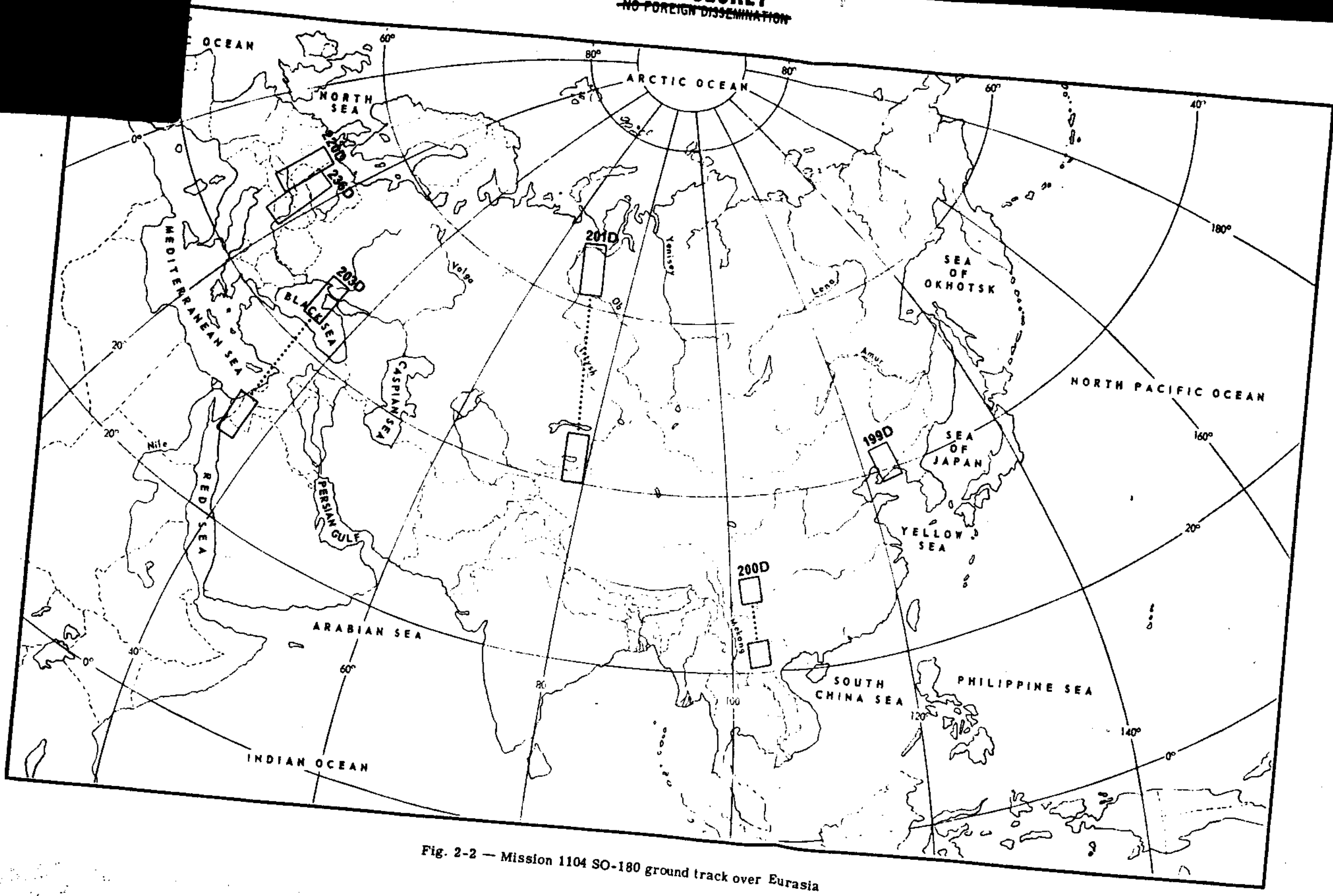


Fig. 2-2 — Mission 1104 SO-180 ground track over Eurasia

TOP SECRET
~~HANDLE VIA~~
~~TALENT-KEYHOLE~~

3. CHARACTERISTICS OF SO-180 FILM

3.1 PHYSICAL STRUCTURE

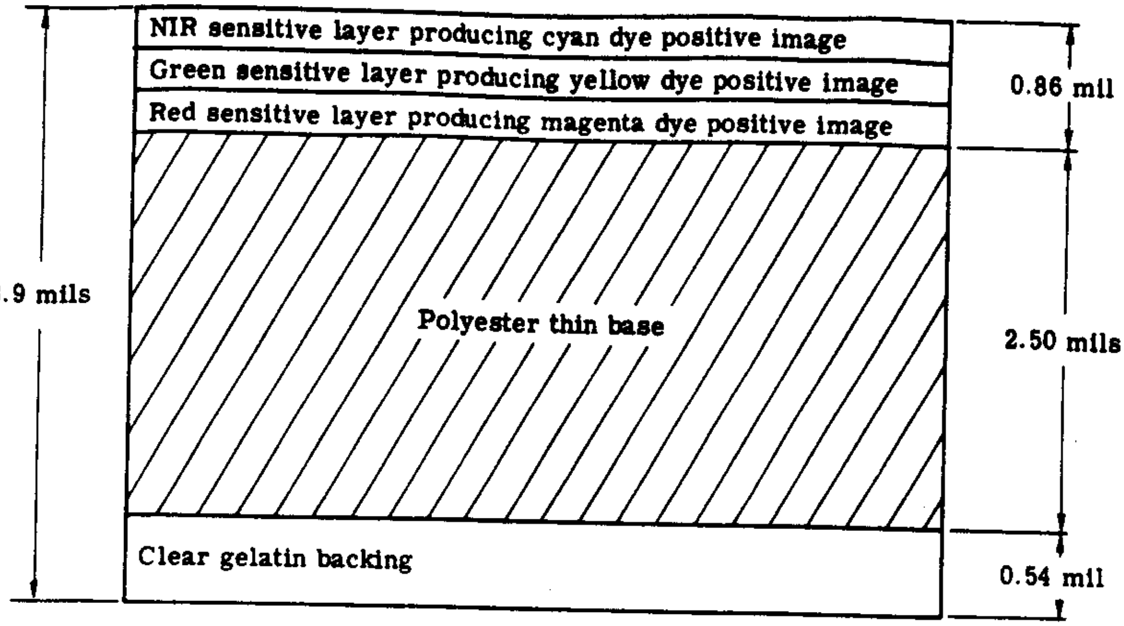
SO-180 film is an Ektachrome Infrared Aerial emulsion on Estar thin base. The film's fundamental physical structure, illustrated in Fig. 3-1, accrues three sensitive layers supported by a polyester (thin) base made from polyethylene terephthalate. This polyester base has advantages in physical strength and dimensional stability over the standard cellulose triacetate support of Ektachrome Infrared Aerial film, 8443. SO-180 is not currently available on 1.5-mil ultrathin base.

The three sensitive layers of silver halide suspended in gelatin of slightly different thicknesses, along with their ancillary layers, occupy a total displacement of 0.86 mil. For anticurl characteristic, a clear gelatin backing 0.54 mil thick is included in the structure. Total thickness of SO-180 thus amounts to an average of 3.9 mils. Image-forming electromagnetic energy first penetrates the near-infrared sensitive layer, then the green sensitive layer and finally the red sensitive layer. What happens as a result of this process is described in the next section.

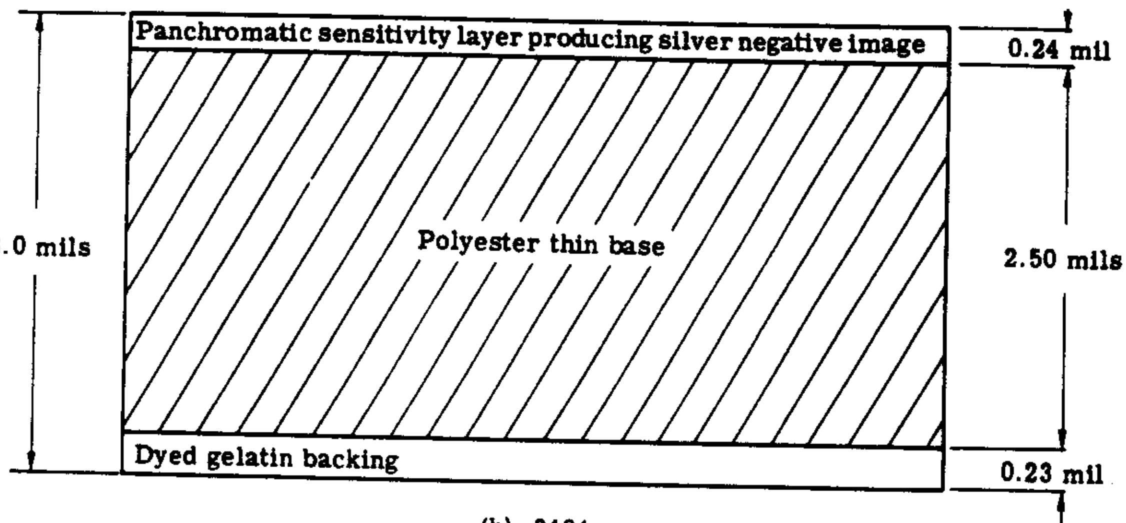
A more detailed examination of the SO-180 physical structure is afforded by an actual cross-section as presented in Fig. 3-2. The specimen slices depicted are less than 2.5 microns thick and were generated on a Sartorius-Werke microtome. In order to retain the dye layer differences, unexposed film was processed and dried normally providing the material to be sampled. Microscopy was accomplished with cover glass sandwiches encasing the film specimen immersed in α-methylstyrene to minimize swelling and optimize refractive index. Photomicrographs were made on Type S Color Negative film (first generation) and Ektacolor Professional paper (second generation). In addition to the principal layers described in Fig. 3-1, three ancillary layers are to be pointed out. There is an obvious subbing layer joining the photosensitive tripack to the base support and a barely discernable subbing substrate in the yellow layer adjacent to the cyan dye layer. There is, finally, a protective coating on the front surface which comes in contact with the scan head rollers during image acquisition in the KH-4B panoramic camera.

Because mission 1104 flew with SO-180 as a tag-on to the 3404 film, a comparison between the two materials is instructive. Film 3404 is a High Definition Aerial emulsion on Estar thin base. This film's physical structure, also illustrated in Fig. 3-1, has a single silver halide sensitive layer supported by a polyester thin base and backed with a dyed gelatin layer to provide antihalation, anticurl and antistatic characteristics. In the crossection (Fig. 3-2), these three principal layers, as well as the subbing layer, are evident. The photosensitive and the backing gel layers are 0.24 and 0.23 mil thick, respectively. With the 2.50-mil polyester base, the total thickness of 3404 amounts to an average of 3.0 mils.

Both gel-layer and base thicknesses exhibit slight variations from the nominal values given here. The SO-180 tripack material is more susceptible to these physical variations than is the 3404 monopack material. Photographic layers are more controlled than ancillary layers.

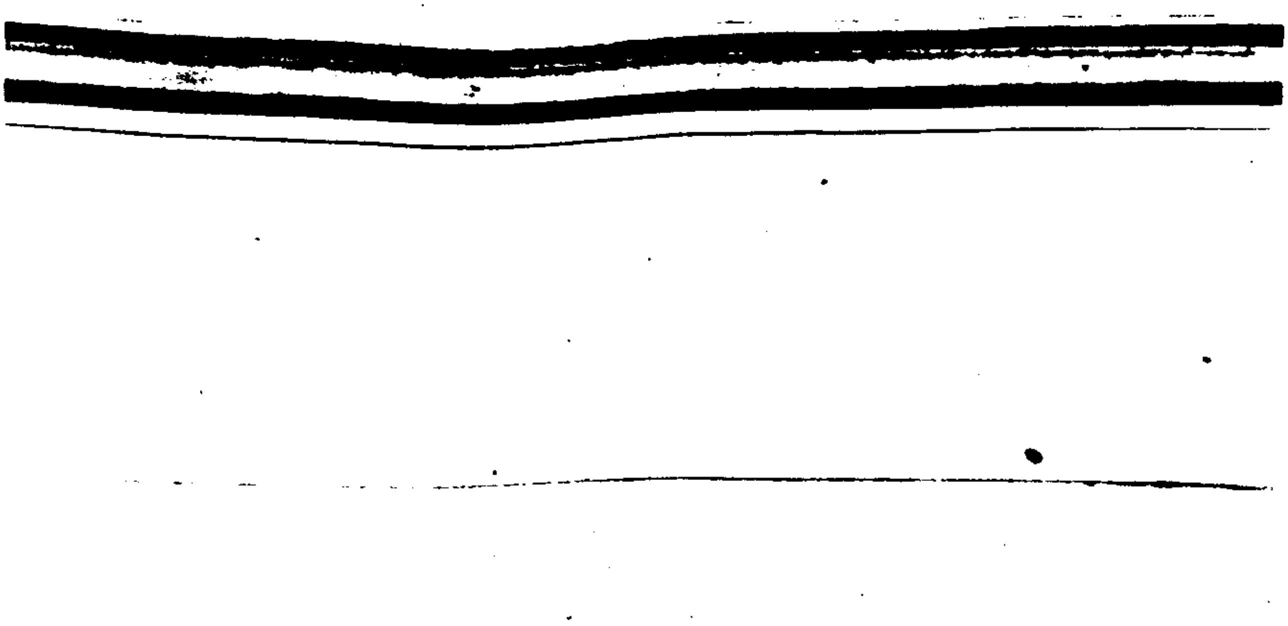


(a) SO-180

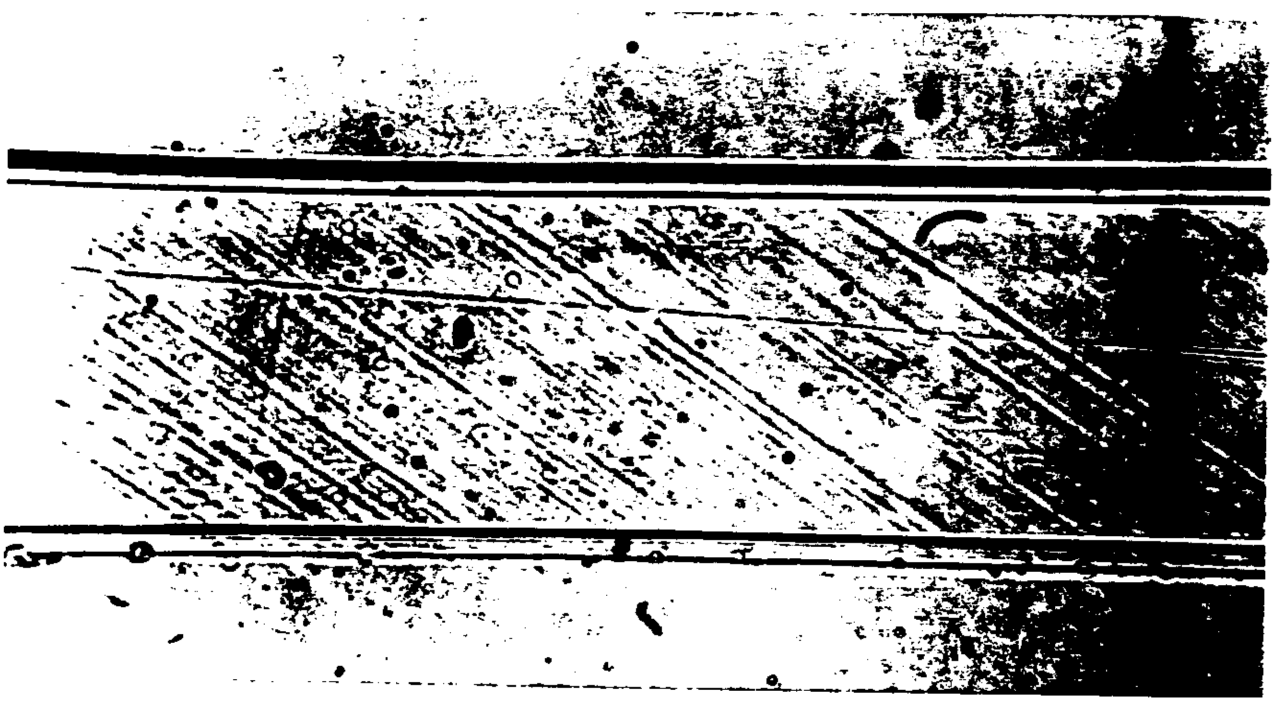


(b) 3404

Fig. 3-1 — Physical structure of SO-180 and 3404 films



(a) SO-180 film



(b) 3404 film

Fig. 3-2 — 700× photomicrographs of cross sections of SO-180 and 3404 films

Variations were within limits established by quality control during manufacture, but additional variations are also introduced by fluctuations in moisture content resulting from changes in temperature and relative humidity. The important point is that while both SO-180 and 3404 emulsions are supported by thin base polyester, the SO-180 film is 0.9 mil thicker than 3404 as a whole. Because of this thickness difference, the film supply for the FWD-looking camera was necessarily less than that for the AFT-looking camera. As a result, photographic coverage during revs D-215 and D-217 was obtained with the AFT-looking camera only.

3.2 PHOTOGRAPHIC SENSITIVITY

Most color films are sensitive roughly to the blue (400 to 500 nm), green (500 to 600 nm), and red (600 to 700 nm) bands of the spectrum. Upon processing reversal color film, the yellow, magenta, and cyan superimposed dye layers transmit visual wavelengths that somewhat simulate the color in the original scene. The SO-180 film, on the other hand, is sensitized to image the extended-red or near-infrared (700 to 900 nm) portions of the spectrum in its cyan layer, and this is information that is not directly available visually. Red information is imaged in the magenta layer and green in the yellow layer.

The spectral sensitivities for each of the SO-180 dye layers are shown in Fig. 3-3. From this it is evident that selective sensitivities to green, red, and near-infrared are more a matter of relative emphasis rather than clear-cut distinctions. In the 500 to 600 nm bandwidth, for example, the yellow dye-forming layer is predominantly sensitive; yet there is some response to this energy in the other two layers as well. By the same token, the principal colors (red, green, and blue) are a pragmatic characterization for a continually varying spectrum. This is to say that there is a diversity in the actual spectral composition of the three primary colors that will produce the entire chromatic range.

When SO-180 film is exposed to an optical image and then processed, the three dye layers, having recorded essentially the 500 to 900 nm information, are subjected to information extraction activities that are visual, i.e., 400 to 700 nm response. This amounts to a spectral shift from the recording to the visual presentation modes, and is known as color translation or "false color." During World War II this technology took the form of a camouflage-detection film that evolved in 1962 into Kodak Type 8443, Kodak Ektachrome Infrared Aerial. This same emulsion on thin Estar base is the SO-180 film.

Each of the three color film layers also has sensitive response to blue light (<400 nm) in varying degrees, the cyan dye-forming layer being most sensitive and the magenta dye-forming layer being least sensitive. Because of this, SO-180 must be supplemented with a minus-blue (Wratten no. 15) filter, with a cutoff in the 500 nm neighborhood. With such a filter incorporated into the imaging optics, the outermost layer is selectively near-infrared (NIR) sensitive and the next-to-base layer is selectively red sensitive (refer again to Fig. 3-1).

The Petzval lens / yellow filter / SO-180 film imaging system is presented schematically in Fig. 3-4. Impression of the image onto the film initiates the photographic process with the SO-180, which culminates in the color positive image of the original mission 1104 imagery, as illustrated in Fig. 3-5.

The yellow filter / Petzval lens image impressed onto the tripack sensitive film layers creates a (different) silver halide latent negative image in each layer determined by the individual spectral sensitivities. The potential color translation information is stored in this form in the SO-180 until the film is recovered and processed. In the first developer, the silver halide is selectively reduced to silver, producing a negative image. This developed silver is bleached out and

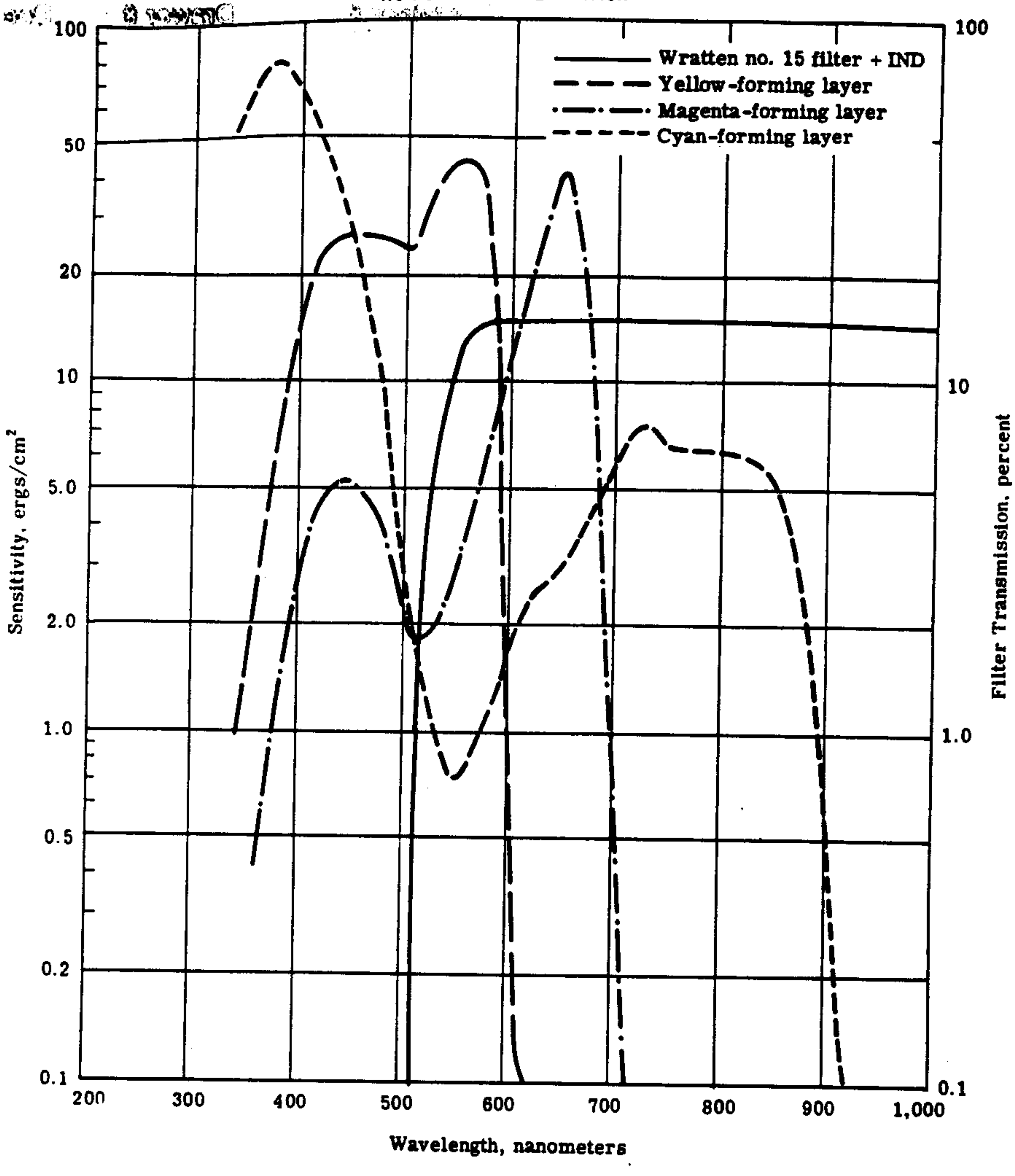


Fig. 3-3 — Spectral sensitivities for the three SO-180 film layers, including the Wratten no. 15 filter transmission used in the mission 1104 FWD-looking camera scan head assembly (Eastman Kodak data)

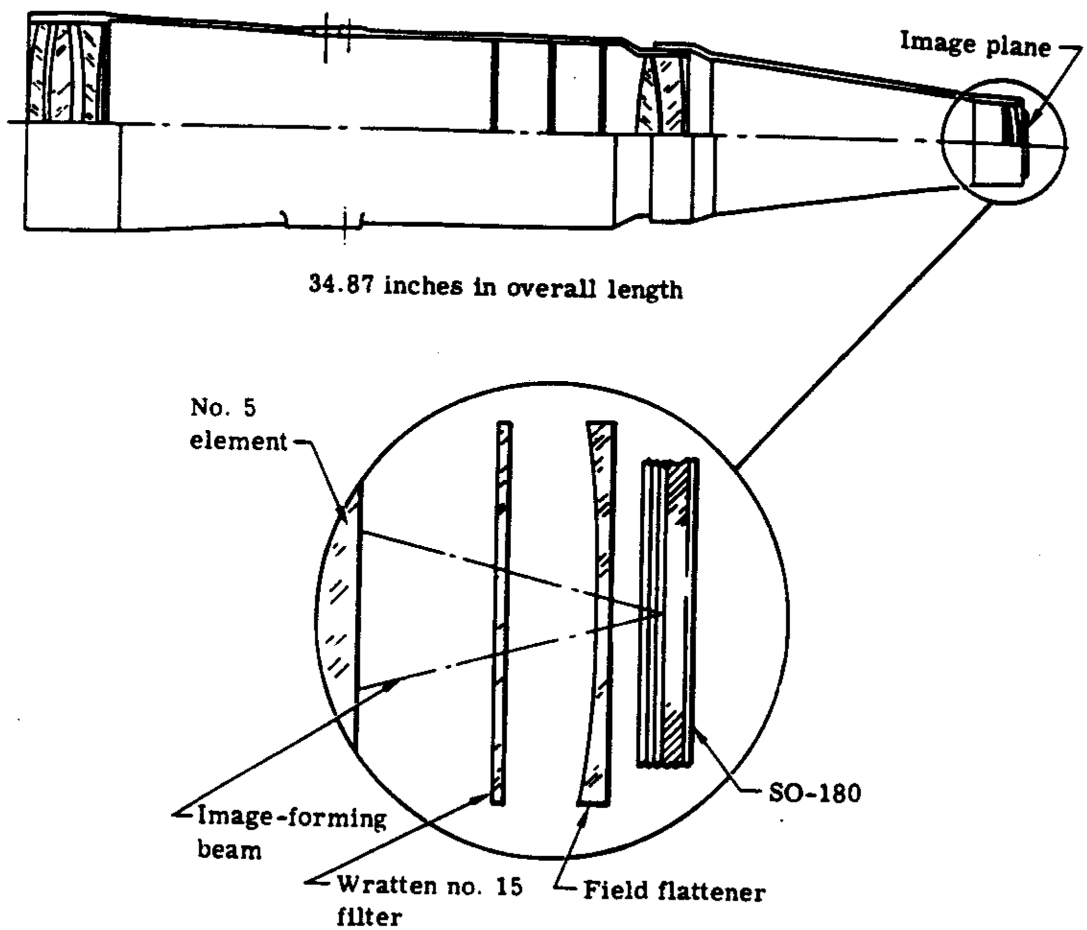


Fig. 3-4 — Petzval lens / Wratten no. 15 / SO-180 film configuration for KH-4B image acquisition

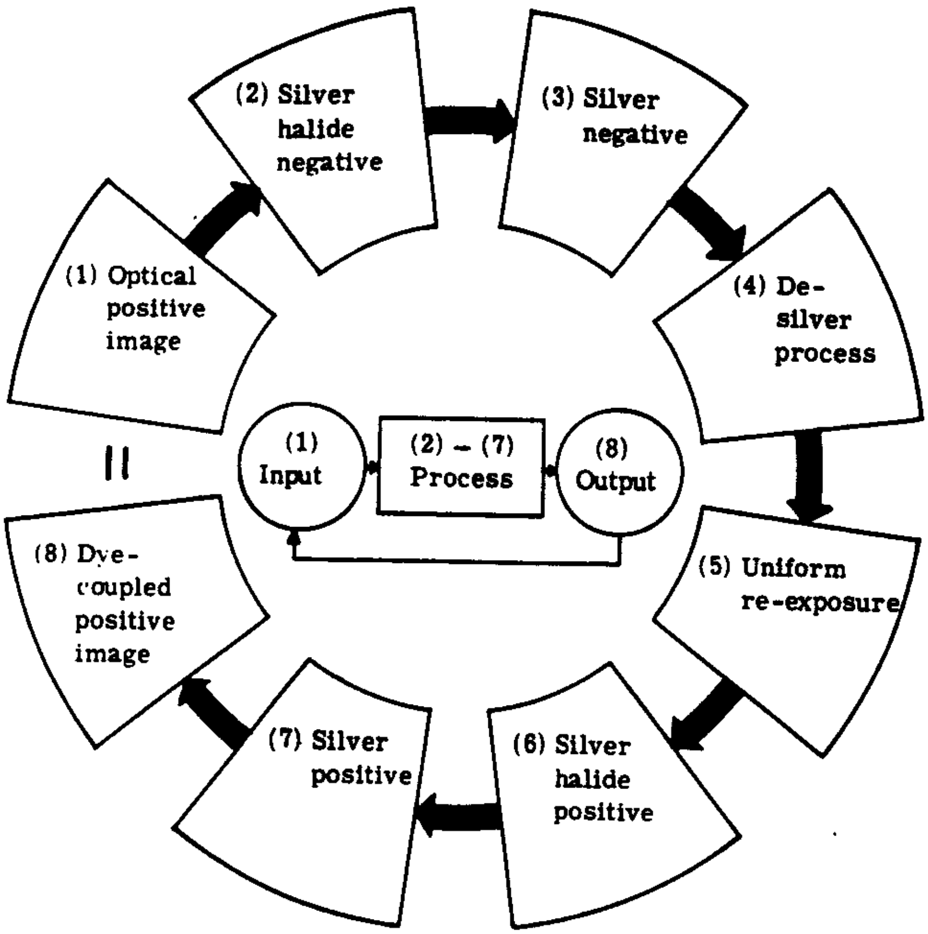


Fig. 3-5 — Schematic representation of the conversion from the Petzval formed image to the SO-180 recorded image the material is uniformly exposed to light. This in effect creates a positive latent image which is then developed. It is at this point that the color chemistry enters the process to couple the three dyes to their respective silver halide distributions. The result is a color positive transparency image that represents the ground scene imaged.

3.3 IMAGE QUALITY

A modest amount of premission resolution testing with SO-180 was done to determine the image quality that could be anticipated from the flight material. Tests were set up on a 120-inch collimator that put a 1.8:1 tri-bar target at infinity for a third generation lens cell (I-220) to form the target image on the film through a Wratten no. 15 filter. Although this was not the actual flight lens for the mission 1104 SO-180, its performance was similar. The tag-on situation was simulated in these tests by splicing sections of SO-180 onto 3404 film and alternating appropriately between Wratten no. 15 and Wratten no. 25 filters. With this technique, it was confirmed that when the optical system was exposing at peak focus for the 3404/Wratten no. 25, the system was set for best focus on SO-180/Wratten no. 15, at least for a color temperature light source of 2,500 °K.

As a result of these tests, SO-180 low contrast resolution as a function of relative focal position for a third generation Petzval lens/Wratten no. 15 filter combination is plotted in Fig. 3-6. This data indicates that a defocused condition of 2 mils either toward or away from the lens incurs an 11 percent resolution loss. With the indicated 35-lines-per-millimeter peak resolution at 1.8:1 target contrast as a baseline, ground resolution was expected to be no better than 25 feet at nominal altitude.

In the actual photography, the earliest assessment of ground resolution on the SO-180 imagery from mission 1104-2 was estimated "TO BE BETWEEN 25 AND 35 FEET."* PET estimated the ground resolution "TO HAVE BEEN APPROXIMATELY 25 FEET."† These estimations were based on experienced judgment alone because no CORN targets were imaged on the color translation film.

A more objective technique for resolution measurement on targetless imagery was devised and applied to the mission 1104 SO-180, the results of which agree well with the above estimations. The alternate procedure is to utilize man-made objects in the imagery that fulfill similar requirements of resolution target bar and space relationships. This ground display must be a repetitive pattern of light and dark spacings and, most importantly, must be at the resolution threshold in the SO-180 imagery. The same substitute "target" is located on the 3404 synoptic imagery as near center of format as possible. Overlaying a glass resolution target directly on this record and matching the tri-bar progressions to the photographic image defines the object's spatial frequency. Since the color image of the substitute "target" is at the limit of resolution, this then defines the SO-180 resolution performance.

---

*[redacted] message no. [redacted], 25 August 1968.
†NPIC message no. [redacted] 16 September 1968.

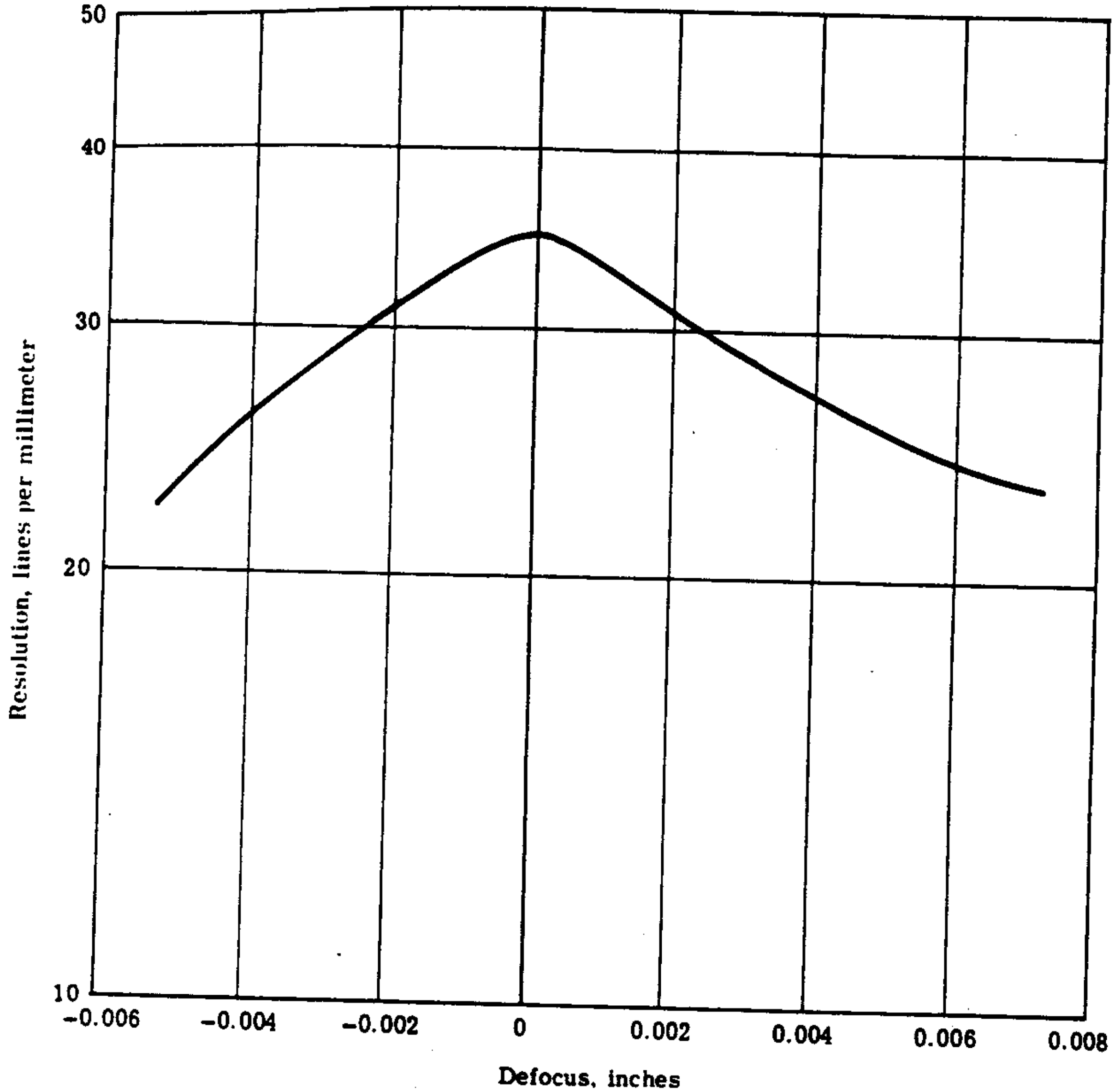


Fig. 3-6 — SO-180 low contrast resolution as a function of relative focal position for a third generation Petzval lens / Wratten no. 15 filter combination

With the film resolution thus determined, ground resolution is computed from the following equations:

$$R, \text{ feet} = \frac{10.7\,a}{r \cos\theta} \qquad \text{(IMC direction)}$$

$$R, \text{ feet} = \frac{10.3\,a}{r \cos^2\theta} \qquad \text{(SCAN direction)}$$

where a = vehicle altitude, nautical miles
θ = absolute value of scan angle from center format, degrees
r = determined film resolution, lines per millimeter

These equations take into account scale changes due to the 15-degree look angle and the variable scan angle as well as geometric perspective in the IMC and SCAN directions.

Three such substitute "targets" were located in the mission 1104 SO-180 imagery, and the resolution levels were determined. The details and results are given in Table 3-1. Averaging the three samples puts the color translation material performance at 24 lines per millimeter on the film and 36 feet on the ground, with the reservation that these determinations were made on SO-271 dupes.

Table 3-1 — Resolution Determinations on Mission 1104 SO-180 Imagery

Location	Israel	California	Hungary
Pass	D-203	D-210	D-236
FWD frame	015	010	020
X coordinate*	50.7	39.8	36.4
Y coordinate*	3.0	4.6	5.3
θ, degrees	12.1	1.9	1.3
AFT frame	021	016	025
X coordinate*	24.6	35.1	28.9
Y coordinate*	2.8	0.8	5.1
Direction	IMC	SCAN	SCAN
r, millimeters^{-1}	23.0	25.4	23.0
a, nautical miles	81.24	80.83	83.58
R, feet	38.6	32.8	37.4

*Note that center of format is X = 37.8, Y = 2.8.

4. NONIMAGE-FORMING ANOMALIES ON MISSION 1104 SO-180

4.1 CYAN CAST

Initial evaluation of the processed SO-180 film recovered from mission 1104 B-SRV revealed an undesirable cyan cast over many of the frames. As noted in the Performance Evaluation Interim Report (PEIR)*

> "... THE FIRST THREE AND ONE-HALF FRAMES OF EACH OPERATION HAD A NOTICEABLE BLUISH/GREEN CAST TO THE IMAGERY. THIS EFFECT WAS DIRECTLY RELATABLE TO THE SIT TIME BETWEEN CAMERA OPERATIONS. DURING VERY LONG SIT PERIODS, THE BLUE/GREEN CAST BECAME HEAVY AND DURING SHORT SIT PERIODS IT IS NOT AS SEVERE. THE BLUE/GREEN CAST WAS DUE TO A LOSS IN INFRARED LAYER SENSITIVITY DURING THESE SIT PERIODS."

This initial evaluation was followed up with more extensive examination and study, and subsequent partial revision has resulted.

The cyan cast is evident on those frames which exhibit no reds and oranges in the fertilized terrain imagery in which these colors normally appear. For an example of a high degree of cyan cast on the SO-180 imagery, see Fig. 5-6(a). However, judgment as to the degree and extent of cast throughout the mission is not at all simple. Several factors interact with the cyan cast in such a way as to render isolated observations of the cast impossible. These complicating factors include cloud cover, corona and dendritic fogging, variations in topographic hue, and differences in exposure that alter color balance. However, studied comparison between successive frames has produced an estimation of the degree and extent of cyan cast present as illustrated in Fig. 4-1.

Raster scan mean density measurements in each of the dye layers were made by Eastman Kodak. Similar ground areas on revs D-200 and D-220 were sampled to produce five sets of data from frame 01 to frame 13. These objective measurements indicate that while the cyan densities do tend to decrease with frame number, the magenta and yellow layers are not necessarily constant and often contribute to the color balance shift. However, because identical ground areas could not be scanned for each data set, quantitative relationships could not be defined.

Note that the original imagery was densitometrically sampled, and adjustments were made in the reproduction process with the intent of improving color balance. As a result, the SO-271 color positive transparencies are decidedly more red than the SO-180 original imagery. As an overall effect this is not distracting; still, duplication also resulted in degradation of some

*NPIC message no. [redacted] 16 Sept 1968.

information hues (particularly the purples, magentas, and greens) found in cultivated areas. Contrast was increased by reproduction, a mixed blessing in that some areas and facilities of low contrast were enhanced and more definitive evaluation was made possible. On the other hand, items of already quite high contrast were amplified and information was subsequently lost. With regard to the cast analysis for this experiment, differences in color balance between original and dupe do not influence the estimation of degree and extent of cyan cast.

In Fig. 4-1, the number of frames in each SO-180 photographic pass is shown with the corresponding estimation of degree of cyan cast caused by a commensurate loss of speed in the cyan dye-forming layer. This estimation reveals that rev 199 (the final 3404 FWD-looking camera operation during which the SO-180 entered the panoramic format) and rev 200 (both operations) exhibit heavy casting throughout all of the judicable imagery. In all of the remaining passes there is an apparent speed recovery after the initial footage. These initial frames indicate maximum speed loss through heavy casting. In two instances there is a measurable demarcation located just off center format where the severity of cast sharply decreases. These most clearly defined instances occur on the final two photographic passes.

Speed recovery seems to improve from rev 201 through rev 203 to culminate with by far the best speed recovery on rev 210. But then rev 211 is again heavily cast throughout, with speed recovery improving on rev 220 and further on rev 236. A plausible explanation of this progression is offered in the next section.

In analyzing the degree and extent of cyan cast, use was made of the horizon imagery as well as the panoramic imagery. Comparing synoptic coverage in successive horizon photographs was easier from an integrating point of view than the panoramic formats because of the smaller scale and the high amount of overlap. Although some contributions could have been made by vignetting and differences in atmospheric path length across the format, there is some indication that the cyan dye-forming layer speed losses are greater at the edges of the format than at the center. This could be explained in terms of differentials in moisture content across the film web that evolved while the film was in a wrapped configuration in the supply cassette.

Before entering the cyan cast analysis, however, it should be noted that in some instances of cyan cast where there is no 700- to 900-nanometer information record, corona fogging has restored the information at least partially. Often the corona fogging simply has spread a non-image-forming density over the cyan cast image area. But there are instances in which the corona-fogged locations in cyan cast areas exhibit selective agricultural reds such as would normally be expected. It is not unreasonable to suppose that in these instances the initial loss of speed in the near-infrared sensitive layer was compensated for by corona fogging which hypersensitized the layer, bringing the speed up to near normal in localized regions.

4.2 SPEED LOSS IN THE CYAN DYE-FORMING LAYER

The cyan dye-forming layer of SO-180 is designed to be slower than the other two layers because the near-infrared (NIR) reflectance of a given target tends to be greater than its panchromatic reflectance. After manufacture, the photographic material is not immediately released for consumption in order to allow the cyan layer especially to stabilize in speed. The cyan layer loses speed significantly and the yellow dye-forming layer slightly increases speed with aging. But once the film is ready for use, its characteristic curves are related to one another as illustrated in Fig. 4-2. This sensitometry was included on the tail end of the actual mission 1104 SO-180 by Eastman Kodak.

[redacted]

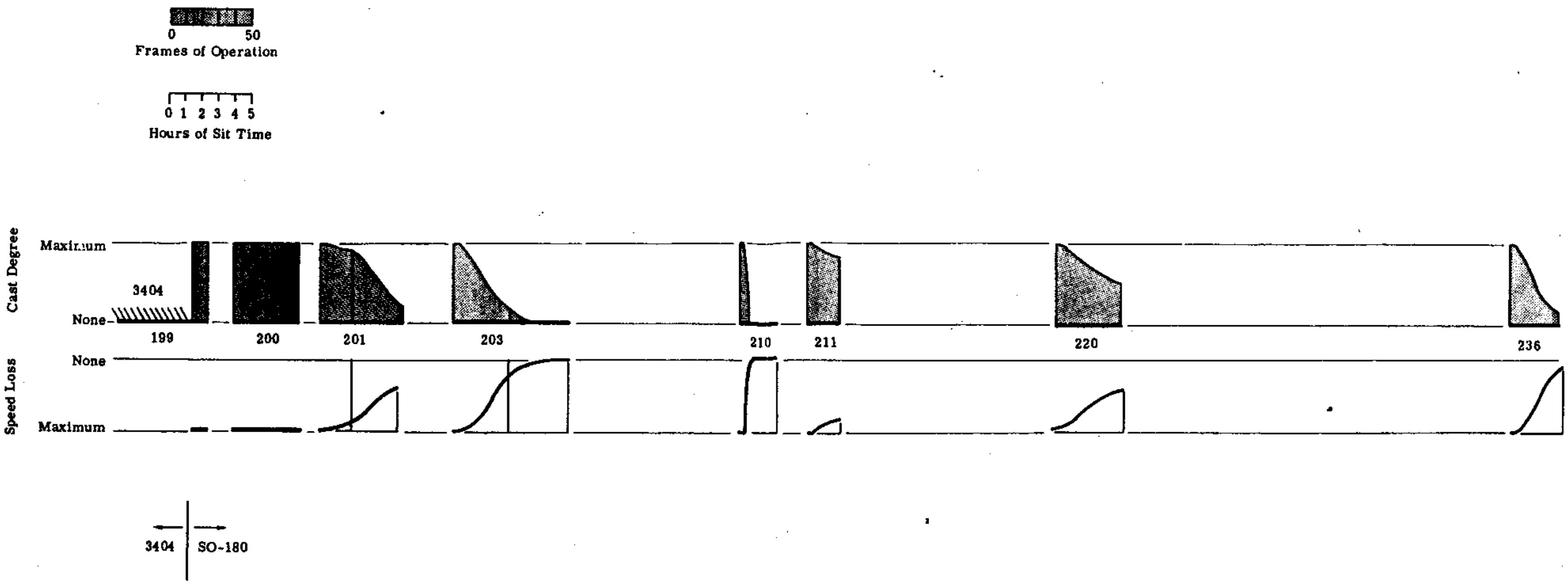


Fig. 4-1 — Each of the seven mission 1104 SO-180 passes with estimated degree of cyan cast over frames progressing from left to right showing proportionate amounts of sit times

[redacted]

[redacted]

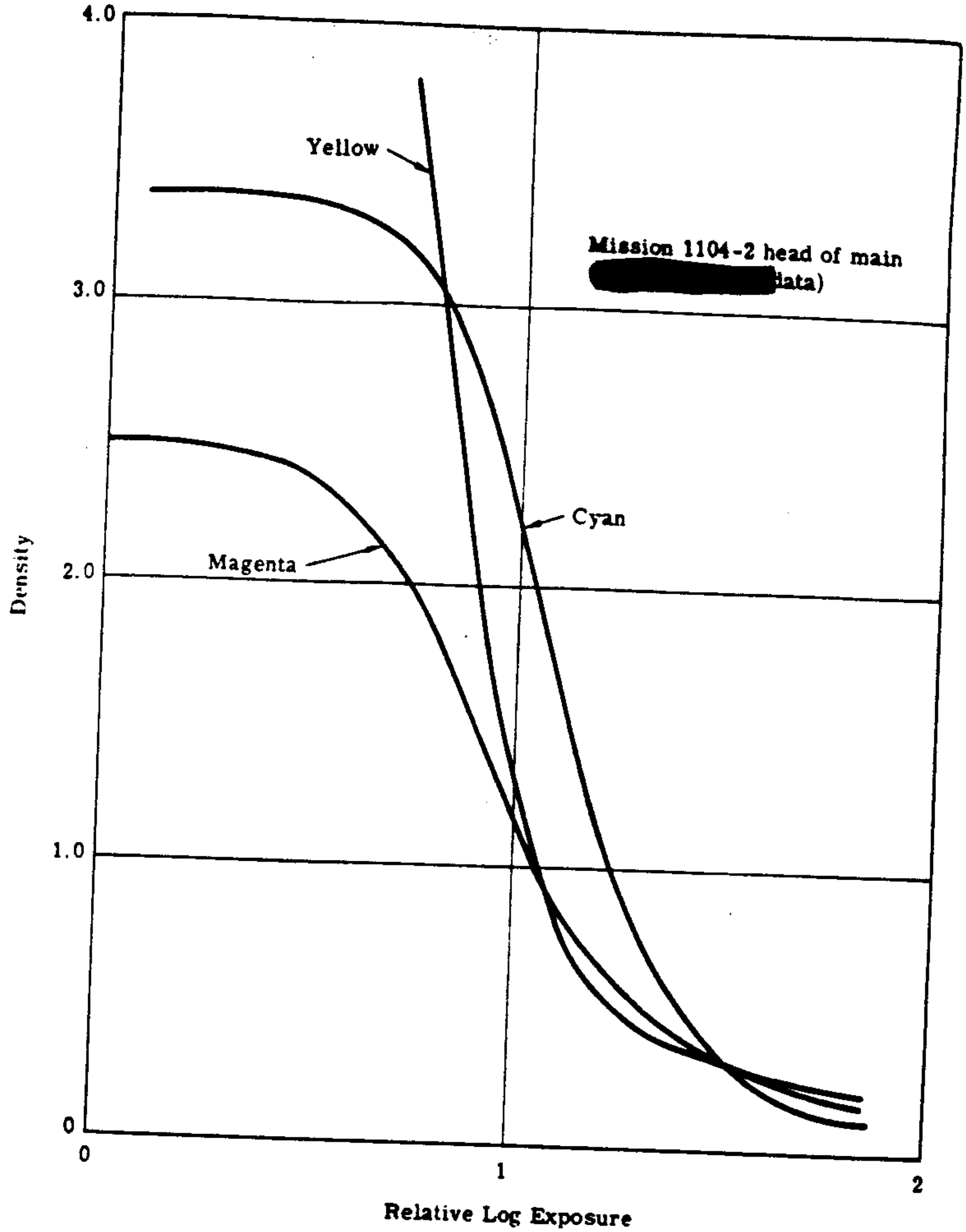


Fig. 4-2 — Sensitometric curves for SO-180

Work done subsequent to mission 1104 by the film manufacturer reveals that decreases in SO-180 relative humidity (RH) incur speed losses in the cyan layer. At a density of 1.0, the speed loss is on the order of 0.10 log E for every ΔRH = −15 percent. The maximum loss (observed at 5 percent RH) has been 0.35 log E, which is more than a complete f/stop.

These measurements of speed loss were made on a basis of the film's RH and not the environmental RH per se, i.e., if film stored at 50 percent RH is given into a lower RH environment. the film will begin to lose moisture in the process of establishing moisture equilibrium. But in the meantime, the film itself has a higher RH than its environment. This is an important consideration with regard to the speed loss problem. The 0.10 log E speed loss per −15 percent ΔRH refers to film RH in equilibrium with environmental RH.

With regard to film RH, the yellow and magenta layers have an essentially flat response, betraying no speed losses over the 5 to 70 percent RH range. Under the 0 percent RH conditions experienced during the mission, then, these facts indicate that the cyan layer lost moisture and experienced consequent speed losses of various amounts. At the same time, the yellow and magenta layers flying in the KH-4B system lost moisture yet remained stable with regard to speed. Speed loss in the cyan layer only constitutes a plausible explanation of the cyan cast retained on much of the SO-180 photography.

Actual rates of conditioning of SO-180 in a KH-4B system are dependent on a number of factors. Preconditioning of the film. ambient conditions during countdown and launch, internal capsule pressure during operations, temperature, tightness of film wrap and the number of protective convolutions, and length of single web exposure all influence conditioning rate and tend to be case history variant rather than generally specifiable. Almost all of the SO-180 moisture content is in its photosensitive tripack. Because of its proximity to the surface, the cyan layer probably tends to dry out faster than the inner layers.

Evidently the initial footage of SO-180, heavily cast over an entire 50-frame length, was dried out while in the supply cassette. It is conceivable that, because of the difference in film thicknesses, the wrapping of 3404 convolutions was not as tight immediately before the SO-180 tag-on as the SO-180 convolutions were themselves closer to the core. If this were indeed the case. this would permit moisture to escape from the first color film footage while at the same time retarding moisture escape from the remaining color film footage. This could explain why revs 199 and 200 are essentially devoid of NIR information while the information is present is subsequent frames.

A recent Itek environmental test determined the amount of moisture loss by weight from two 24,000-foot spools of SO-380 in a supply cassette (S/C) due to a vacuum environment. As part of the data collection during this test, pressure was monitored as a function of time both in the chamber and in the S/C itself. Both monitoring gauges were calibrated against each other so that a comparison of readings is valid. The point of relevance here is that for simulated high altitude conditions. the pressure in the S/C can maintain a level two orders of magnitude higher than the chamber pressure, which represents the pressure in the payload vehicle (P/L V).* Although this test data is not for 3404 film with an SO-180 tag-on, does not meter off film periodically. and does not last for 2 weeks, the implication is relevant. It is not unrealistic to

---

*During the 5-day altitude simulation, the pressure differential ranged from 2.1 microns in P/L V with 104 microns in S/C to 0.1 micron in P/L V with 23 microns in S/C. At 16- and 50-micron P/L V levels, indications are that the S/C pressures were on the order of 150 microns.

suppose that all of the SO-180 film was not necessarily completely dried out in the S/C as the mission progressed. Further environmental testing of moisture losses from mixed films has indicated that film supplies without S/C or flange protection lose moisture about six times faster than film supplies with flange and S/C protection.

The fact that the first 3.6 frames without exception are heavily weighted toward the blue-green part of the spectrum is understandable in that this length of film is exposed for an extended time to 0 percent RH in a single web path from the supply station to the panoramic format area.

Film paths within the payload vehicle are illustrated in Figs. 4-3(a) and 4-3(b). The SO-180 film came off the no. 1 cassette on the port side, traveling to the image-recording station with its backing toward the gold-plated inner wall of the capsule. The detailed lengths of a single web exposure from the supply to the takeup stations are depicted in Figs. 4-4 and 4-5. In some camera operations, shutdown creep distance can be as much as 5.5 inches, effectively lengthening the distances shown in these figures. The importance of these film path lengths is discussed below.

Although there is a definite decrease in cyan cast on the fifth frame as compared with the third frame on revs 201, 203, 210, and 211, only on revs 220 and 236 is there a measurably sharp line of demarcation on the fourth frame. The maximum cyan cast extent measures 114.5 inches on D-220 and 113.6 inches on D-236. Referring to Fig. 4-4, 114 inches corresponds to the distance, AG, from the end of the panoramic format to the constant-tension assembly output guide. If this was indeed the case, then the indication is that there was little or no creep during the FWD-looking camera shutdown near the end of mission 1104-2.*

This length of film (114 inches) is exposed to 0 percent RH during sit times between photographic passes. Sit times are multiples of roughly the orbital period, depending on how many revolutions are made between image acquisition runs. The period for mission 1104 was 88.6 minutes. Accurate sit times experienced on 1104-2 are listed in Table 4-1.

Because most aerial films tend to reach 90 percent RH equilibrium with low RH from medium RH in approximately 15 minutes, it can be safely assumed that the single web SO-180 film lengths were completely dried out during sit periods, producing the 0.35 log E maximum speed loss selectively to the cyan dye-forming layer.

The FWD-looking camera supply spool on which the SO-180 was wrapped consisted of a 6-inch outside diameter machined magnesium hub and two 28.25-inch-diameter by 3/8-inch-thick aluminum honeycomb and magnesium skin flanges. Along with the AFT-looking camera spool, this was carried in the supply cassette. During camera operation, the transport mechanism allowed continuous motion of the film in to and out of the camera and yet held the film stationary in the panoramic platen while it was being exposed. The camera input metering assembly pulled the SO-180 continuously from the supply spool and fed it into the storage shuttle in the camera.

One cycle of the lens cone was approximately 2 seconds long. Rate of film transport was 19 inches per second, and the total path length from the supply cassette exit to the takeup cassette entrance was 21 feet. As a result of all of this, a fixed spot on the SO-180 film, when passing from supply to takeup wraps during camera operation, was exposed to 0 percent RH as a single web in the camera film path for only 13 seconds. Retention of some moisture, even during transport through the camera, is not an absolute impossibility. If interior convolutions of SO-180 in the supply cassette were effectively retaining moisture content as we hypothesize above, the transport

---

*It is somewhat surprising that the clearly defined cast length is not the AH distance, since one would expect that the film within the constant tension assembly would not be protected from the hard vacuum associated with the P/L V interior.

situation as described here could allow for sufficient film RH at the time of image recording to explain those frames that exhibit sufficient cyan layer speed to record NIR information.

Revs 200, 201, and 203 were two operation acquisitions with brief camera shutdown periods (see Table 4-1) which provide helpful experimental evidence. Because of its continual heavy cast, rev 200 affords no analysis, but both revs 201 and 203 exhibit no definitive increase in cast as a result of the short sit times. The decreasing and relatively high degree of cast on D-201 frame 39 appears not to escalate on frame 41 despite the 4-minute break. Similarly, the decreasing and relatively low degree of cast on D-203 frame 34 appears to continue to decrease on frame 36 despite the 2-minute halt. Indication is that the emulsion outgassing was insufficient to establish significantly lower film RH.

The question is now raised if the cyan cast need not be only a pre-exposure phenomenon. Postexposure effects seem possible as well. Referring again to Figs. 4-4 and 4-5, it is evident that the mission 1104 SO-180 was exposed to 0 percent RH in a single web configuration from the format to the takeup cassette during camera shutdown. One would expect that the last 125 (or more) inches on each photographic pass would exhibit 0.35 log E speed loss due to the fact that this film dried out completely during interoperation orbiting. Fig. 4-1 reveals, however, that such a tendency is not at all present in the experiment. The indication is that once the interstitial ions have moved to combine with the trapped electrons in the sensitivity specks upon absorption of radiation quanta, the susceptibility to speed loss is arrested. Further research of the internal photoelectric effects in SO-180 as influenced by moisture conditions and latent image formation seems warranted.

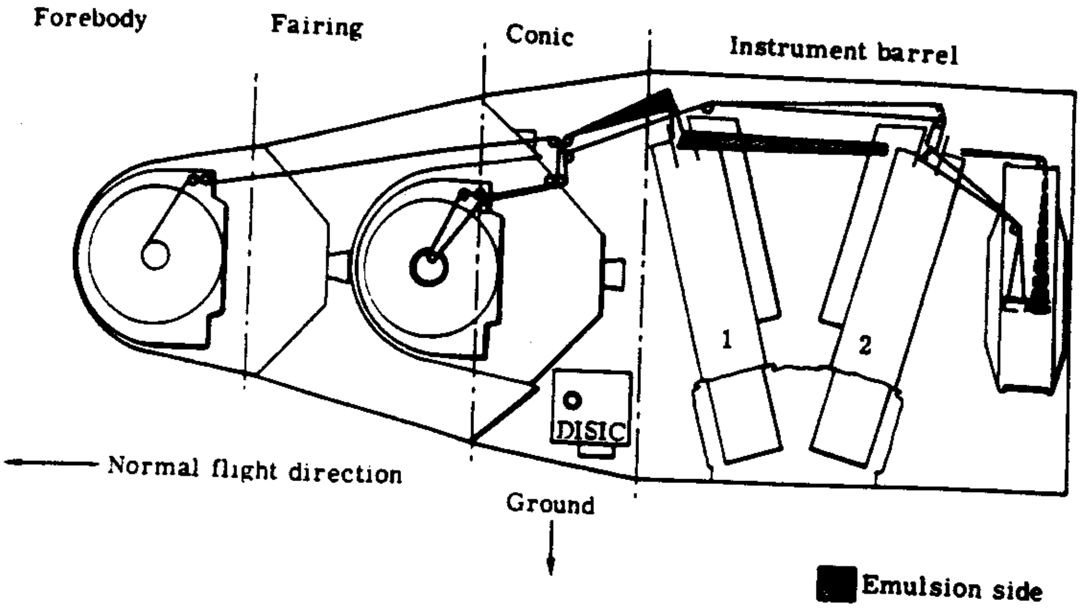
When SO-180 film is flown in future missions, the cyan cast problem (and not corona fogging) is expected to be the prime difficulty. For a full-load SO-180 mission, a two-filter arrangement could be utilized. For initial frames, a filter to slow down the magenta and yellow layers by one stop could be used in conjunction with relatively wide slit widths. For the bulk of the frames, then, a normal Wratten no. 15 could be brought in and exposure set for narrow slit widths to take advantage of the SO-180 high speed to arrest image motion. However, such programmed filter changes would require two or three frames to make the changes. If SO-180 could be used in a KH-4B camera system without much attenuation from neutral density filtering, the advantage of faster scan could be achieved. This would permit even lower altitudes and larger scales (assuming sufficient drag makeup was available on the Agena vehicle) without added image smear. Alternatively, the faster film speed could be utilized in acquiring low sun angle photography at latitudes not normally accessible.

For another tag-on assignment, though, the most immediate corrective measure is to initiate each photographic pass at least four frames prior to the beginning of the desired ground coverage. In addition to padding the coverage, however, the above analysis indicates that proper premission planning could alleviate the cyan cast problem at least to some degree. We recommend investigation into SO-180 preconditioning, wrapping tensions, and supply spool/cassette modifications to optimize moisture retention for future KH-4B missions and modified filtration. The alternative would be to purposefully completely dry out on orbit all the SO-180 film supply and employ appropriate color balance filtration in the scan head roller assembly.

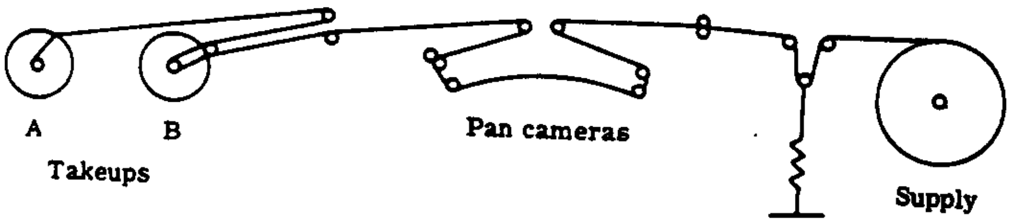
4.3 ELECTROSTATIC DISCHARGE FOGGING

From the processing site, NPIC reported on the mission 1104 SO-180 electrostatic discharge fogging as soon as the film was developed.

"THE MAJORITY OF THE SO-180 PORTION OF THE MISSION IS DEGRADED BY A VARIETY OF DENDRITIC AND CORONA FOG THAT

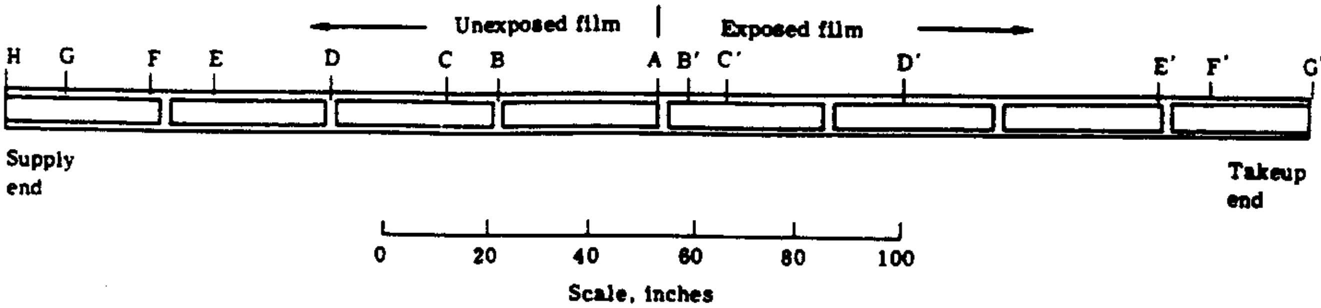


(a) Cross-section of P/L V



(b) Schematic

Fig. 4-3 — Film paths for the main cameras in the KH-4B system



Location	Inches
A = End of pan format	0.0
B = Input H.O. format center	31.1
C = Near-contact with input metering roller	41.3
D = Input metering/pressure rollers	63.0
E = Input guide (first roller on camera)	86.3
F = Supply cassette outrigger guide	98.3
G = Constant-tension assembly output guide	113.7
H = Supply cassette exit	126.4

Location	Inches
A = End of pan format	0.0
B' = Frame metering/pressure rollers	6.3
C' = SLP block center	12.7
D' = Output guide (last roller on camera	47.0
E' = Barrell conic interface	95.0
F' = First I.R. roller	104.9
G' = "B" cutter-in	125.4

NOTES: 1. Rectangular blocks represent panoramic formats on the indicated length of SO-180 film.
2. Indicated dimensions disregard creep distance.

Fig. 4-4 — Film path lengths in mission 1104 FWD-looking camera

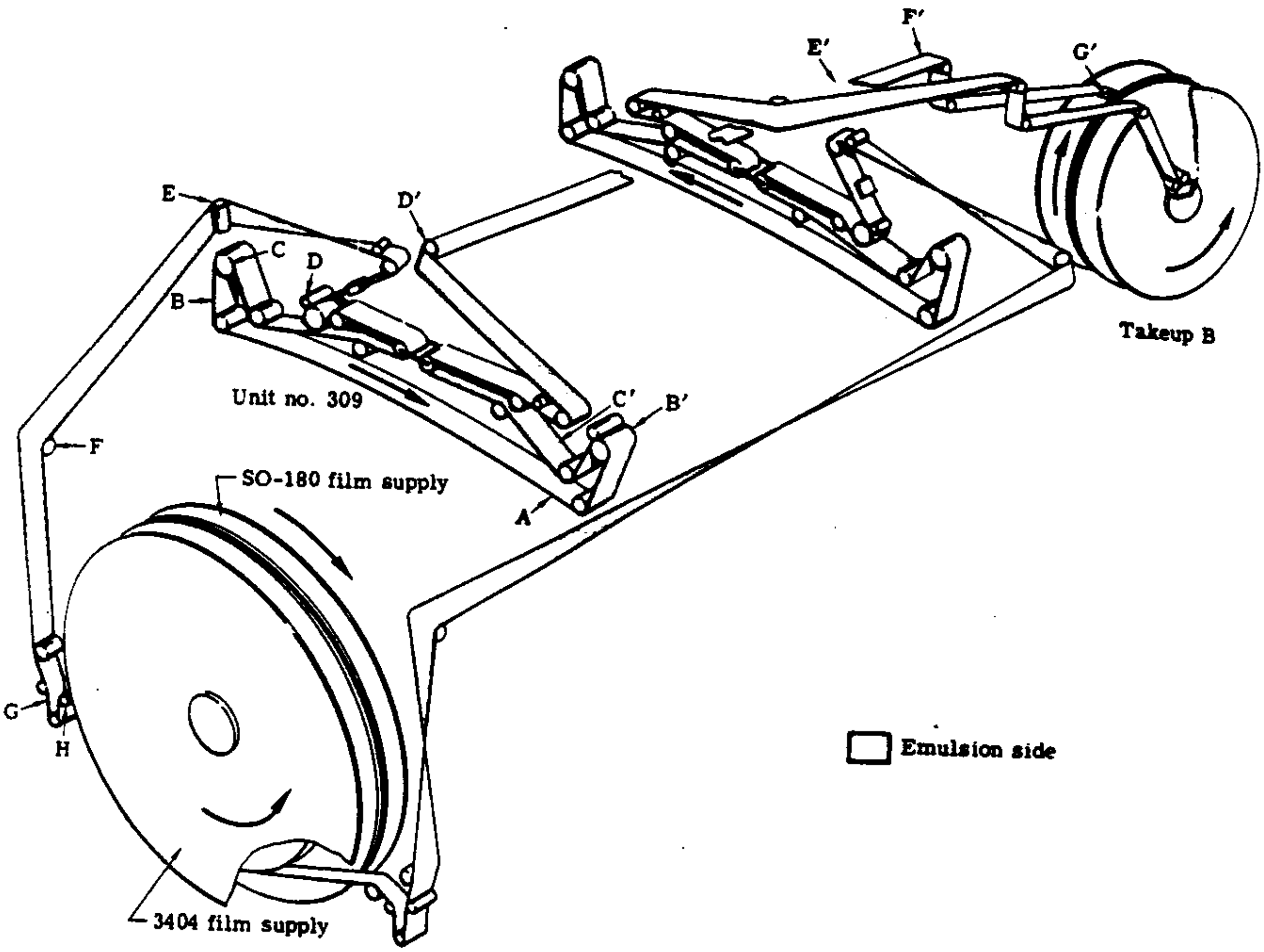


Fig. 4-5 — Film threading diagram for mission 1104 KH-4B main camera system, B-mission

NOTE: Letters correspond to Fig. 4-4.

Table 4-1 — Mission 1104 SO-180 Sit Times

Sit Time		Preceding	
Hours	Minutes	Pass	Frame
00	00*	199	20-28
01	29	200	01-20
00	01	200	22-41
01	16	201	01-39
00	04	201	41-71
02	56	203	01-34
00	02	203	36-39
10	18	210	01-25
01	41	211	01-20
12	59	220	01-40
23	37	236	01-31

*07 hours, 20 minutes was the actual sit time between the initiation of photographic operations on rev 199 and the end of the preceding photographic operations. However, it was 3404 film that was exposed to the vacuum in the camera film paths during this time while the first footage of SO-180 was in the supply cassette.

IS RECORDED AS RED. THERE IS SUFFICIENT UNAFFECTED IMAGERY TO DETERMINE THE VALUE OF SO-180. SOME OF THE CORONA FOGGING IS SO SUBTLE IT IS DIFFICULT TO DIFFERENTIATE BETWEEN IR REFLECTIVITY AND THE CORONA FOGGING."*

NPIC personnel then issued a special follow-on message on SO-180 from their own facility which in part commented further on the fogging.

"1. THE PREDOMINANCE OF CORONA-INDUCED FOG ON THE SUBJECT FILM . . . CAUSES CONCERN AS TO THE INTERPRETABILITY OF THE FILM. . . 2. FOLLOWING ARE SEVERAL POINTS WORTHY OF CONSIDERATION: A. THE CORONA STATIC-INDUCED FOG CAUSES A GENERAL RED CAST OF VARYING SATURATION IN THE AFFECTED AREAS. THE CORONA DISCHARGE IS EITHER LOW INTENSITY BLUE LIGHT OR AN ENERGY ONLY AFFECTING THE CYAN LAYER OF THE EMULSION, AND THEREFORE IS IMAGED AS RED. THAT REDNESS IS NOT ASSOCIATED WITH INFRARED ENERGY. B. THE CORONA-INDUCED FOG IS ADDITIVE TO THE IMAGE, . . . RED IMAGE SATURATION MAY BE EXAGGERATED AND OTHER COLORS CONTAMINATED."†

Finally, the anomaly was referred to in the PEIR.

"SOME OF THE IMAGERY CONTAINS CORONA AND ELECTROSTATIC FOG WHICH APPEARS RED ON FILM TYPE SO-180. THIS CONDITION VARIES FROM NO MARKING TO EXTREMELY SEVERE MARKING. THIS CONDITION OCCURS ON THOSE OPERATIONS WHEN THE PMU PROVIDED SYSTEM PRESSURES OTHER THAN DESIRED."‡

Examples of this photographic anomaly appear in Figs. 5-3 and 5-12. Over the whole of the SO-180 imagery, dendrites and corona markings can be categorized into at least six different types, which might intimate different sources of the nonimage-forming radiation. There are examples of patterned repetitions of specific types of markings with varying frequencies. These patterns are related to discharges associated with roller configurations. Although most of the corona fogging is indeed a red color, there are instances of both pinkish and all-white markings as well. These colors are directly a function of particular layers affected by the electrostatic discharges, as explored further in Section 4-4.

The effects of electrostatic discharge on the SO-180 imagery include both sharply defined dendrites and corona fogging of various degrees of fuzziness. Of the two, the corona fogging is the most detrimental to the mission 1104 SO-180 imagery. Electrostatic potential is created in the camera by moving contact of the film with film, rollers, and guide rails. In the KH-4B system cameras, the prime source of corona discharge is the metering rollers. Discharge occurs through ionization of local gas molecules within the capsule. The hydrated proton was identified in 1966 as the primary ionic species in positive corona charging, even at very low moisture concentrations. Dendrites are caused by discharges directly associated with the film surface under ambient conditions, usually during defilming. Corona fogging is caused by more remote sources of the discharge radiation within the camera under vacuum conditions.

[redacted] message no. [redacted] 25 Aug 1968.
†NPIC message no. [redacted] 29 Aug 1968.
‡NPIC message no. [redacted] 16 Sept 1968.

Instrumental causality for the mission 1104 fogging is described in detail in Appendix A. Ramifications of the unique spectral content of the fogging are explored in Section 4.4.

4.4 PANCHROMATIC DUPING THROUGH SELECTIVE FILTERING

Because the SO-180 material is a tripack film, there is a separate contribution in each of the dye layers constituting the color image. Each contribution is determined by the spectral transfer characteristics from the ground scene distribution through the atmosphere, lens, and filter to the film's selective response, and finally transformed to its dye color qualities. Information content in each of the layers is expressed by both the image quality and the tonal relationships within each layer. The integrated tripack imagery as a whole attains a third degree of freedom by way of color contrast. Study of the information content in the individual SO-180 layers and combination of layers was implemented with panchromatic duping through selective filtering.

To demonstrate feasibility from first generation duplicate positives issued by NPIC, one SO-180 frame was chosen (D-210-013) which exhibited cultural detail, variegated vegetation and corona fogging, and was free from color imbalance introduced by the cyan cast anomaly. An appropriate section of this frame was contract printed onto SO-243, producing a series of seven panchromatic negative reproductions. The series consisted of an unfiltered white-light reproduction together with dupes through each of six different Wratten filters selected both to isolate and suppress each of the three dye-image layers. Fig. 4-6 shows the filter transmissions used and the roles they played.

Cyan dye is blue-green in appearance. Information content for this layer is the lack of cyan dye (burned away, if you will, by the near-infrared image-forming radiation), the result of which appears red. Cyan dye layer information, therefore, is isolated by red filtration (Wratten no. 25). Similarly, yellow dye layer information is isolated by blue filtration (Wratten no. 47), and magenta dye layer information is isolated by green filtration (Wratten no. 57). Individual dye layer suppression is accomplished through complementary filtration. Cyan dye layer information is suppressed with a minus-red filter (Wratten no. 44) that transmits blue and green. Yellow dye layer information is suppressed with a minus-blue filter (Wratten no. 12) that transmits green and red. Magenta dye layer information is suppressed with a minus-green filter (Wratten no. 32) that transmits blue and red. In Fig. 4-6, the isolation/suppression roles of each Wratten filter are symbolized by the colored blocks that represent each of the three dye layers.

It is to be noted that use of these gelatin filters was an approximating way to accomplish the dye layer isolation and suppression reproductions. Note the spectral characteristics of each of the dye layers in the SO-180 film pack is shown in Fig. 4-7. More precise dye layer information isolation and suppression could be effected with narrowband filters centered at the wavelengths associated with the peak density of the desired dye layer or with minimum interaction from the unwanted dye layers. In any case, the method used is of sufficient accuracy to reveal the fundamental differences between each of the three SO-180 information recording layers and the effects these had on the mission 1104 coverage.

The most immediate result of this work was the observation that the corona fog evident on the SO-180 is reproduced as density streaks* on all dupes that retain the cyan dye layer information (e.g., filters 0, 12, 25, and 32). These density streaks are absent on the panchromatic reproductions which reject the cyan dye layer information (e.g., filters 44, 47, and 57). The indication is

*An interesting aside is the observation that corona fogging appears less objectionable on the neutral density reproduction than it does on the SO-180 film. On panchromatic material the fogging appears mostly as but minor density variations.

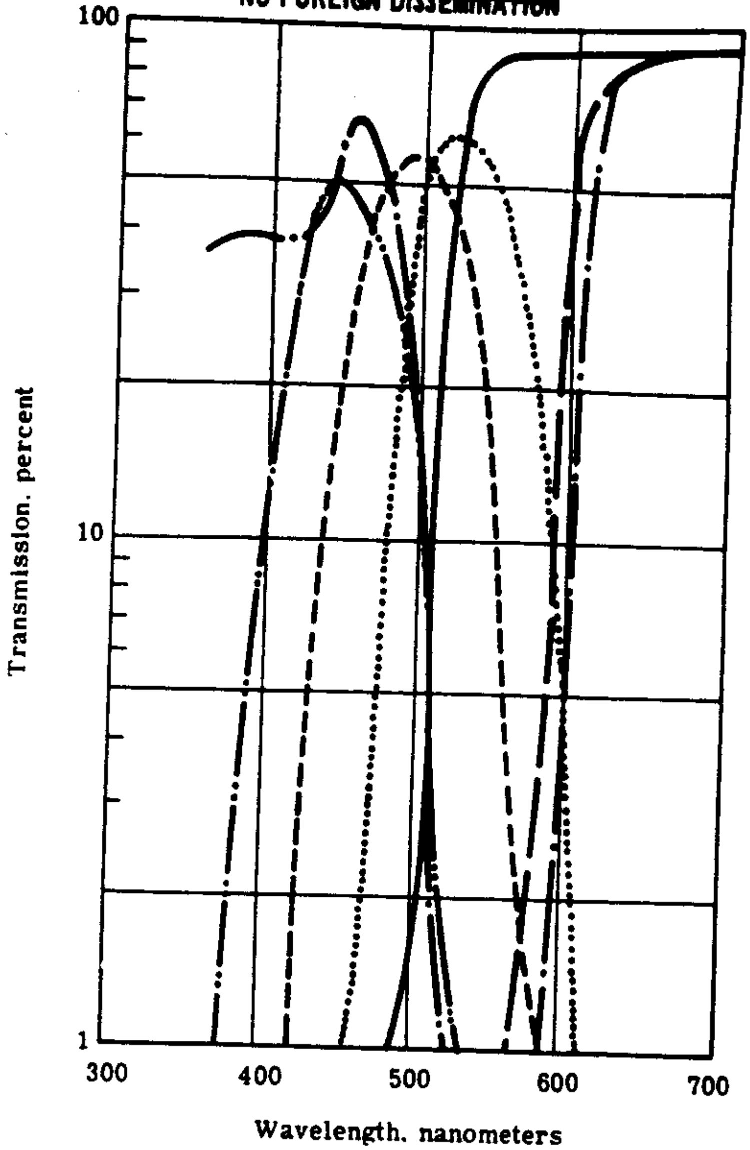
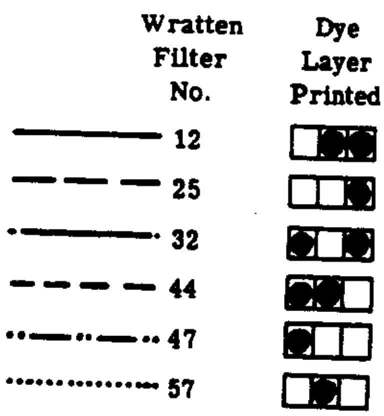


Fig. 4-6 — Six Wratten filters used to both isolate and suppress each of the SO-180 dye-image layers onto a panchromatic negative material



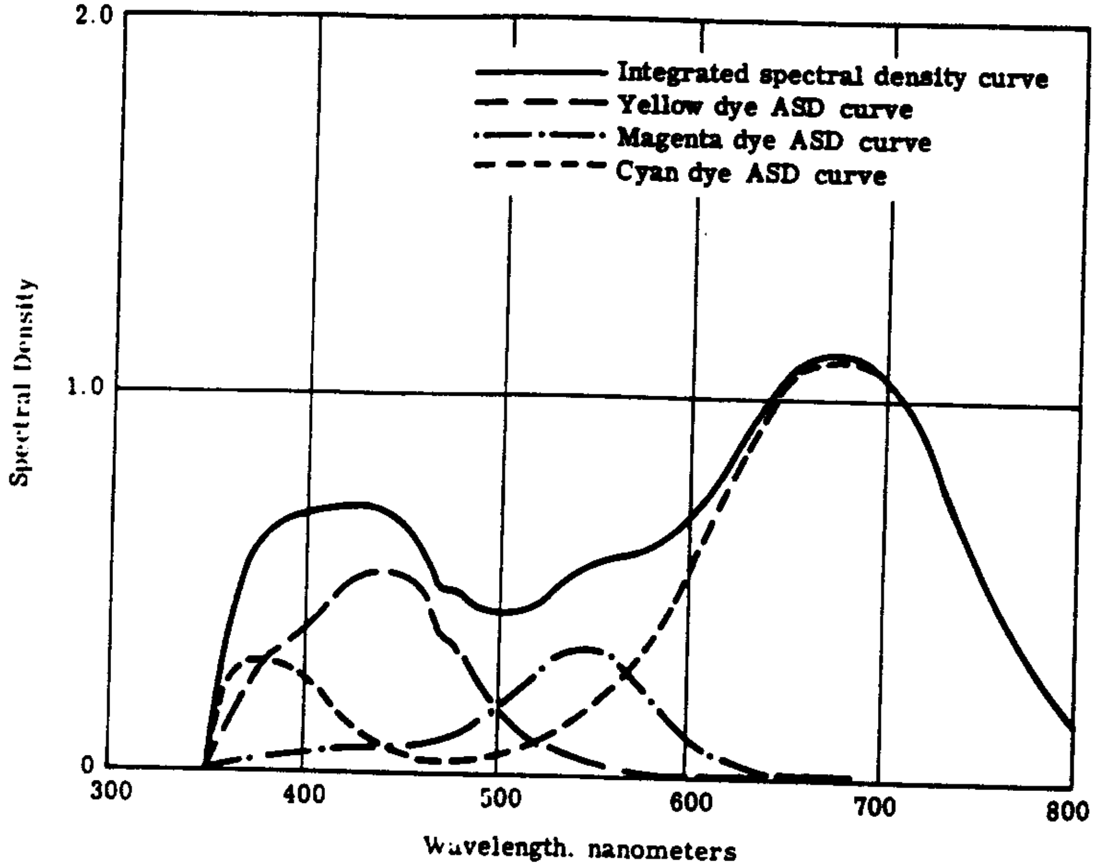


Fig. 4-7 — Cyan, magenta, and yellow analytical spectral density curves for dye samples of SO-180 type emulsion