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]

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.

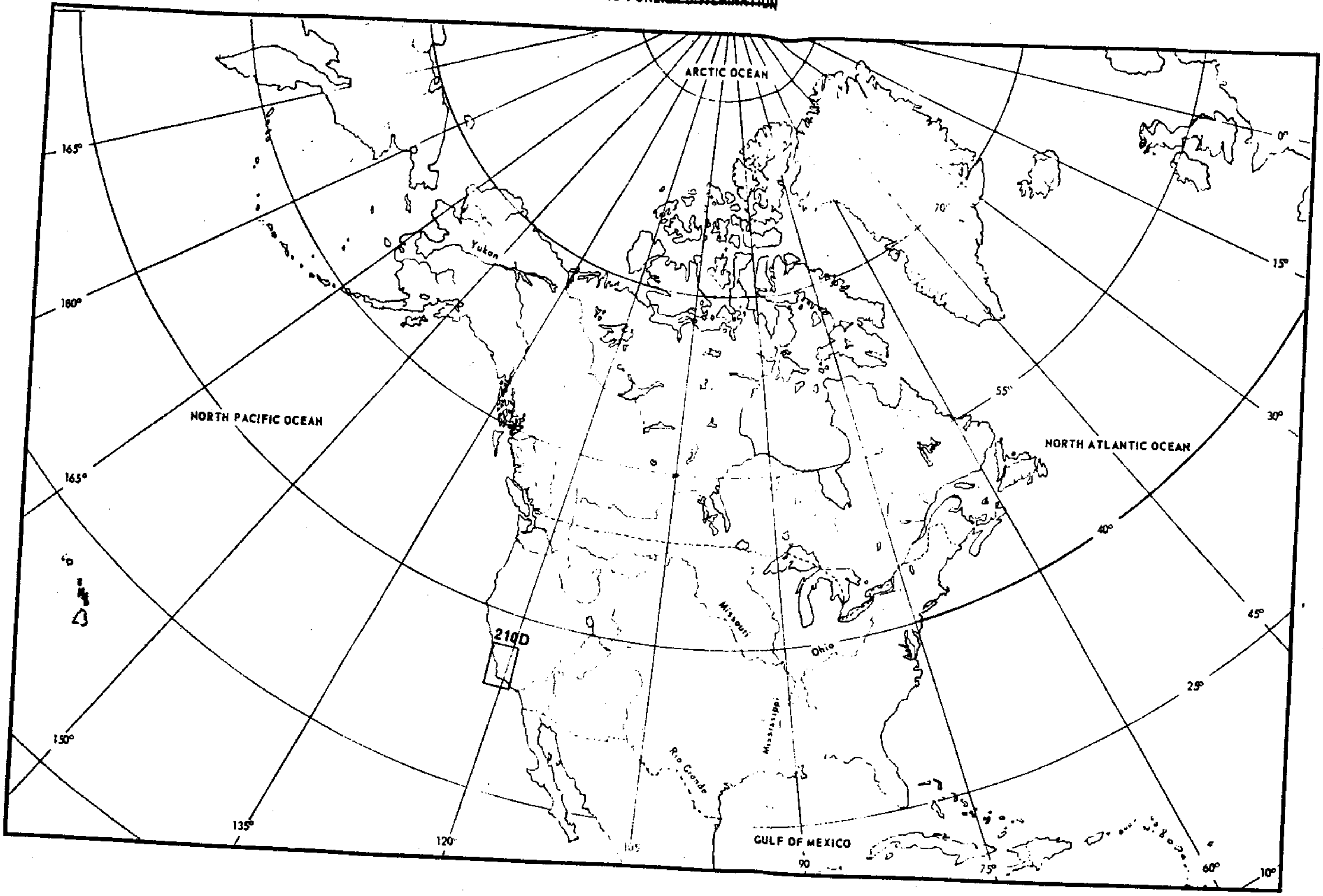


Fig. 2-1 — Mission 1104 SO-180 ground track over United States

[redacted]

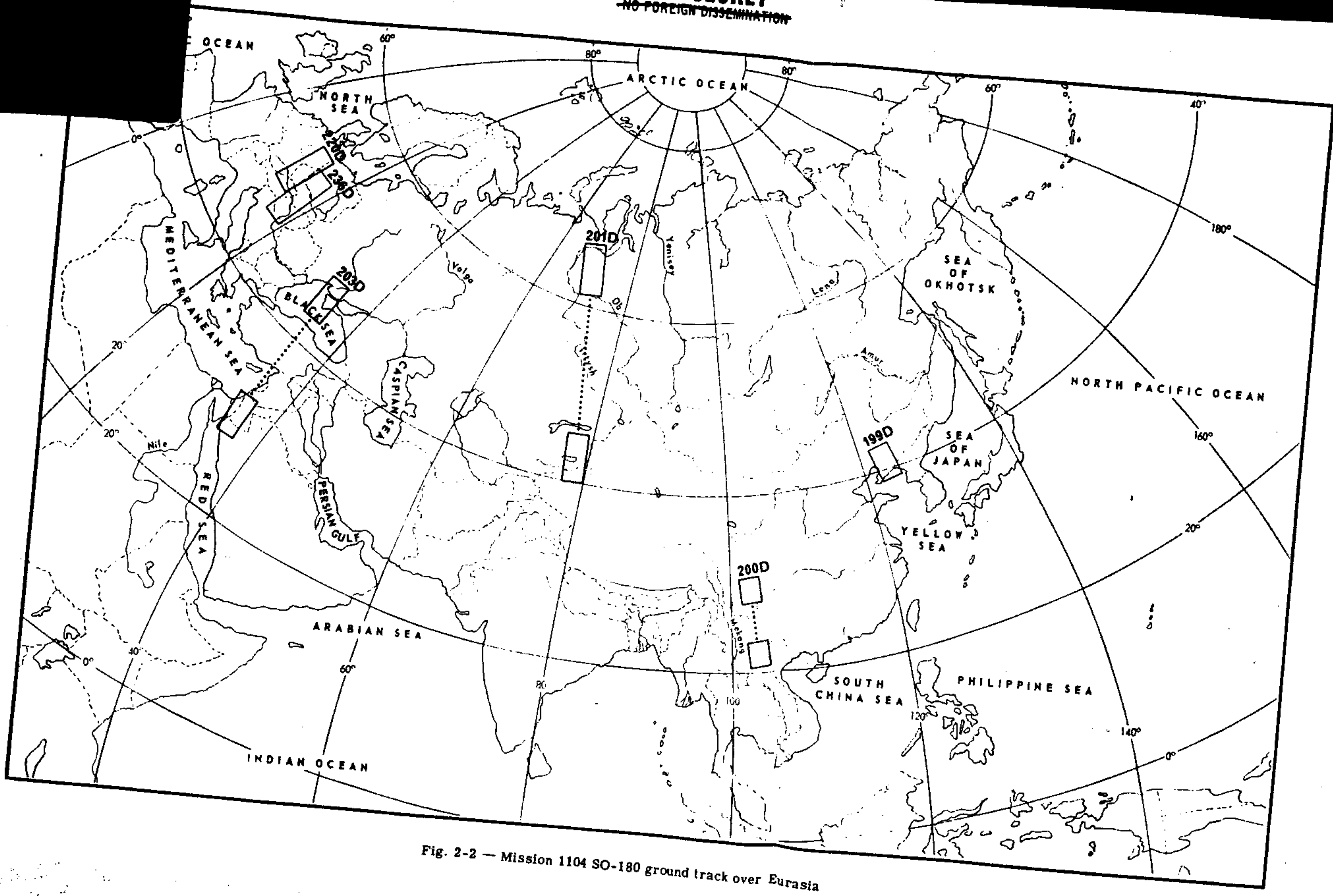


Fig. 2-2 — Mission 1104 SO-180 ground track over Eurasia

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 crosssection 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.

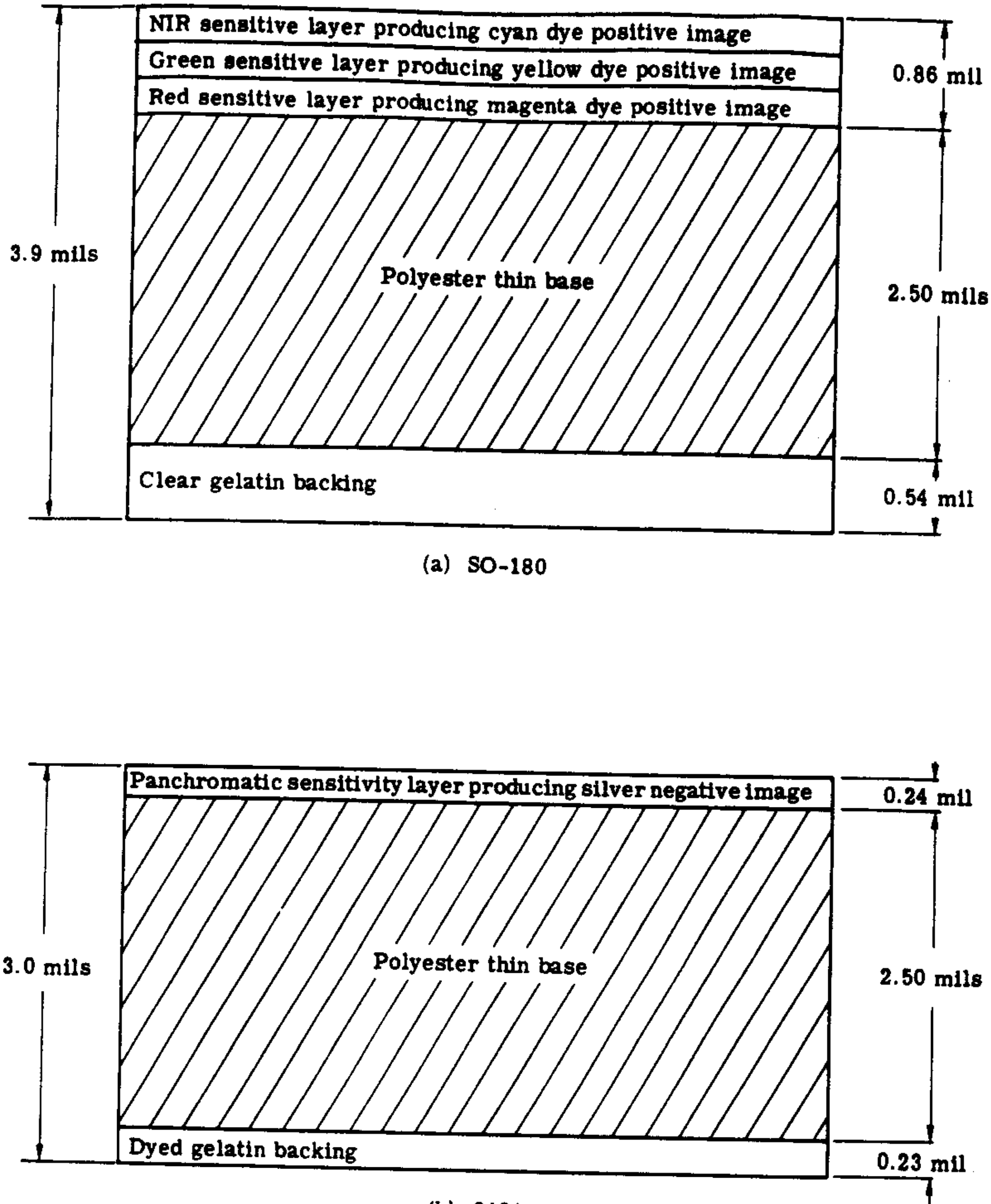
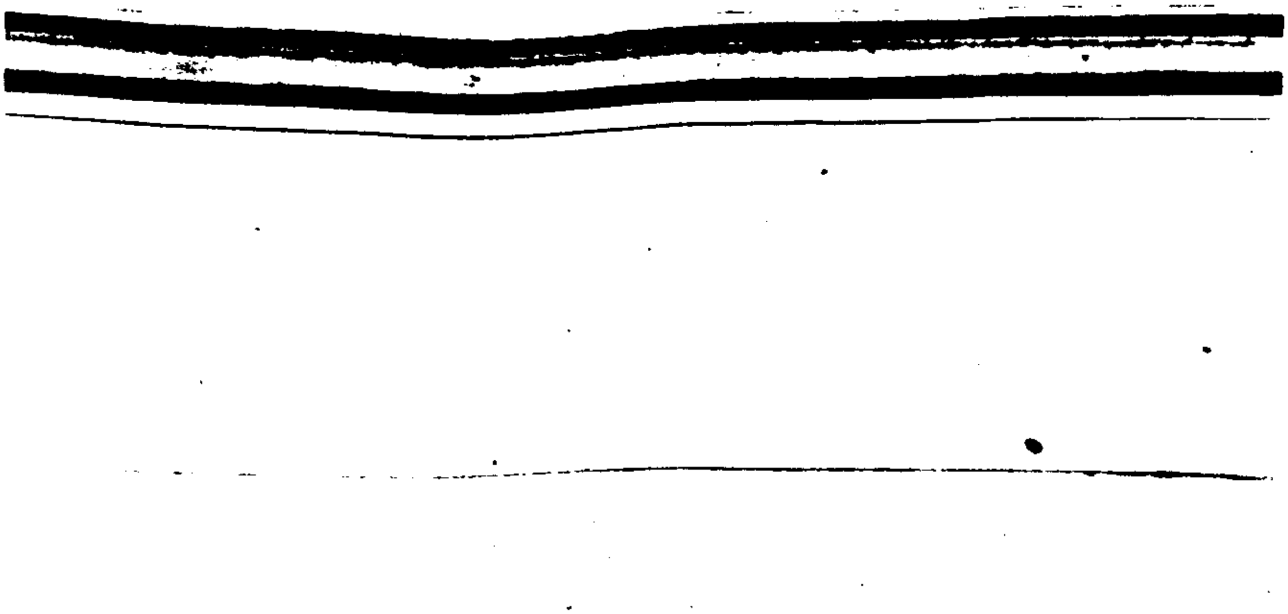
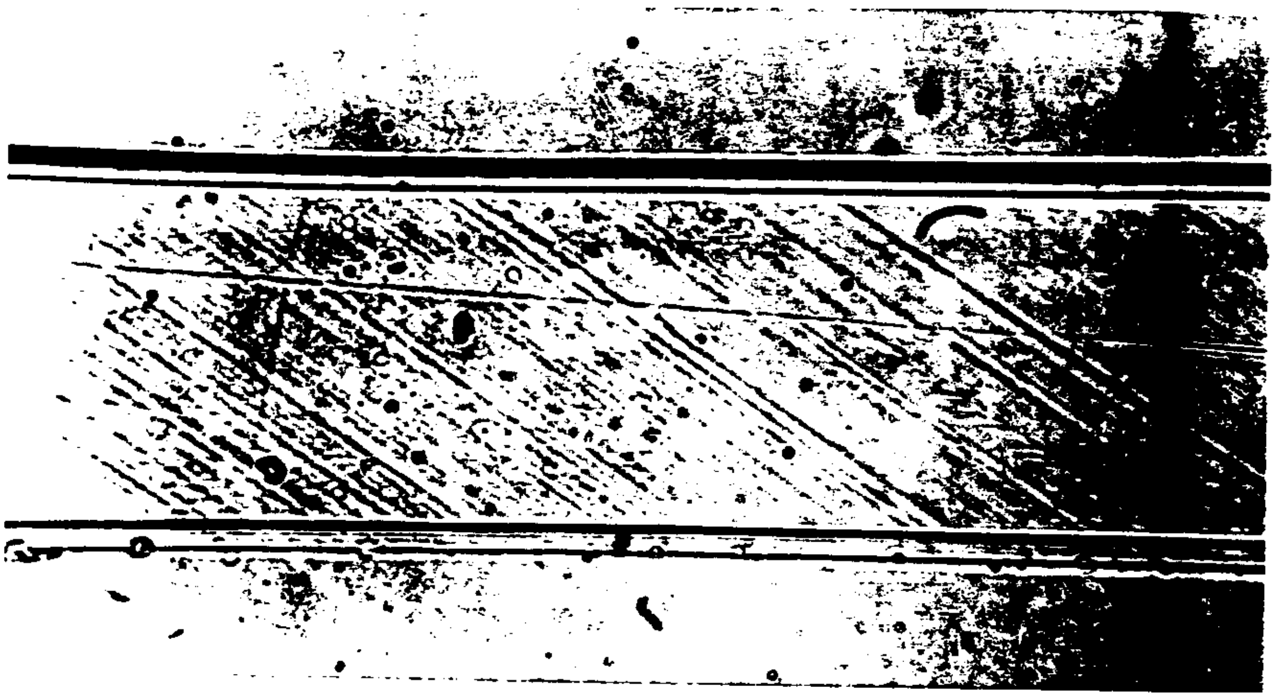


Fig. 3-1 — Physical structure of SO-180 and 3404 films



(a) SO-180 film



(b) 3404 film

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

Variations are 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

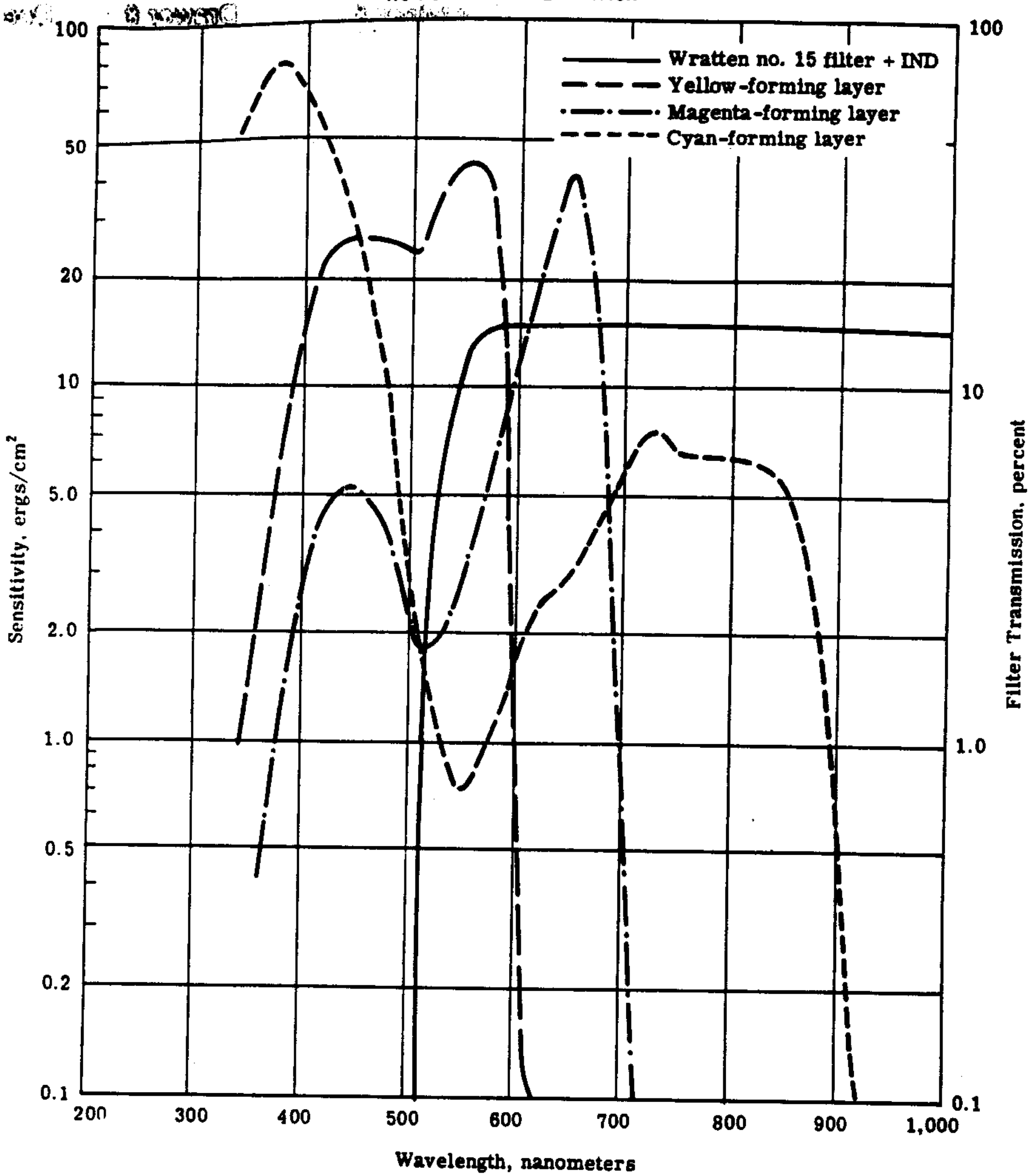


Fig. 3-3 — Spectral sensitivities for the three SO-180 film layers, including the Wratten no. 15 filter transmission used in the mission 1104 FWD-looking camera scan head assembly (Eastman Kodak data)

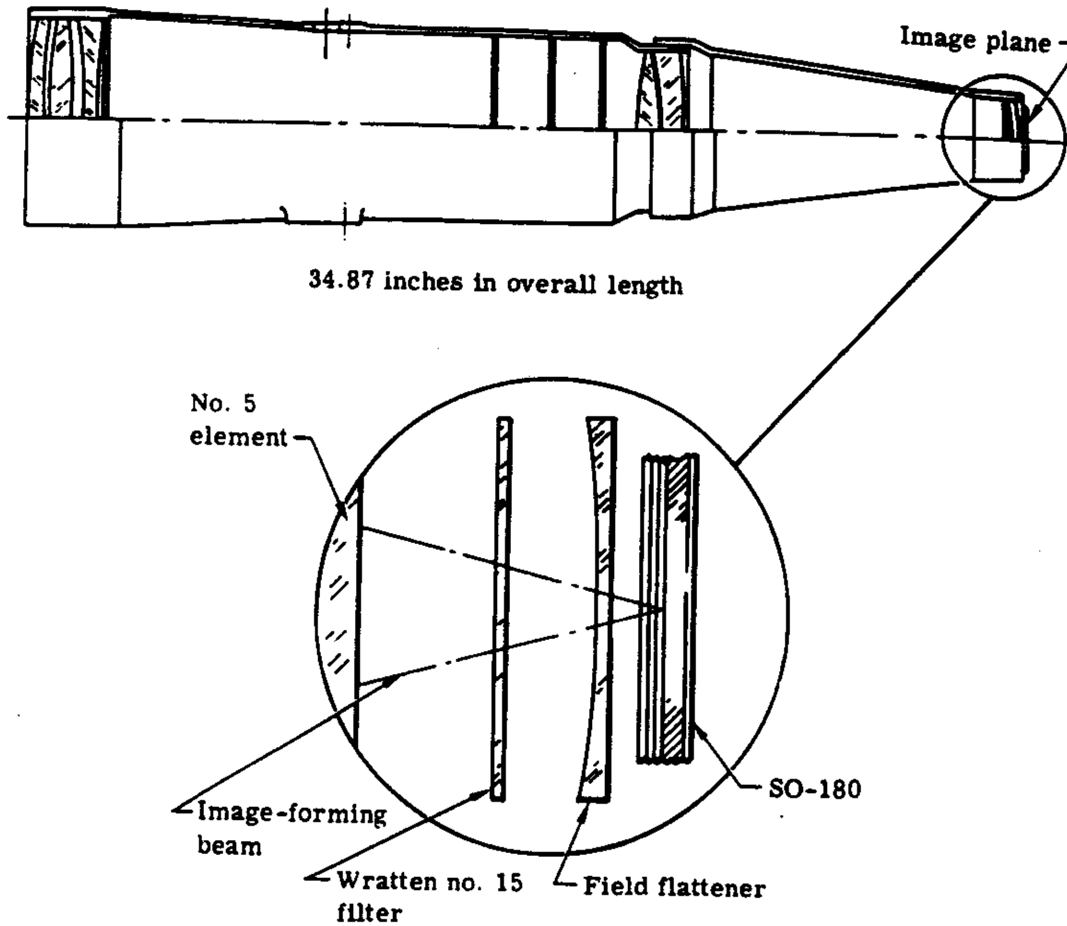


Fig. 3-4 — Petzval lens / Wratten no. 15 / SO-180 film configuration for KH-4B image acquisition

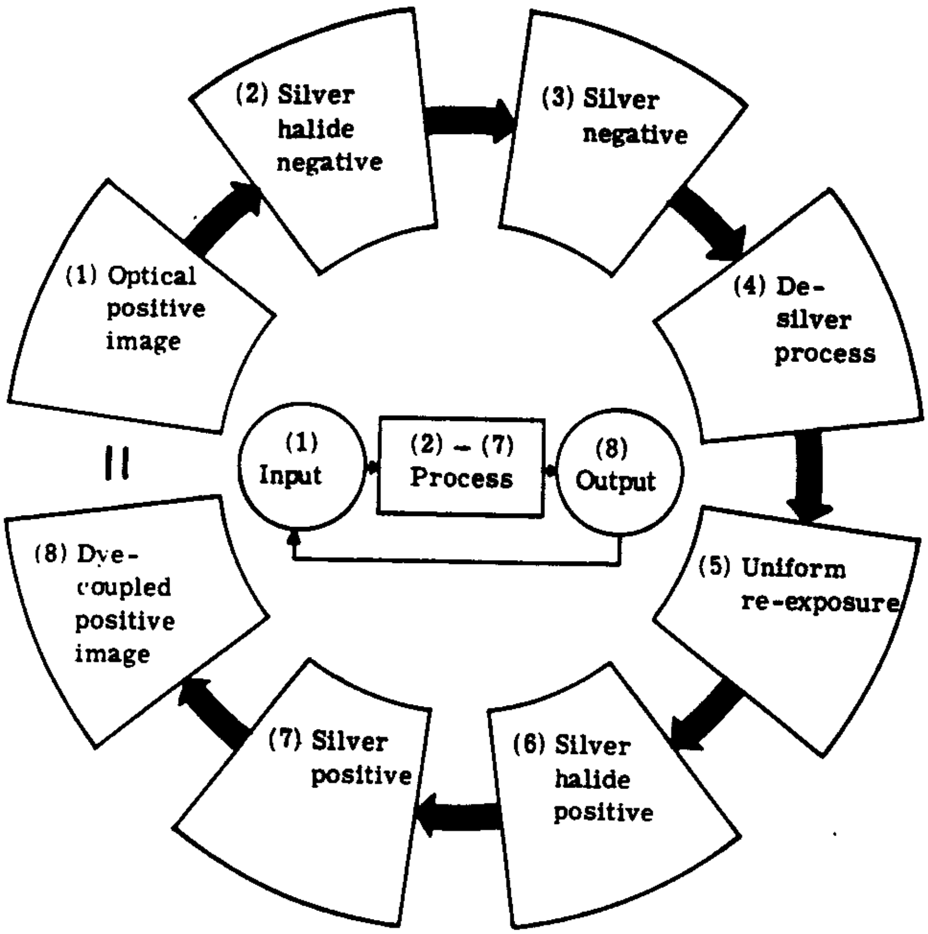


Fig. 3-5 — Schematic representation of the conversion from the Petzval formed image to the SO-180 recorded image

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.

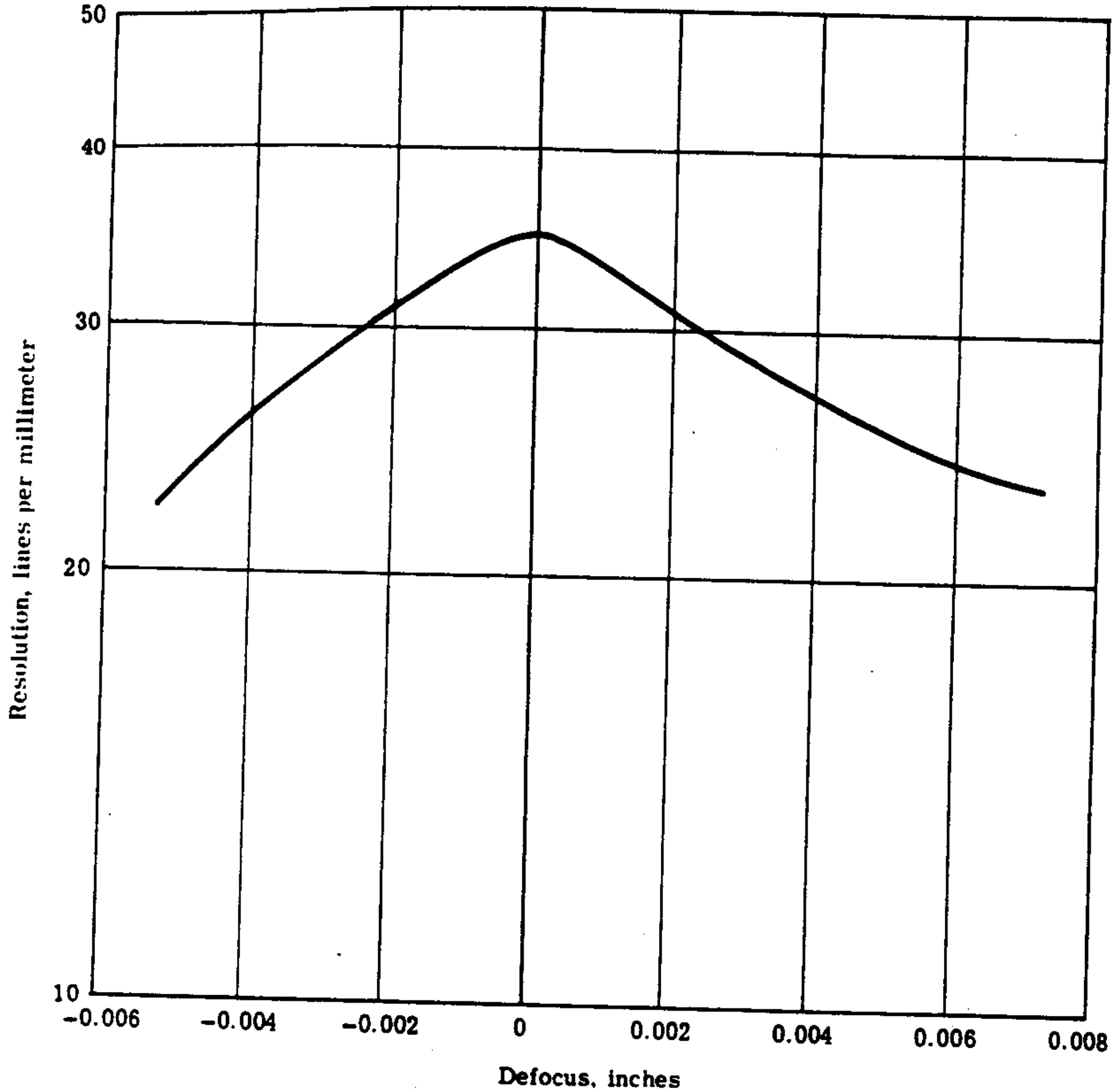


Fig. 3-6 — SO-180 low contrast resolution as a function of relative focal position for a third generation Petzval lens / Wratten no. 15 filter combination

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.

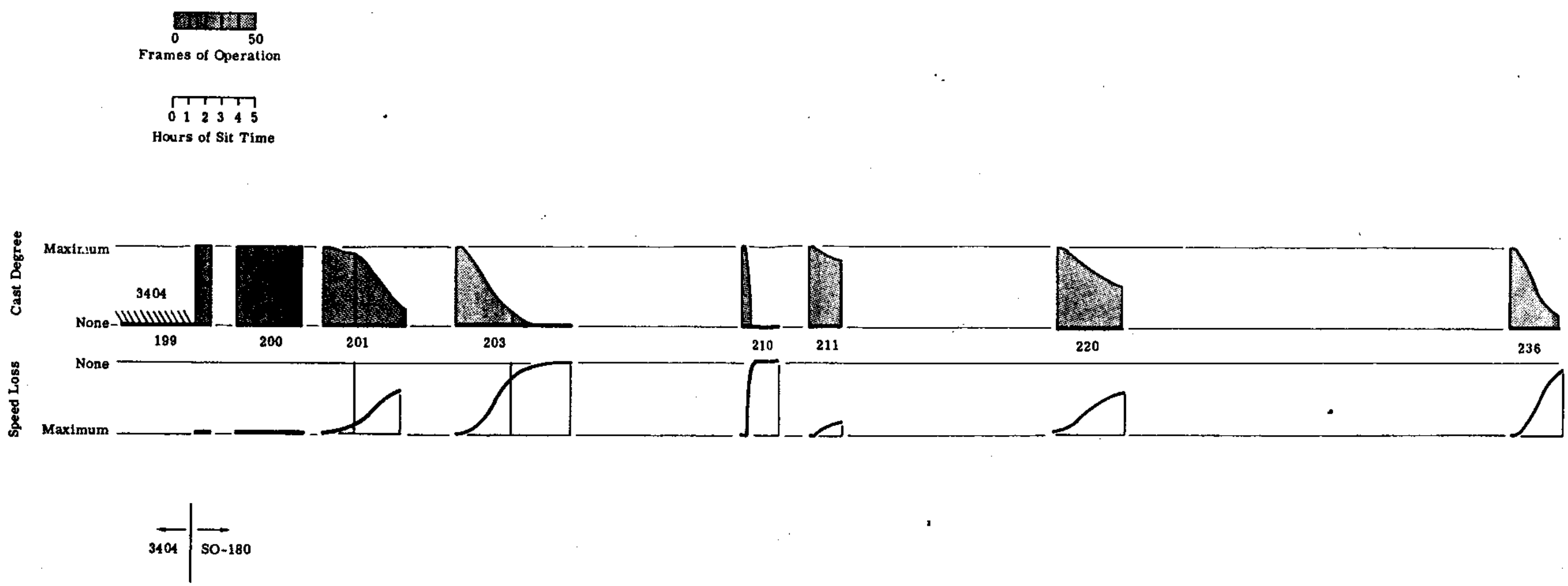


Fig. 4-1 — Each of the seven mission 1104 SO-180 passes with estimated degree of cyan cast over frames progressing from left to right showing proportionate amounts of sit times

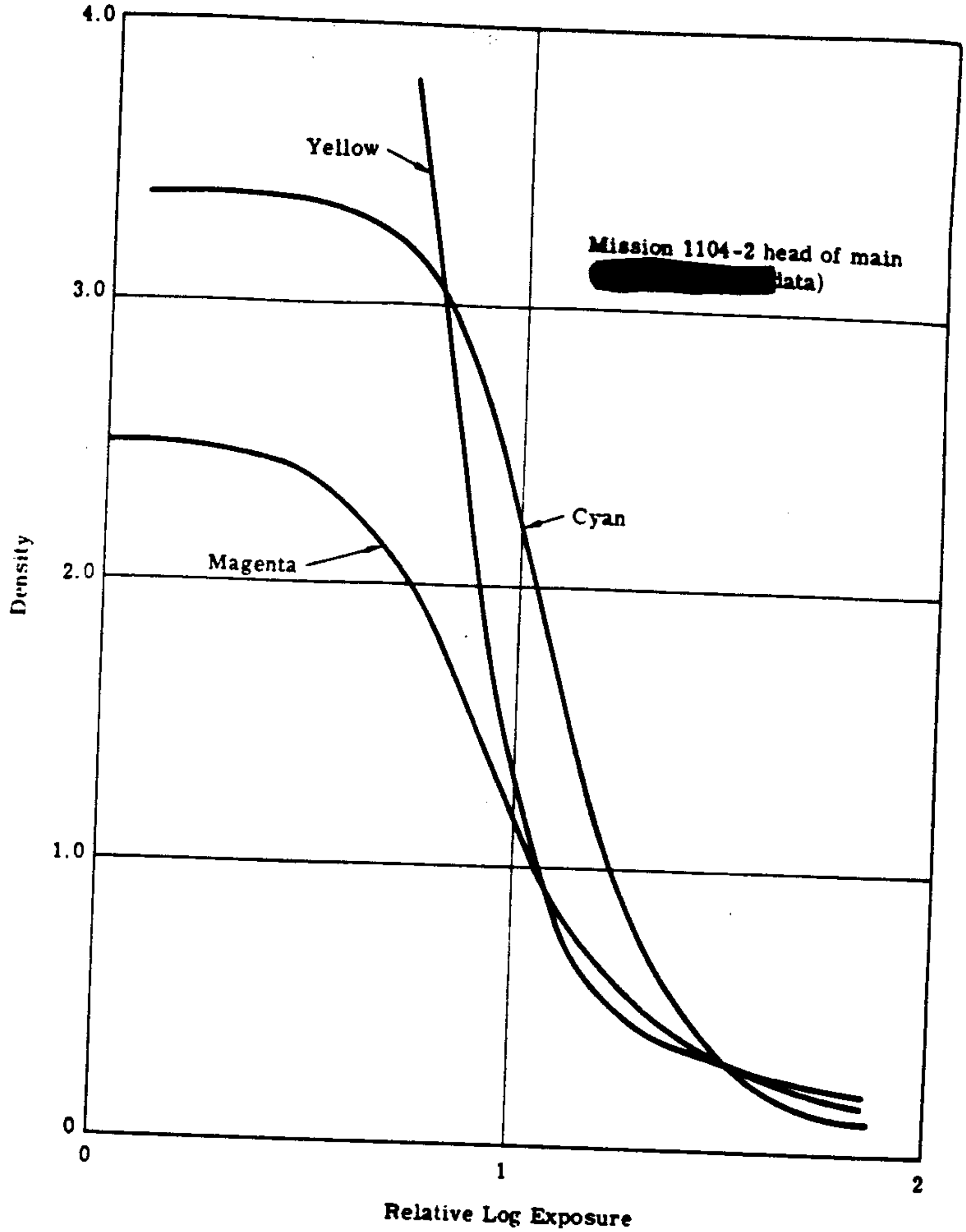


Fig. 4-2 — Sensitometric curves for SO-180

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 $\Delta RH = -15$ 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.

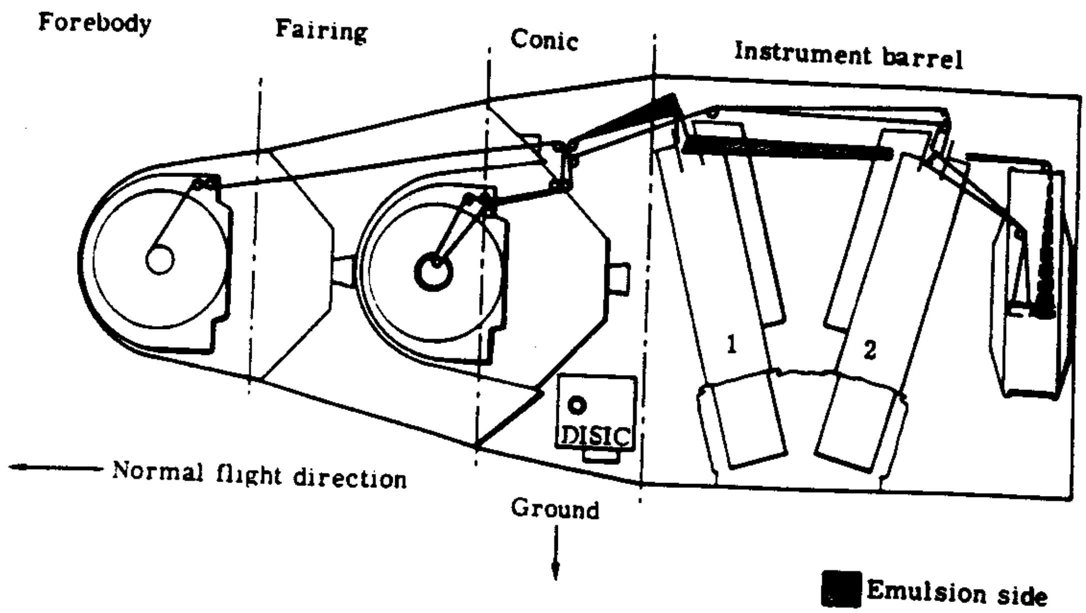
When SO-180 film is flown in future missions, the cyan cast problem (and not corona fogging) is expected to be the prime difficulty. For a full-load SO-180 mission, a two-filter arrangement could be utilized. For initial frames, a filter to slow down the magenta and yellow layers by one stop could be 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.

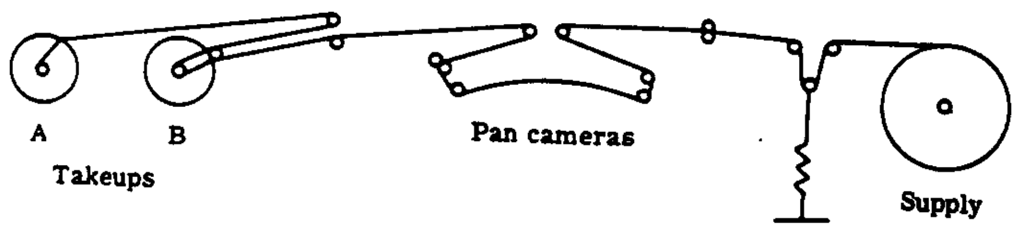
4.3 ELECTROSTATIC DISCHARGE FOGGING

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

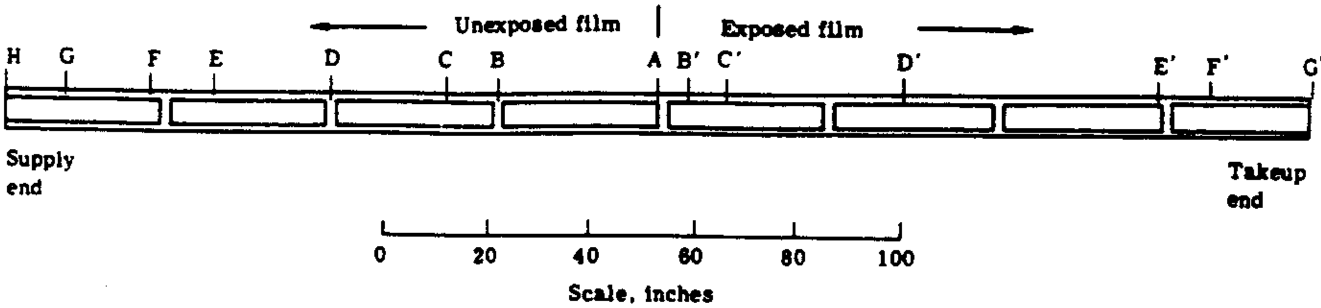


(a) Cross-section of P/L V



(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

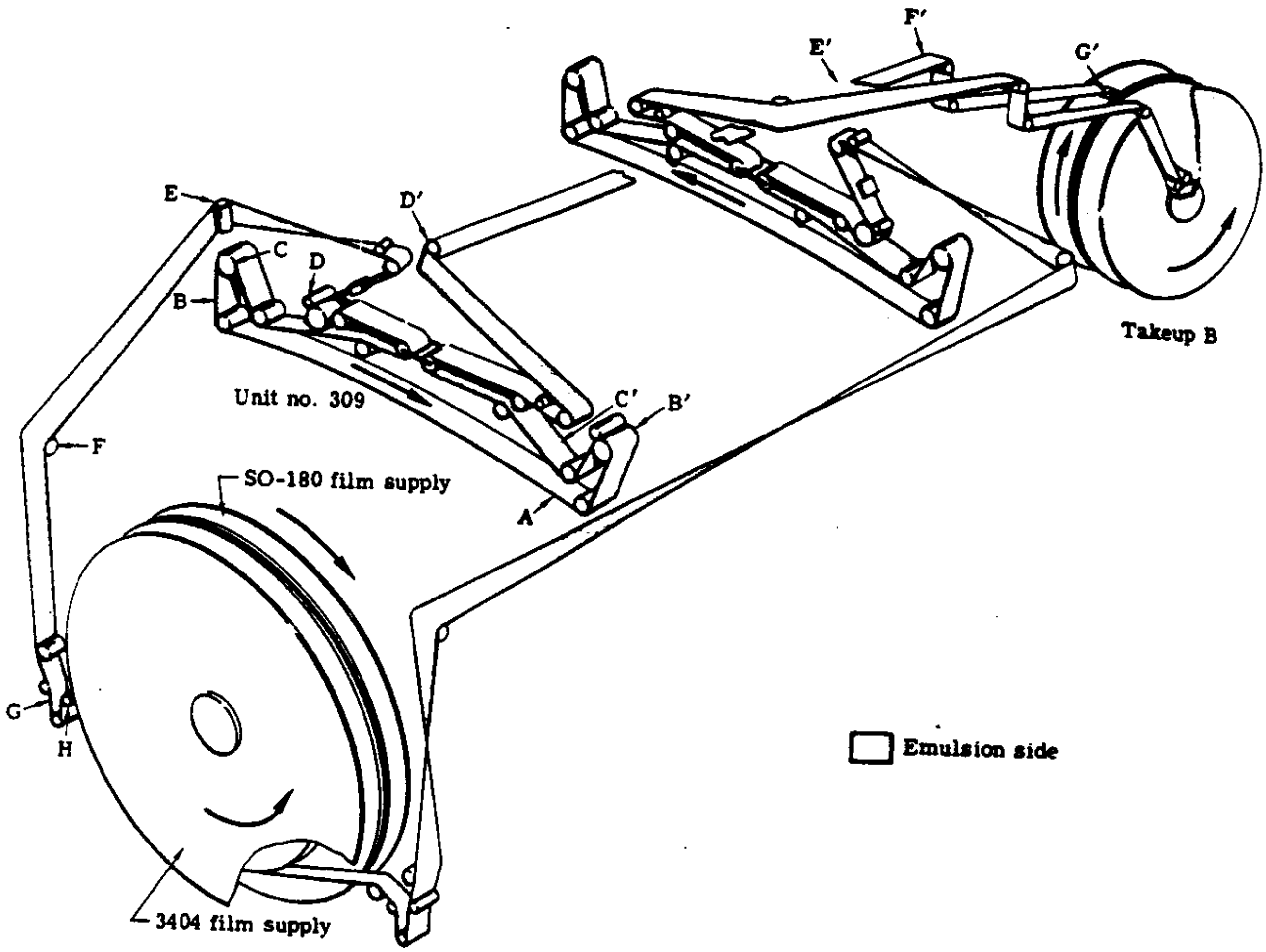


Fig. 4-5 — Film threading diagram for mission 1104 KH-4B main camera system, B-mission

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.

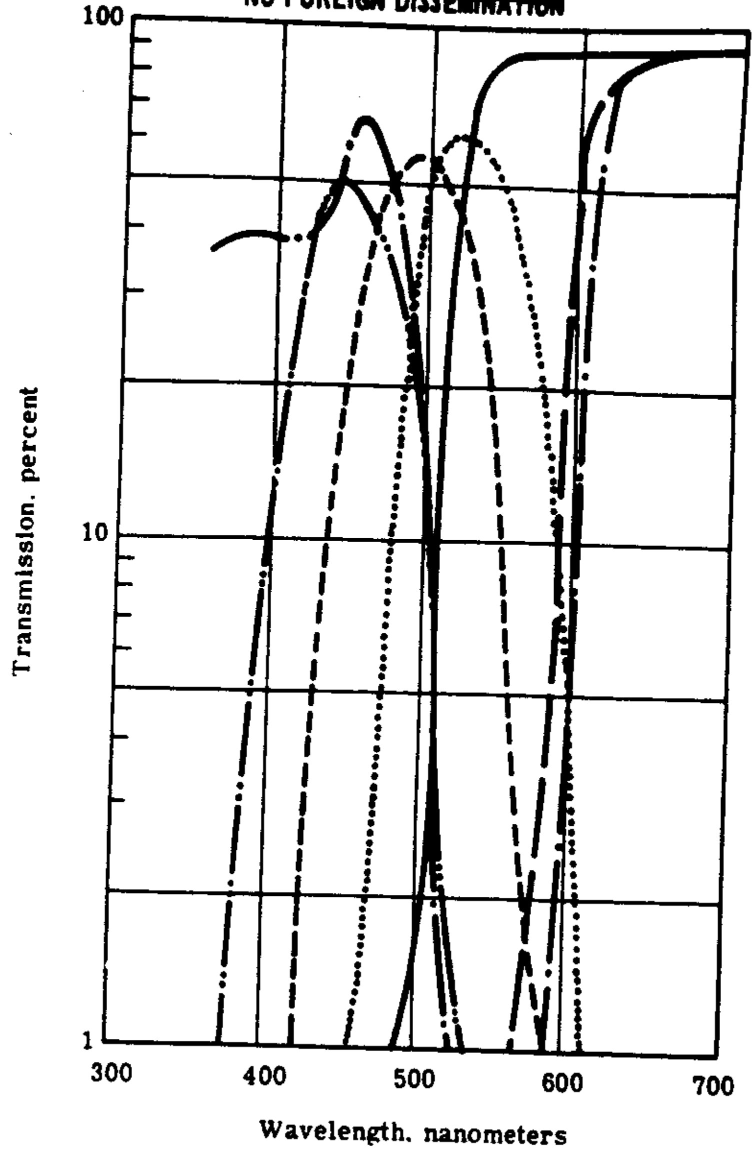
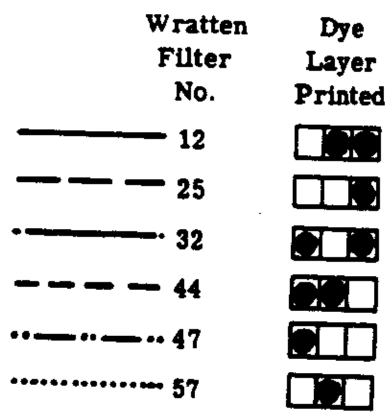


Fig. 4-6 — Six Wratten filters used to both isolate and suppress each of the SO-180 dye-image layers onto a panchromatic negative material



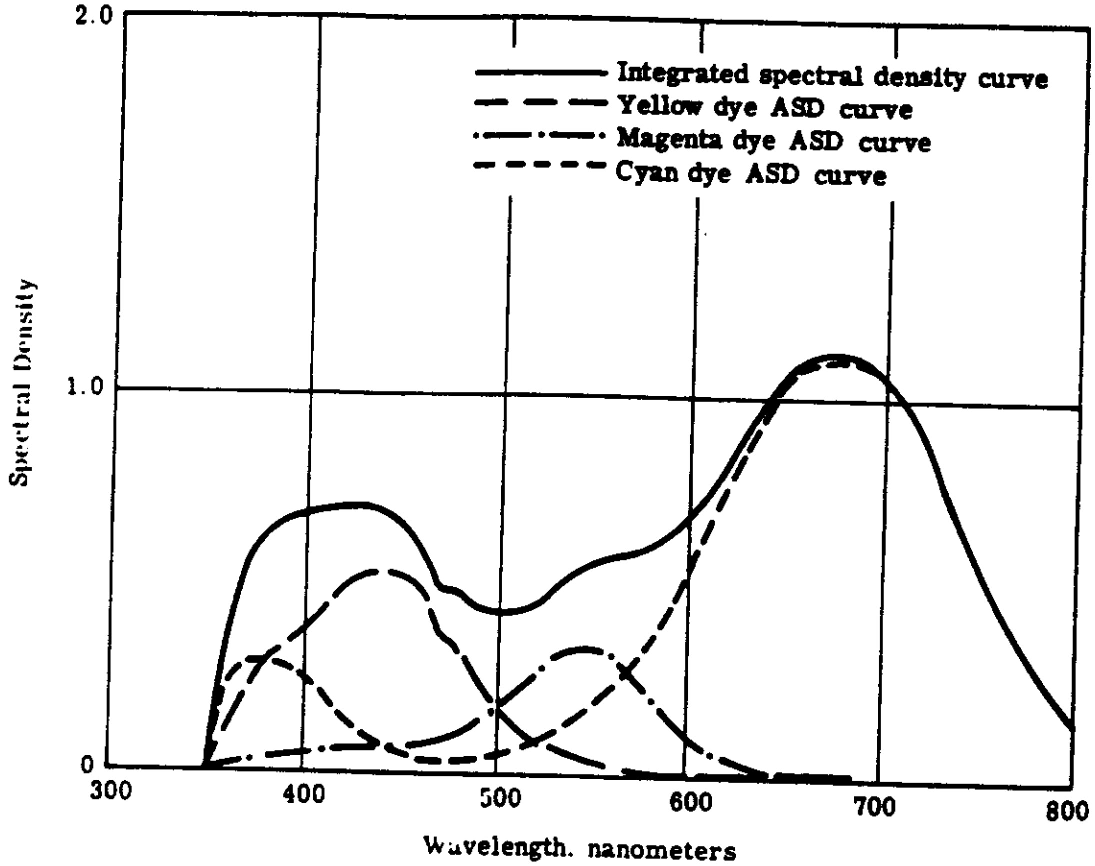


Fig. 4-7 — Cyan, magenta, and yellow analytical spectral density curves for dye samples of SO-180 type emulsion that only the cyan dye-forming layer was (at least predominantly) sensitive to the corona discharge within the instrument barrel.

This demonstration was also carried out on one of the most severely fogged frames (D-199-022)(see Fig. 5-12) of the entire mission 1104 SO-180 footage. The fact that corona fogging is reproduced for this case in all three dye layer isolation reproductions indicates that there was electrostatic discharge in the camera of sufficient intensity and spectral composition that all three layers could respond to it during maximum corona situations. The spectral composition of the energy causing the SO-180 fogging was hypothesized at an early date to be weighted towards the blue end of the spectrum.

The results of these two tests support the hypothesis that corona discharge is predominantly blue in its spectral composition. This would explain the fact that light-to-moderate corona fogging is restricted to the cyan dye-forming layer, whereas intense corona fogging is picked up by the yellow and magenta dye-forming layers as well. It is only to radiation below 500 nanometers that all three sensitive layers have a measurable response (see Fig. 3-3), with the cyan being an order of magnitude more sensitive than the yellow, and the yellow being an order of magnitude more sensitive than the magenta dye-forming layer.

More extensive studies on the image quality within the structural components of SO-180 film were carried out based on more controlled panchromatic duping through selective filtering. The entire domestic pass (D-210), original positives, were duped onto SO-345 (Kodak Panchromatic Aerial Duping Film) in the Eastman Kodak Rainbow Continuous Printer at AFSPPF to produce dye layer information isolation and suppression black-and-white reproductions with minimal duplication degradation and optimum spectral selectivity.

In a more precise way, the above demonstration with regard to location of corona fog in the SO-180 records was thus carried out. The effect of panchromatic duping through selective filtering on the presence or absence of corona fog is shown in Fig. 5-3. Wherever the cyan layer information is included in the reproduction, as in (a), (b), (c), (f), and (h), the corona fogging is evident. On the other hand, wherever the cyan layer information is suppressed, as in (d), (e), and (g), the fogged areas have disappeared.

The AFSPPF equipment is a high resolution, low distortion contact printer operating at a speed of 100 feet per minute, employing a 2-inch fixed slit and possessing a slew capability. A threading diagram for the printer is shown in Fig. 4-8, illustrating the relative configurations of the mission and duping films. Spectral control is achieved with three printing lamps selectively differentiated with red, green, and blue filters. A schematic of the lamphouse is presented in Fig. 4-9. Filtered lamp intensities are regulated individually by the control unit and are monitored with Macbeth Quantalog densitometers modified as photometers. Photometer readings are on a 0 to 4 density scale in 0.02 increments. The color filters (Pittsburgh plate glass with Corning coatings) are designed to match the spectral characteristics of Kodak reversal aerial duplicating color films.* This represents a more accurate dye layer isolation/suppression than the preceding work with Wratten filters. The printing light beams are combined through a system of mirrors and converged onto the printing slit.

* "Integral Status-A" densities are the Kodak standard characterization for related color materials.

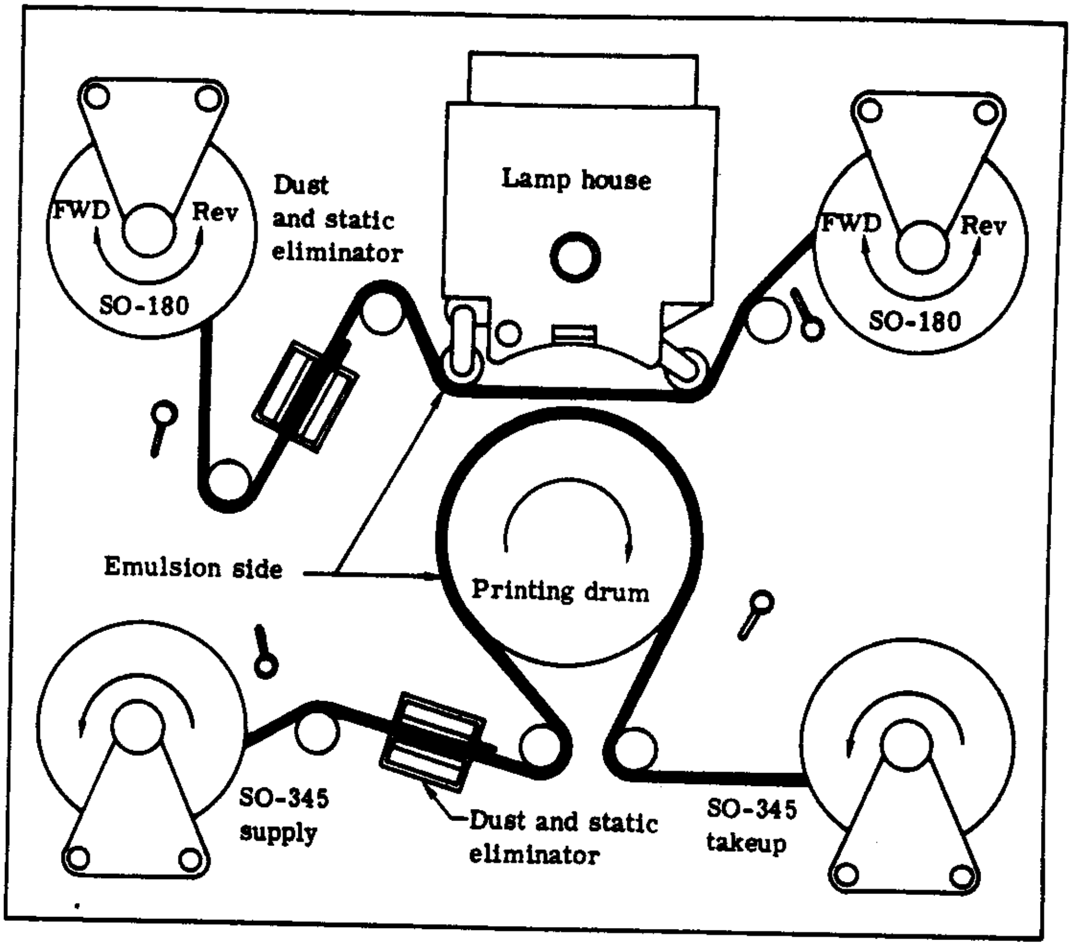


Fig. 4-8 — Threading diagram for the Rainbow Printer (in neutral position)

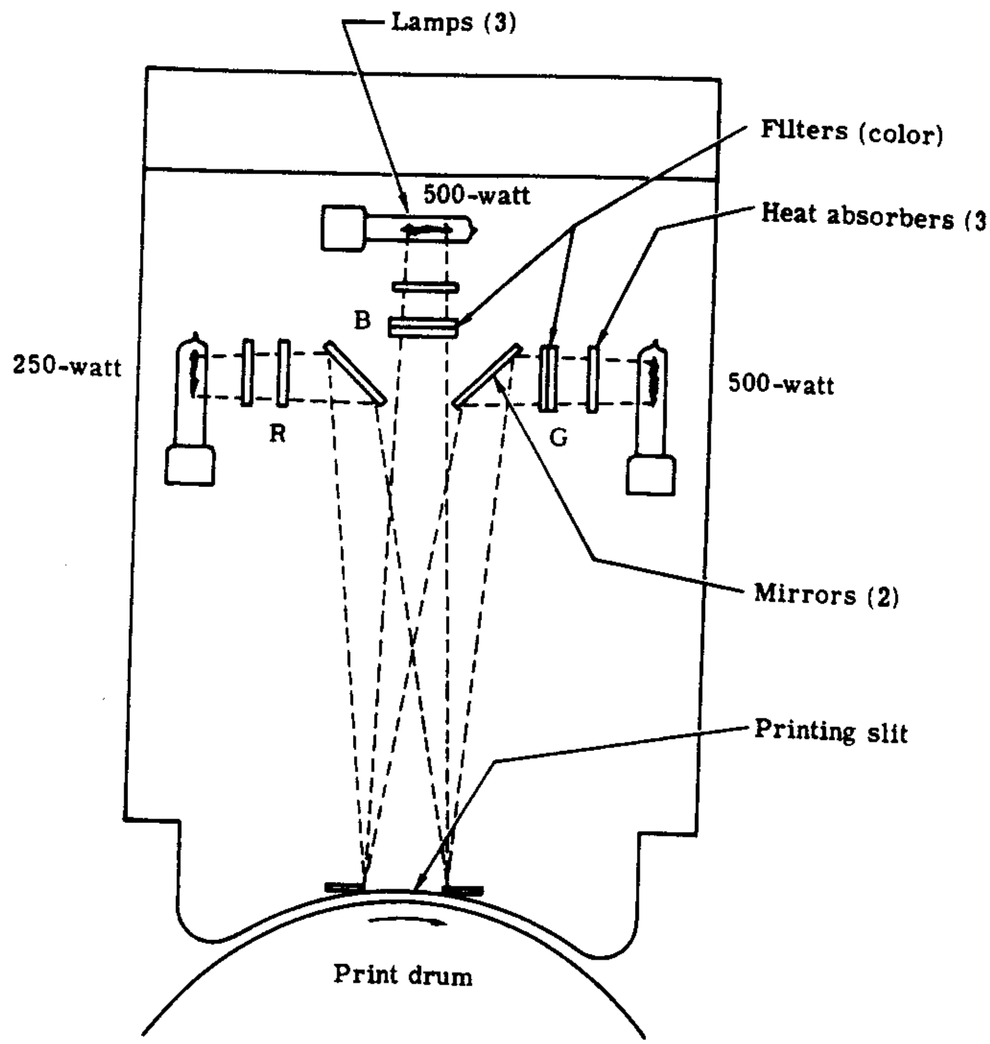


Fig. 4-9 — Schematic of three light paths in lamphouse of the Rainbow Printer

Table 4-2 — Photometer Settings on the Rainbow Printer Required to Achieve Selective Filtering and Good Tone Rendition on SO-345

Dye Layers Represented	Photometer Readings		
	Red	Green	Blue
C	0.60	4.00	4.00
M	4.00	0.40	4.00
Y	4.00	4.00	0.75
MY	4.00	0.70	1.05
CY	0.90	4.00	1.05
MC	0.90	0.70	4.00
MCY	1.10	0.90	1.25

M = magenta dye layer information
Y = yellow dye layer information
C = cyan dye layer information

Final photometer levels on each of the three lamps required to achieve the desired dupes with reasonable tone reproduction characteristics are given in Table 4-2. The photometer readings are inversely related to the light intensity being used in the printing. In isolating the cyan dye layer information, for example, zero intensity (4.00 reading) is used on the green and blue lamps, and the amount of red light required to produce a good reproduction is indicated by the 0.60 photometer reading.

From the entire D-210 pass, five different scenes were selected to serve in an experiment to rate relative image quality through comparative analysis. For each of these five scenes, the single SO-180 first generation duplicate positive (SO-271) and the seven SO-345 second generation duplicate negatives were put in random sequence with their identities marked. An experienced image analyst then studied the imagery with regard to edge definition, detail acuity, and overall sharpness. Using these parameters of image quality, he was able to make comparative judgments regarding the relative merits of each element in the series of eight replicate images. Although much of the preference ranking was based on very subtle differences, and although there were instances of nonuniform image quality, he was able to establish with confidence the eight representations of each scene into a ranked order with regard to image quality. His results are presented in Table 4-3.

These rankings indicate that the magenta layer (M) has the best image quality (IQ) and the cyan layer (C) has the worst IQ. It is to be noted, however, that the superiority of M is evident only after careful scrutiny, whereas the inferiority of C is immediately obvious. Unanimous agreement among all the scenes was also reached with SO-180 on the fourth rank and the yellow layer (Y) down on the seventh rank. The MY and CY combination layers are much the same with regard to IQ, but MY has a higher probability of being in the second rank. The MC and MCY combination layers are very similar, with MC assuming fifth rank and MCY sixth rank only statistically. Based on this data, the ranking which represents the situation as a whole is:

Rank	Imagery
1	M
2	MY
3	CY
4	180
5	MC
6	MCY
7	Y
8	C

Part of one of the scenes used in this experiment is reproduced in Figs. 5-3(a) through 5-3(h). Although the subtle progressions in image quality are necessarily lost in the paper print enlargements, subjective comparison under 10 to 30× magnification does reveal differences in photographic noise level, edge definition, and tonal relationships. Notice, for example, the gold patch (red flower cultivation) near the center of format of Fig. 5-3(a), together with the red field below it and the cyan field above it. In the different dye layer permutation reproductions, these three patches reproduce in different tonal relationships to one another. Density traces made on these scenes indicate that the isolated layer records tend to exhibit higher contrast than the confirmation layer records.

Table 4-3 — Comparative Ranking According to Image Quality for Five Different Scenes on Rev D-210

	Scene				
Rank	I	II	III	IV	V
1	M	M	M	M	M
2	CY	MY	MY	MY	MC
3	MY	CY	CY	CY	CY
4	180	180	180	180	180
5	MC	MCY	MC	MC	MCY
6	MCY	MC	MCY	MCY	MY
7	Y	Y	Y	Y	Y
8	C	C	C	C	C

M = magenta dye layer information
Y = yellow dye layer information
C = cyan dye layer information
180 = tripack color information

What is of immediate interest is the fact that three reproductions gain in IQ over the master SO-180 (SO-271). As would be expected, the straight white-light duplication of SO-180 is ranked just below it, presumably the loss in IQ being attributed to the duplication process alone. The cyan layer is definitely more grainy than any other reproduction. This can only be due to the fact that this layer has the largest dye globules. The low IQ of this layer is unexpected in view of the fact that it is physically the first layer that encounters the image-forming light (Fig. 3-1) and thus is the least subjected to light scattering within the emulsion.

A plausible explanation of the superiority of the magenta layer IQ over the other layer permutations can be obtained by examining polychromatic modulation transfer functions of the 24-inch Petzval third generation lens. Fig. 4-10 presents the effective transfer functions producing the optical image incident on each of the three SO-180 layers in the KH-4B camera. These chromatic MTF curves were computed for the third generation lens design, weighted by the Wratten no. 15 filter transmission and the spectral sensitivities of each of the SO-180 dye layers, taking into account the focal displacement defined by the sensitive gel layer thicknesses.

The striking superiority of the MTF associated with the magenta layer lends credence to the first preferance ranking of the magenta layer image reproduction IQ. In the same way, the relative inferiority of the MTF associated with the cyan layer, coupled with the excessive photographic noise level in this layer's imagery, lends credence to the poorest ranking of IQ in the cyan layer reproduction.

This work demonstrates a twofold gain in isolating the tonal pattern array in the magenta layer of SO-180. The first advantage is the suppression of corona fogging that is relegated to the cyan layer. With this black and white reproduction, there is the same image area freed from the occluding effects of corona fogging and the deleterious effects of cyan cast as well. The second plus value resides in the fact that the magenta layer imagery has superior IQ to either of the other dye layers or any combination of the three layers.

Because this imagery is formed during the acquisition mode by essentially red light, panchromatic reproduction of this information distribution is similar to a 3404 record made through a Wratten no. 25 filter. Of course, detail rendition in the SO-180 magenta layer reproduction is far inferior to the 3404/Wratten no. 25 record [see Figs. 5-4(b) and 5-4(c)]. However, there could be a gain in interpretability over the original SO-180 imagery with regard to some marginal detail. But the real value is in providing an alternate record for use in a stereo viewing mode. Whereas the color record itself together with the comparative 3404 record in stereo has some visual adaptation difficulties and poorer mensuration characteristics, substituting the SO-180 with its magenta layer reproduction can do something to alleviate these difficulties. Thus, this isolated record not only provides tonal rendition similar to a 3404 record, but also has the best image quality of all of the other black and white reproductions. As such, together with 3404 coverage, it constitutes a stereo model for the photointerpreter of the type with which he is used to working.

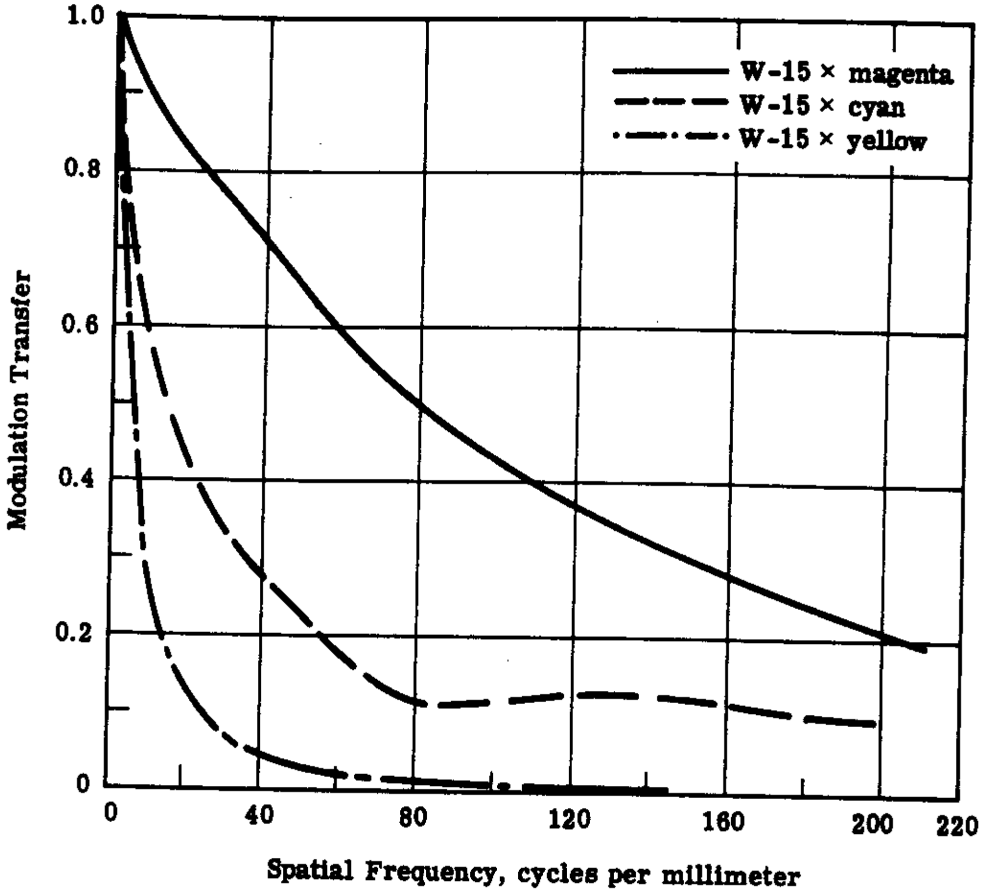


Fig. 4-10 — Third generation Petzval lens (nominal design) chromatic MTF's cascaded with Wratten no. 15 filter and SO-180 film dye layer sensitivities

5. INTERPRETABILITY OF MISSION 1104 SO-180 IMAGERY

5.1 NATURE OF COLOR TRANSLATION

The visual effects of color translation (synonymous with false color and spectral shift) in SO-180 reversal film is presented schematically in Fig. 5-1. In this scheme, a listing is made of relationships between typical ground scene colors and their chromatic rendition on SO-180 after color translation recording. Some examples of this can be seen in the following illustrations. The yellow-gold rectangular patch just left of center in Fig. 5-3(a) is a field of red flowers in Lompoc, "the flower seed capital of the world." In fact, in this commercial flower growing scene, all the translations of bloom color are noteworthy. The magenta patches in Fig. 5-4(a) are lawns and cultivated fields. The different shades of blue rivers in Fig. 5-9(b), (d), and (f) reflect different colors of water resulting from variations in stream depth and silt content as well as differences in look angle.

To further exemplify the visual effect of SO-180 color translation in the KH-4B system, the horizon optics constitute a simplified case. A horizon camera is mounted on each end of the film transport bridge of each panoramic camera. A deep red filter (Wratten no. 25) is used because of the long atmospheric path length involved in this imagery. The exposure is made by a single action, self-cocking, between-the-lens, leaf-type shutter. The exposure control system consists of a motor-driven attenuating filter that slides in front of the lens for films faster than the basic 3404.

Horizon images of supra-atmospheric space appear black in color because no green, red, or near-infrared energy is incident on the film, such that all three layers are filled with dye and transmit no light. In the earth imagery, the Wratten no. 25 filter precludes green light, with the result that there is always a full course of yellow dye remaining in the film. This means that whites are impossible in the horizon images. All earth and cloud information, then, is formed only by red and NIR energy, variably reducing the amounts of magenta and cyan dyes. With no loss of speed in the cyan layer, this produces shades of green and red earth imagery, depending on the relative amounts of vegetation in the areas covered. If the light level from these regions gets too high, information is destroyed and only the yellow color remains. With speed losses in the cyan layer, earth imagery is only green.

Because NIR is absorbed by water, only red energy reaches the SO-180 from its surface, removing only the magenta dye with the resultant viewing transmission of only green light. High energy levels reflected from the clouds inevitably burns away all the magenta and cyan dyes, producing cloud imagery in yellow. In cases of corona fogging in the space imagery, the cyan dye is reduced, lessening the ability of the film to absorb red from transmitted light beams, and so corona fogging looks red.

The cyan layer is designed to be slower than the other two layers (Fig. 4-2) because targets of special interest for this material have relatively more energy in the NIR than in the red and green. Spectral reflectance curves of various typical foliage types are given in Fig. 5-2. With

Object ⟶ Reproduction Color

Yellow flowers = Green

Red flowers = Yellow

Blue (dark green) grass = Red

Bright green grass = Pink-magenta

Dead trees = Blue-purple

Broad leaf trees = Reddish brown-cyan brown

Pine trees = Reddish brown

Urban areas, concrete, buildings, etc. = Neutral to slight cyan cast

Red brick roof tops = Greenish yellow

Metallic aircraft = Neutral

Dirt roads = Neutral

Hot-top roads = Cyan

Sand = Neutral

Coastal water = From light green to cyan to dark blue (depending on depth)

Salt water = White, light blue, dark blue, light and dark green

Fresh water = Blues and greens, cyan

Tidal water = Greens to blue

Tidal water (contaminated) = Yellow to blue

Deep ocean = Dark blue

River beds with growth = Cyan to blue

Clouds = White (neutral)

Cultivated fields = Red through neutral (depending on state of growth)

Growing hayfields = Red

Fallow fields = Neutral to cyan

Volcanic mountains = Black to gray

Rocks = Greens, brown, gray

Swimming pools = Bright blue

Fig. 5-1 — Objects and their general reproduction on SO-180

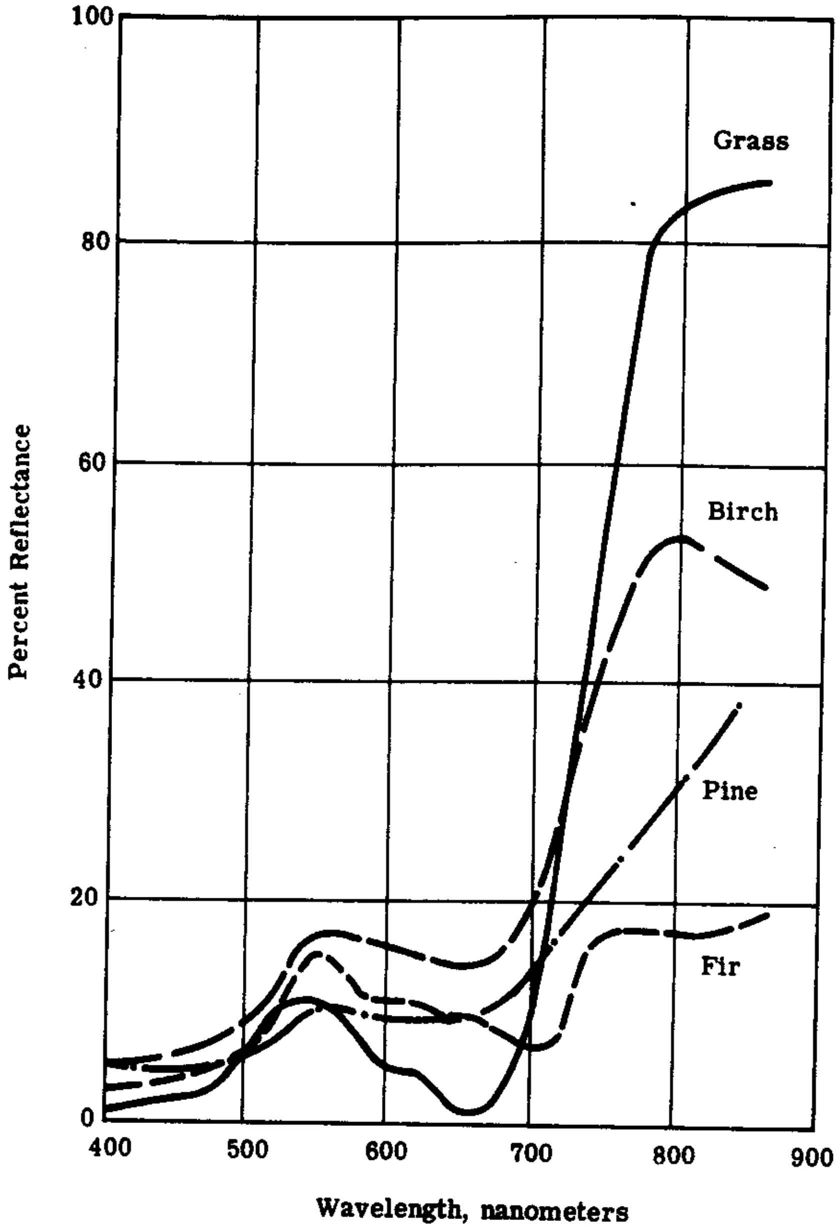


Fig. 5-2 — Spectral reflectance curves of various typical foliage types these curves the relative predominance of green over blue and red in the visual wavelengths, as well as the principal energy content in the NIR, is evident. A value of photographic sensitivity in this spectral region is the unqualified predominance of reflected energy over thermal emission. There is only insignificant absorption of the photographic infrared by the atmosphere, and the scattering is less than for the visual wavelengths—all of which increases the probability for high contrast imagery in this spectral region.

The original intent for camouflage detection type of film sensitivity was to be able to characterize and distinguish between healthy plants, those that were damaged, and camouflage materials. The prime value of SO-180 is still in the detection of changes or differences in the 700- to 900-nanometer region. Such changes are not visible directly.

Application is especially effective for information requirements in forestry, agronomy, agricultural economics, and other sciences. For example, revelation of diseased vegetation and polluted water is possible with this photographic infrared. It is to be pointed out, as a precaution, that detection of "hot" objects or delineations of pressure and temperature at various altitudes in the atmosphere is not possible with NIR energy SO-180 sensitivity as it is with thermal infrared sensors.

But regardless of the application, the discrimination capacity depends on both the exposure level and color balance of the acquisition SO-180 as well as the tone reproduction of working copies. When working with the material and its duplications, it must be kept in mind that the key advantage of color translation imagery is the enhanced signal-to-noise ratio of targets from their background through color contrast. This technique could be of major importance to users of the KH-4B system as well as for multispectral orbiting reconnaissance systems of the future which will incorporate the projection of images from several sensors.

Extracting information from color translation records requires some different interpretive skills, both with regard to visual perception and reference association, than are required for data reducing either black and white or normal color imagery. However, the psychological adaptation and learning required is not so demanding as to be a depreciating factor in an overall assessment of SO-180 capability. A short period of orientation and use should allow the interpreter to feel at home with the medium. Those experienced in correlating imagery or output from conventional photographic systems with passive infrared, radar, or laser systems should experience no difficulty, since their minds are receptive to having several possible signatures for a single object.

The spectral quality of the viewing conditions can play a critical role in the appearance of the transparencies. This is true not only for the light source directly, but for induced effects from surrounding colors as well—because the human visual system autonomously makes chromatic compensations. That is, the visual system adapts in viewing a transparency so that whites appear white even if they are not objectively white.

In order to serve a user's special interpretation needs, it is promising that intentional color imbalance could be introduced so as to enhance the color contrast and thus escalate the amount of information extracted. For example, the photographic illustrations in the following section could have been printed with different color balances to enhance the points of interpretation being made rather than duplicating the appearance of the original film, as was done.

5.2 SUBJECTIVE EVALUATION

In order to evaluate the interpretability of the mission 1104 SO-180 imagery, and relate this to the anomalies degrading the photographic performance, a subjective evaluation including psychometric ranking was carried out. With regard to detail rendition of the imagery, there is no doubt that the 3404 record is far superior to the SO-180 record. At the same time, both the color dimension of the SO-180 and its ability to record other-than-visible radiation provide information of which the high-definition 3404 is incapable. For the mission 1104 color imagery, information extraction at a magnification of 12 to 15 diameters appears to be the most practical limit. Interpretation of the false color records involves a minor re-orientation to unique ground signatures (see Section 5.1).

Seven operational passes were made using the test film, one domestic and six foreign. Not all of these could be used for critical evaluation, but four were suitable for intensive investigation. These four photographic passes were:

1. D-200 covering South China and North Vietnam in two operations.
2. D-201 covering the Soviet Union in the north at the Ob River estuary and in the south at Lake Balkhash in two operations.
3. D-203 covering the Soviet Crimea and Israel-Jordan in two operations.
4. D-210 covering California from Monterey to the Santa Barbara Channel Islands in one operation.

Considerable variations in climate, geographic location and cultural differences are included in the areas observed. Semideciduous tropical forests, scant population and numerous rivers were apparent in rev D-200. The arctic tundra, middle latitude steppes, and mountains with extensive glaciation were covered in rev D-201. The fertile Crimea, the populated coast of Israel and the deserts of southern Jordan and Israel were shown in rev D-203. Rev D-210, along the California coast was half water coverage, but was well populated and contained many items of military interest. The wooded cover is primarily Mediterranean scrub forest.

For the sake of an orderly subjective evaluation of SO-180, the evaluation is segmented to cover a series of representative categories. Each is a reflection of the comparative performance of the film in that particular set of circumstances.

5.2.1 Culture

The various works of man, as distinct from the natural state of the environment, comprise the global category of culture. Military and transportation installations, structures, and support facilities, while being cultural, are treated as separate categories because of their special interest.

Cultural influences are evident in all passes. Those consisting of small buildings and second or third class roadways show as poor* in the SO-180 records. If the built-up area is broad and contains large buildings and has a good road system, it may rate as fair. The presence of trees among buildings is readily apparent in the test film because of the red response of the chlorophyll. In the 3404 film, trees are often indistinguishable and confuse the shape and size of structures.

Industrial interpretation is limited in many cases by unresolved detail in the SO-180. However, for larger industrial facilities, mass and configuration are usually sufficient indicators of specific functions and/or operations. Such facilities can be rated as fair (rank 4). For smaller

---

* Explanations of the qualitative ratings used in the test are given in Appendix B. These ratings are subjective incremental progressions in a comparative ranking context.

industrial facilities, more reliance is placed on detail rendition, and the rating is generally poor (rank 3).

An instance of unique signature presence is illustrated in Fig. 5-6 relating to waste disposal. The subject is well defined in the 3404 record, but the SO-180 sample exhibits a chlorophyl response. The presence and quantity of vegetative growth is indicative of the presence of water and nutrients in excess of what should be expected for the area.

5.2.2 Military

Evaluation of military facilities and vehicles is approached in the same manner as is cultural evaluation. Essentially the difference is in the separation of man-made objects intended for civil use from those intended for military applications.

The larger permanent bases and support facilities are essentially urban areas in that the functions performed are the same as would be found in small to medium size towns. Interpretability of SO-180 in this category, as related to 3404 is poor, the same rating as determined for residential urban areas.

Military airfields are relatable to civil installations serving the same function. The overall complex is rated as fair, the support facilities are poor and, generally, the detection of aircraft is at the interpretation threshold (rank 2) while the identification of aircraft is not interpretable (rank 1). Refer to Fig. 5-5. In this illustration there is a comparison of two different airfields on SO-180 and 3404. The upper comparison is of the type usually encountered, exhibiting the interpretive values as described above. In the lower comparison, however, specular reflections off the aircraft provide their detectability that would otherwise be below threshold. In the format of the FWD-looking camera there is a band of coverage, varying in location with sun angle, that records any specular reflections that might be possible. An aircraft appearing in this area is highly reflective, and therefore is detectable and possibly even identifiable. A dark aircraft against a bright background will also be enhanced but not to the same degree as in the first case.

In the SO-180 records, ships, whether they be civil or naval, can be counted, but at rank 3, poor as compared with 3404 imagery. Identification by type is possible only in the case of very large, special-purpose vessels such as aircraft carriers.

The missile facilities covered on mission 1104 SO-180 can be conveniently classified into defensive and offensive categories. Generally the larger installations are associated with offensive activities, while the smaller installations tend to be defensive in character. In the coverage evaluated, defensive sites are of the surface-to-air type, probably utilizing SA-2 Guideline missiles. Poor to fair ratings are assigned to this imagery. It should be noted that the detection and identification of these sites in the SO-180 records was possible primarily because of the pattern signature of these configurations independent of resolution.

Assault missile launch and storage areas are also ranked poor to fair. As illustrated in Fig. 5-6, storage areas are generally larger and more complex than launch areas. Earth covered storage bunkers and unusual transporter roads show better in the duplicate transparencies than in the originals due to contrast enchancement in the duplication process. The missile transporters visible in Fig. 5-6 are the only definitive case of vehicle detection and identification. The proximity to the storage sites and their size are the responsible factors; but they could not be interpreted as such without the comparative coverage 3404 record.

In summary, the SO-180 affords no additional information over the 3404 film for this target classification as the situation stands. However, this observation must be qualified by the fact that the loss of speed in the cyan layer in this coverage has precluded realization of the full potential of color translation imagery.

5.2.3 Geology

Probably the most unique feature imaged with the main camera system is the geology of our planet. The extensive view of the KH-4B System panoramic cameras allows the overall structure of an area to be viewed and analyzed. Geological features are better imaged with high resolution integrating panchromatic response or low resolution differentiating color translation response, depending on the type of geological information required. Gross features are well presented by both films. Small detail capability is better in black and white; but color film records not only the configuration and extent of objects but also the nuances of chromatic differences and spectral responses beyond the capability of panchromatic films. Here, as in other phases of the SO-180 evaluation, it becomes evident that there is much information to be obtained from color differences that is not present in the black and white record.

More so than with most of the other categories in this section, geology is a three-dimensional science, such that relief distinction by stereo viewing is an essential requirement. The stereo mode operation of the KH-4B panoramic camera provides such relief distinction. Combination of false color and black and white transparencies provides a stereo model.

The use of high resolution records results in a well defined stereo model because of the superior capability of the eyes to fix on an object. A low resolution level in one record does reduce the vertical discrimination capability, but it does not preclude stereopsis. If, in addition, the lower resolution record is color imagery, the contribution of chromaticity from the SO-180 tends to combine with the contribution of accuracy from the 3404. As a result, an image of superior information content is generated.

To those new to the technique there may be some strain resulting from each eye trying to attain dominance over the other. With experience or practice, however, this conflict is minimized and the resulting image is one with high resolution and faint color. Judicious use of light intensity can regulate the color saturation and the observer will be able to control his eye response to allow more color or more resolution at will.

Monoscopic distinction of geological features rates from superior to the standard (rank 8) to the extreme of recording information not interpretable in the 3404 record (rank 11). Indications of stratification vary from poor to fair. Porosity is indicated in many cases by the growth of vegetation within well-delineated areas. This is generally indicative of a higher moisture content and a more porous structure.

One of the outstanding features observed was the superior capability of the SO-180 to record in an accentuated manner the differences between soil and parent rock. In several areas, including the Sinai Desert, as illustrated in Fig. 5-7, the 3404 indicates little difference between adjacent areas that record very distinctive hue differences on the SO-180. Pockets of yellow are visible in faults and many outwash areas show the same color. Translated to normal color references, this is probably red and could be indicative of a deposit worthy of investigation.

While not a geological feature, mention should be made of the salt extraction operations at the south end of the Dead Sea covered on rev D-203. There are numerous enclosed areas devoted to evaporation extraction of chemical salts and both records make unique contributions. The 3404 details the physical structure of the retaining walls, canals, plant structures and even the rake marks in the shallower areas. The SO-180 shows the presence of water with greater certainty and the low incidence of vegetation in the area.

The vivid multicolored responses of SO-180 to the salt pans in San Francisco Bay as shown in the EKIT test series* are noticeably absent in the Dead Sea. These are biologically produced either by plankton-size animals or plants. Because of excessive salinity and other factors, the Dead Sea is barren of all life forms except a few small fish found at the north end where there is a fresh water influx.

5.2.4 Vegetation

Natural vegetation, that is, those plants indigenous to an area, is important in many respects. Cover for military operations and as an economic resource are only two of the manifold uses that experienced intelligence personnel can utilize.

Rev D-210, covering the southern part of California, provided initial disappointment in the lack of vivid color response from the natural forest cover. Examination, however, indicated that the lack of chlorophyllreflectance could be, and indeed was, a signature for coniferous scrub vegetation. The general detection of natural cover and delineation of its limits is rated as better than, or superior to, the 3404 standard (ranks 7 or 8). In mountainous areas, the distinction is very hard to make with black and white, particularly if the vegetation exhibits low contrast. On the other hand, SO-180 provides more distinct delineation and detection capability even if the chlorophyll response is not vivid.

The arctic tundra recorded in the first segment of rev D-201 is very colorful, as can be seen in Fig. 5-8. This is a unique area of permafrost and arctic vegetation. The growing season is very short, a matter of 3 or 4 months at the most. Mission 1104 was flown in August, at the peak of summer growth. Black and white coverage of the area has superior detail as can be seen in Fig. 5-8(b), but in an uninhabited area such as this, it becomes a minor consideration. Color translation [Fig. 5-8(a)], though, makes very graphic distinctions between ice, rock, bodies of water, and various species of vegetation. Comparatively, the color coverage is exceptional (rank 9). Orchard crops are not easily detected as such by SO-180. A vegetation color signature is present and the growth area can be delineated, but the resolving power required to show trees is absent, ranking the capability for this task as poor (rank 3). Other cultivation, though, rates very high by comparison. Delineation of the extent of growing areas rates from equal to 3404 in the Crimea to exceptional in California. An example of exceptional cultivation rendition can be seen in Fig. 5-3(a).

Grains reaching maturity have a tendency to exhibit less reflectance in the NIR and, when used with previous coverage, can provide a baseline for prediction. For example, wheat is harvested when the heads turn yellow and the stems retain some green color. The point is that SO-180 film has unique advantages with regard to synoptic coverage.

The ability of SO-180 photography to determine crop types and indicate maturity is a function of both infrared/chlorophyll response and color translation. A field crop may change the response of an area drastically as growth proceeds. Rice paddies, for instance, will change as the shoots develop above water level and the exposed plant area increases in relation to the water area. Of the paddy areas viewed, it was observed that detection was at the threshold of detectability for SO-180 due to their small size.

---

*[redacted] Report No.[redacted] "Evaluation of SO-180 Infrared Color Film," [redacted] 14 August 1967.

An interesting comparison of crop coverage was possible by utilizing photography from the EKIT series with the present material. Because the two missions are separated by 15 months, they graphically show the changes occurring in cultivation as a function of time. Possibilities for application to the agricultural aspects of earth resource investigation are very promising due to this aspect. Color saturation of the orbital photography (mission 1104) is superior to that of the manned aircraft passes, but that is primarily a matter of exposure improvement. The factor of 8 difference in scale between these two experiments does not preclude comparison of the delineation capabilities of SO-180 as a function of time.

5.2.5 Hydrology

The larger area of the earth's surface is covered with water, either in its liquid state or locked in extensive areas of snow or ice. Intelligence reconnaissance deals mostly with the activities of man on that portion of the earth's surface that is dry land, and as a result, the majority of KH-4B coverage concentrates on this domain. The water areas that are covered are critical to human activities and include lakes, ocean shorelines, rivers, canals, inundated areas and all those features of hydrology that are of military or economic importance.

Hydrologic features recorded on SO-180 and 3404 during this mission presented prolific imagery for investigation. Hydrology is a feature associated closely with most of the categories evaluated in this report. This is so because an area without water is not inhabitable, or only so at great difficulty. As a result, hydrologic interpretation interlaces with vegetative, transportation, geologic, cultural, and military considerations.

Surface water courses vary in interpretability and are dependent on many factors. Comparative rankings of SO-180 as compared to 3404 vary from fair to equal (ranks 4 to 6). Delineation of the larger streams is ranked about equal on SO-180 and 3404; but as the size diminishes, the preference tends towards the 3404 records. However, streams that are small and not well defined may be detected on SO-180 by the presence of vegetation along their courses. Within the confines of the streams and rivers themselves, sand bars and shallow areas with reflective bottoms will tend to assume the same color as the stream on SO-180, and their detail will tend to rank only fair in definition.

Detection of the presence of wet lands not exhibiting open water is possible on SO-180 due to the uniform color response of plants occuping this ecological domain. Even the most insignificant waterway may be detected and delineated if the proper lighting is present. As mentioned previously in Section 5.3.2, specular reflections can be of use. These appear only in a limited area of the FWD-camera format; but any increase in information is useful. This phenomenon is helpful in delineating rice paddies, ponds, and small reservoirs that might ordinarily escape detection. The color contrast found where bodies of water are bordered by vegetation will present a signature superior to that obtained with black and white coverage.

In this context, rev D-201 covering the Russian tundra near the Ob River, as illustrated in Fig. 5-8, shows numerous ponds with widely differing color responses. Since these are quiet water areas, the colors are probably a result of the ecological balance and would change with season. Another contributor could be water depth differences. By comparison, the SO-180 rates as superior to the standard 3404 in the detection of these features. As an example, the tonal patterns in Fig. 5-8(b) are amplified by the addition of hue and saturation in Fig. 5-8(a).

Delineation of shorelines along the larger bodies of water (oceans, seas, etc.), is dependent on the land form bordering the water. If the land is precipitous with no beach, then the rating is good.

Where there is a beach, however, the rating is only fair. Water washing up on the sand is confused on SO-180 the same way as in the stream beds mentioned above. The 3404, however, shows distinct differences in tone between water, wet sand and dry beaches. The higher resolution reveals the line of flotsam deposition marking a previous high tide limit. Where the fluctuations in tidal level are essentially vertical, as among rocks, the vegetation exposed at low tide gives a limited red signature. Of course, the area would have to be within the resolution capability of SO-180.

Hazards to navigation in the form of submerged rocks or rocks awash are rated at the threshold of interpretation for color (rank 2), due primarily to their generally small size. Sand bars are usually more extensive in area and rated from fair to equal by comparison with 3404.

The presence of areas of aquatic growth show so well with the NIR color response and so poorly with the panchromatic film, that it is rated as rank 11. Weeds clogging a canal are detectable, but the most dramatic example is found in rev D-210 along the California coast. As illustrated in Fig. 5-10, kelp beds lying parallel to the coast are detectable, delineated, and interpretable in Fig. 5-10(a), whereas they are barely present in Fig. 5-10(b) even though the print image was enhanced through dodging. Reference to previous mission coverage of this same area utilizing FWD- and AFT-looking cameras and a variety of filters (including the SF-05 green for bi-color) failed to show these beds.

Infrared radiation is absorbed within a layer only a few inches in depth at the surface of a body of water. Floating live vegetation at the surface will produce the distinctive magenta signature with SO-180, where panchromatic film shows little, if anything; depending on the tone reproduction of the duplicate. The color of the area will change with look angle across the format. As the end of the format is approached, the magentas gradually change to a dark olive green. This is apparently a function of sun angle and the angle of reflectance of the energy required to produce the effect at more oblique format positions. Kelp beds of the extent observed constitute both a hazard to small boat navigation and are a commercially important resource. In the case of the latter, cut lines made by commercial harvesters are well defined (refer again to Fig. 5-10).

Wave trains of substantial size are made quite apparent as they travel through the kelp beds, at several places along the coast. Though some waves are recorded on 3404, the SO-180—kelp combination has produced a unique opportunity for analysis (Fig. 5-10). Measurement of the wavelength of the train of waves approaching the coast and correlation of their height with the position where they finally break allows approximate water depth measurements to be made. Depth determinations were checked against published bathometric contours and were found to be in very good agreement.

SO-180 imagery of river systems acquired on rev D-200 are especially interesting for their color differences and some extra attention was paid to their analysis. Three different samples are presented in Fig. 5-9 along with the corresponding 3404 coverage.

In the first sample, Fig. 5-9(a) and (b), the main stream is green; probably a hue translation from yellow-orange, and is indicative of suspended sediments. The tributary stream is very blue, indicating a green original color with less sediment in suspension. At the interface of the two streams, the line of demarcation is very distinct. Constriction of the stream channel, the presence of turbulence, and the entrance angle of the blue stream indicate a more resistant rock structure in this area. The tributary watercourse faces upstream and there is an equilibrium of forces present at the surface that contributed to the distinct line of demarcation.

Due to its longer course, the main stream has had more opportunity to absorb solar radiation and is probably warmer than the tributary, which has a smaller surface area and has traveled a shorter distance. At the interface, the cooler water, being more dense, will tend to settle under the warmer. The depressed gradient and constriction of the stream at this point both affect the level the inflow would seek. It would naturally gravitate to areas of lesser velocity, either at the edges or the bottom. Since settling would be present because of the temperature/density difference, the bottom would be the more likely area for it to direct itself.

The situation existing in the second sample, Fig. 5-9(c) and (d), is that of the normal confluence of two streams. By comparison, the volume of the blue stream is less than that of the green. Mixture of the waters takes place at a gradual rate with the blue losing identity in proportion to the distance from the intersection. The clearer blue water eventually mixes with the more tubid green and the result is still green, but diluted to an extent too minor to be distinguished visually with any accuracy. It is a situation somewhat analogous to putting clear water into inky water. The blackness of the inky water diminishes, but still remains quite black.

The third sample, Fig. 5-9(e) and (f), is an unusual case of two tributary streams intersecting a main river at the same location, opposite each other and at right angles to the main watercourse. The interface of the larger tributary with the main stream extends for some distance because of the large volume flowing in and results in a more gradual mixture of colors. By comparison, the outfall from the smaller tributary is quickly absorbed. While the higher definition of black and white shows the interface at stream junctures more distinctly, the color differentiation is apparent for a greater distance downstream and is a more readily interpretable signature.

The use of color in rev D-203 over Krasnoperekopsk in the Soviet Crimea (Fig. 5-11) depicts a pollution source and delineates the distribution pattern in a manner that is not possible with the panchromatic record. Indication of turbidity and depth are well defined in black and white but the yellow signature present in the SO-180 record is not detectable.

The source at the south end of the causeway is a well saturated yellow area, and as the waterbourne suspension moves north along the causeway the distribution and dilution can be followed. Since the SO-180 record presents a yellow hue for the item, the true color is probably red. The color film thus not only indicates the degree of water pollution but also helps in identifying the type of pollution and in tracking it to its source.

A contributor to the hydrologic importance of many areas of the world is the storage capability of snowfields and glaciers. The second segment of rev D-201 covered an extensive area of glaciers south of Lake Balkash. The color of these features varies with the distance from the point of origin to the terminus. The snowfields at the head are shown as brilliant white. As the snow consolidates into ice and moves downslope, the hue shifts gradually toward the blue. As morains join the flow of the main body, the color changes even more, this time to the browns, until at the terminal end the ice is completely covered by overburden.

The overall detail, composition, and extent of glaciers are shown in a superior manner (rank 8) by SO-180. Fine detail and tarn lakes are equal (rank 6) to the 3404 record, and terminal morains are fair (rank 4). The certainty that ice is present when viewing glacial areas provides a color key that is useful when interpreting permafrost areas such as the tundra mentioned above.

5.2.6 Transportation

An efficient transportation network is a principal ingredient for economic growth and is essential to military logistics. Transportation facilities are classified into five categories for the purpose of this report; roadways, railways, waterways, airports, and seaports.

Roadways vary in detection probability and interpretability depending on their size, the construction materials employed, cover, frequency of occurrence, and intended use. In the SO-180 imagery viewed, the roadways were in good contrast with the background. Two of the locales were somewhat primitive and the roads were rated poor. The other two areas were more advanced technologically and agriculturally and the roads were rated as fair. These culturally more advanced areas exhibit road systems designed for heavier use and convenience of access to all important areas.

Vehicle detection is, in the main, below the detection threshold. Rev D-210 provides some indication of traffic, but only for vehicles in contrast with the road surface. In Fig. 5-4(a), both light vehicles on dark roads and dark vehicles on light roads can be detected. Lesser contrasts markedly reduced detection capability.

Railways constitute a major factor in the overall capability of a land transportation network to move heavy or bulk cargo. Though much of these loads are moved by river barges in Eurasian areas during the warmer seasons, it falls to the rails to maintain year-round service. The long, cold winters in much of the Soviet Union incapacitate waterways by freezing, such that a well maintained rail system is essential.

As with roadways, detection and interpretation of railroads is dependent on many factors including isolation from distracting items, contrast with the background, and size. Generally, the ratings are either at the threshold of detection for SO-180 or poor by comparison with 3404. The one exception occurs in the Vietnam-China part of rev D-200 where isolation from distracting factors and contrast with the background rated the record as fair.

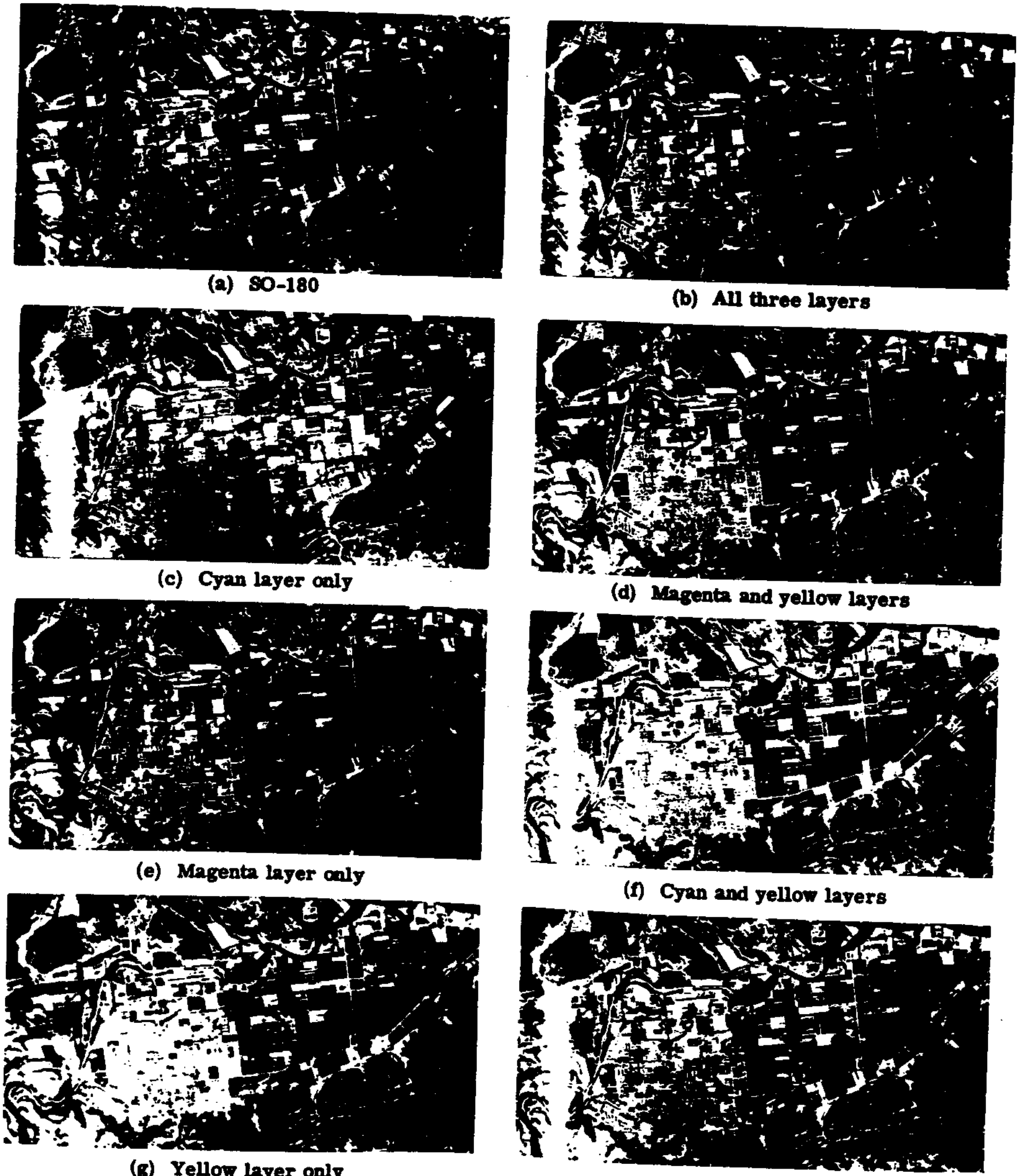
The small physical size of a railroad track or right of way is a severely limiting factor. In open areas where the tracks are somewhat isolated they are more readily detectable. Yard facilities and sidings are barely detectable and rolling stock can be located if a good 3404 record is used as reference. The geometric regularity and construction techniques used in railroad layout are prime keys in distinguishing roads from railroads.

Most inland waterways of any extent are usually natural watercourses. The major rivers of all the continents are also major transportation routes. The observations made in Section 5.3.6 (Hydrology) regarding the delineation of streams would place the natural water routes on an equal basis (rank 6) for both SO-180 and 3404. The smaller canals would be placed proportionally lower for SO-180 observations and generally occupy a position of fair (rank 4).

Facilities for docking, storage, and transhipment rank from poor (rank 3) to not interpretable (rank 1) for the SO-180 record. Winter storage of barges is detectable on SO-180, but was unranked and is related to the size of the vehicles, their cluster configuration and location relative to shore facilities and the banks. Individual barges are delineated on the 3404 record. The operation of loading facilities for bulk cargo, specifically oil, can be located by finding the terminus of pipelines at river edges. These are identifiable on SO-180 mostly by secondary indicators such as cuts through woods and disturbed earth in open country. Because of its higher resolving power, 3404 presents explicit items for interpretation.

Airports are discussed in Section 5.2.2, Military.

The seaports observed are of secondary importance and would be categorized as poor (rank 3) or fair (rank 4), depending on the size of the installation. Essentially, they are of the same character as small or medium size settlements, but with the addition of loading facilities.



(a) SO-180

(b) All three layers

(c) Cyan layer only

(d) Magenta and yellow layers

(e) Magenta layer only

(f) Cyan and yellow layers

(g) Yellow layer only

(h) Magenta and cyan layers

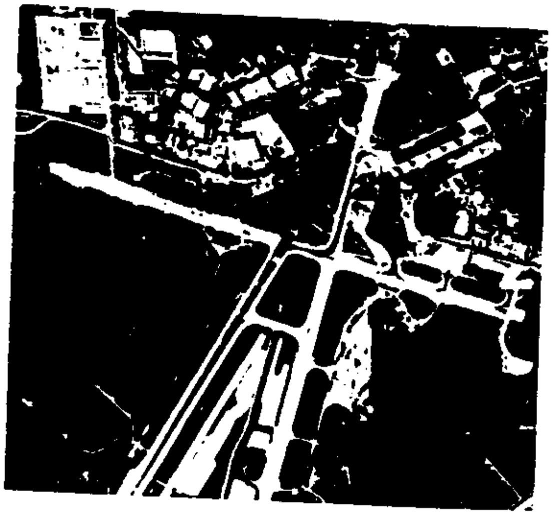
Fig. 5-3 — 1.5× enlargements of Lompoc, California, and the Santa Ynez River (rev D-210-013 FWD)

(a) SO-180 rev D-210-013 FWD

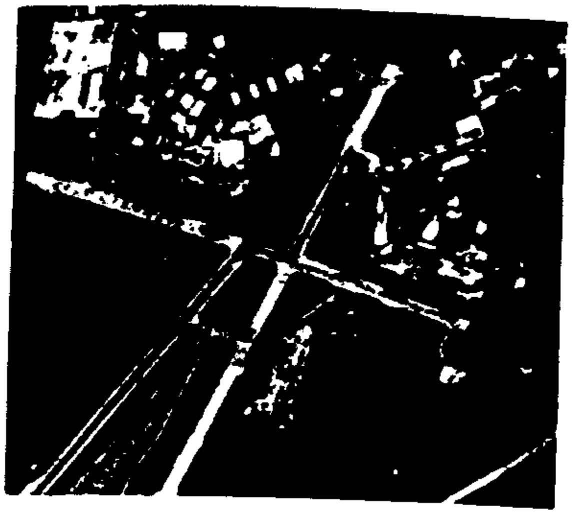
(b) 3404 rev D-210-016 AFT

(c) SO-180 three layer monochrome reproduction

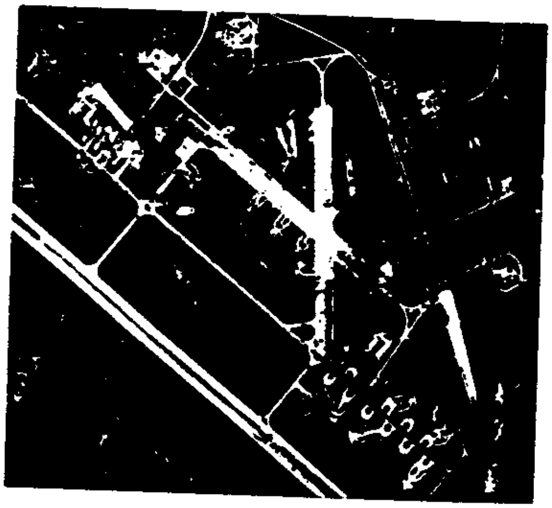
Fig. 5-4 — 10× enlargements of Lompoc, California



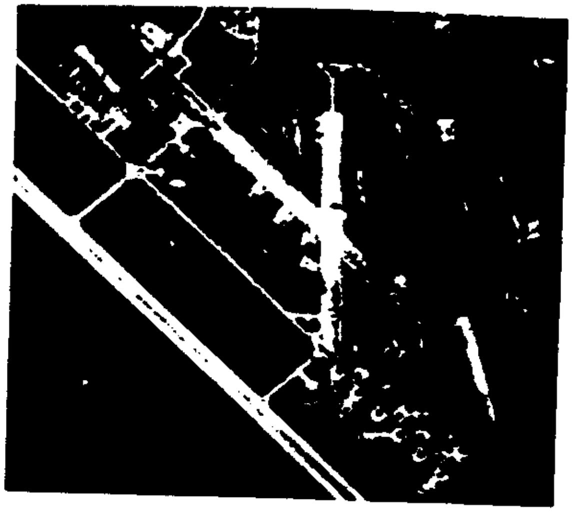
(a) 3404 rev D-203-044 AFT



(b) SO-180 rev D-203-038 FWD

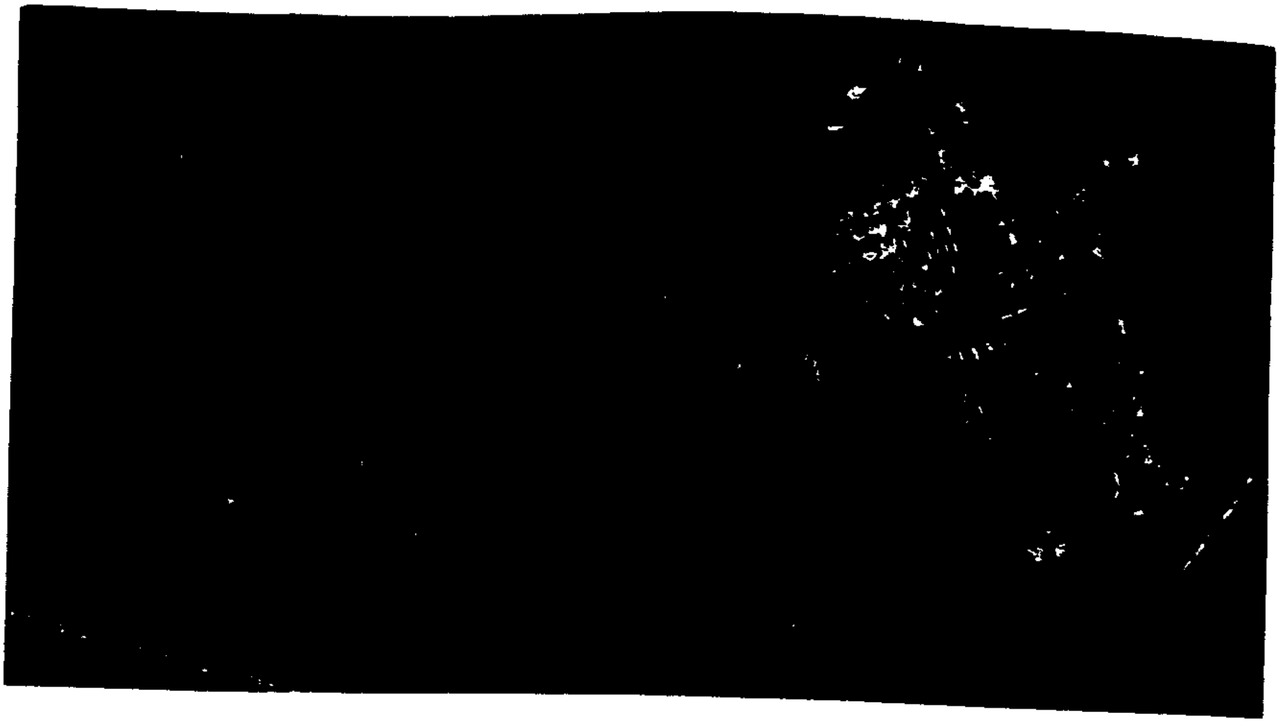


(c) 3404 rev D-203-022 AFT

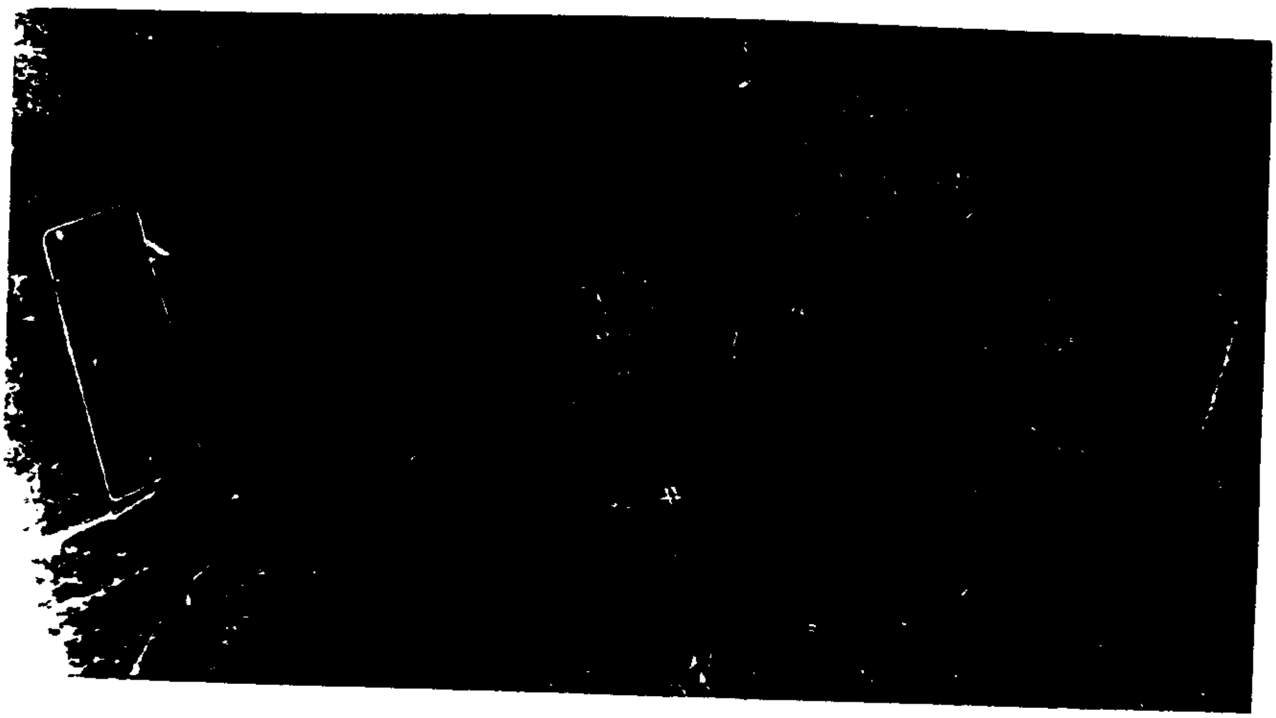


(d) SO-180 rev D-203-016 FWD

Fig. 5-5 — 10× enlargements of two different airfields



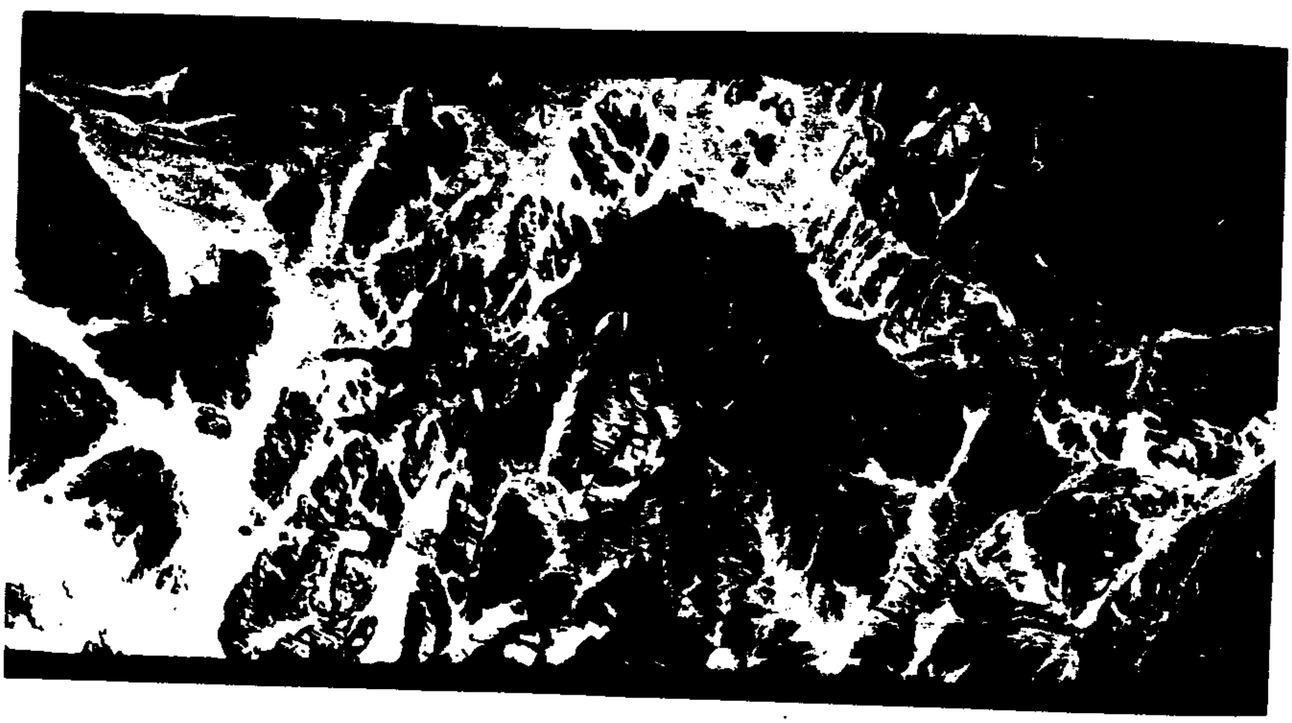
(a) SO-180 rev D-201-047 FWD



(b) 3404 rev D-201-053 AFT

Fig. 5-6 — 10× enlargements of Russian missile site

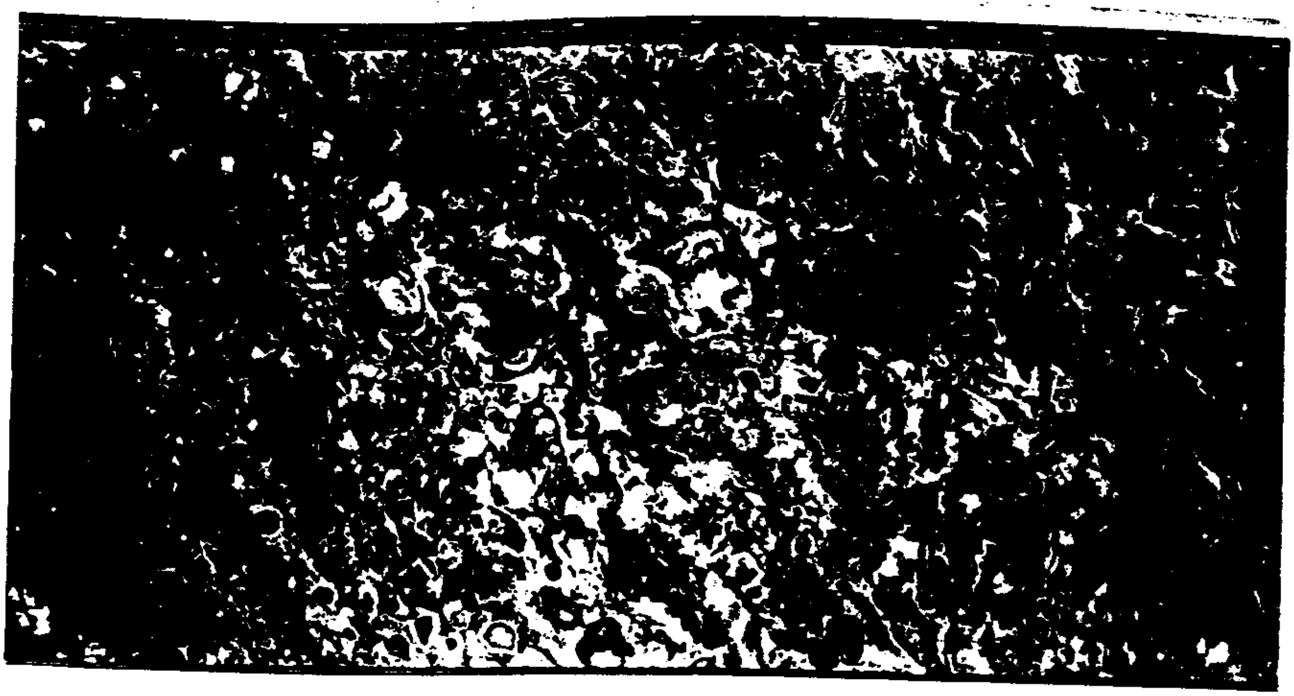
(a) SO-180 rev D-203-059 FWD



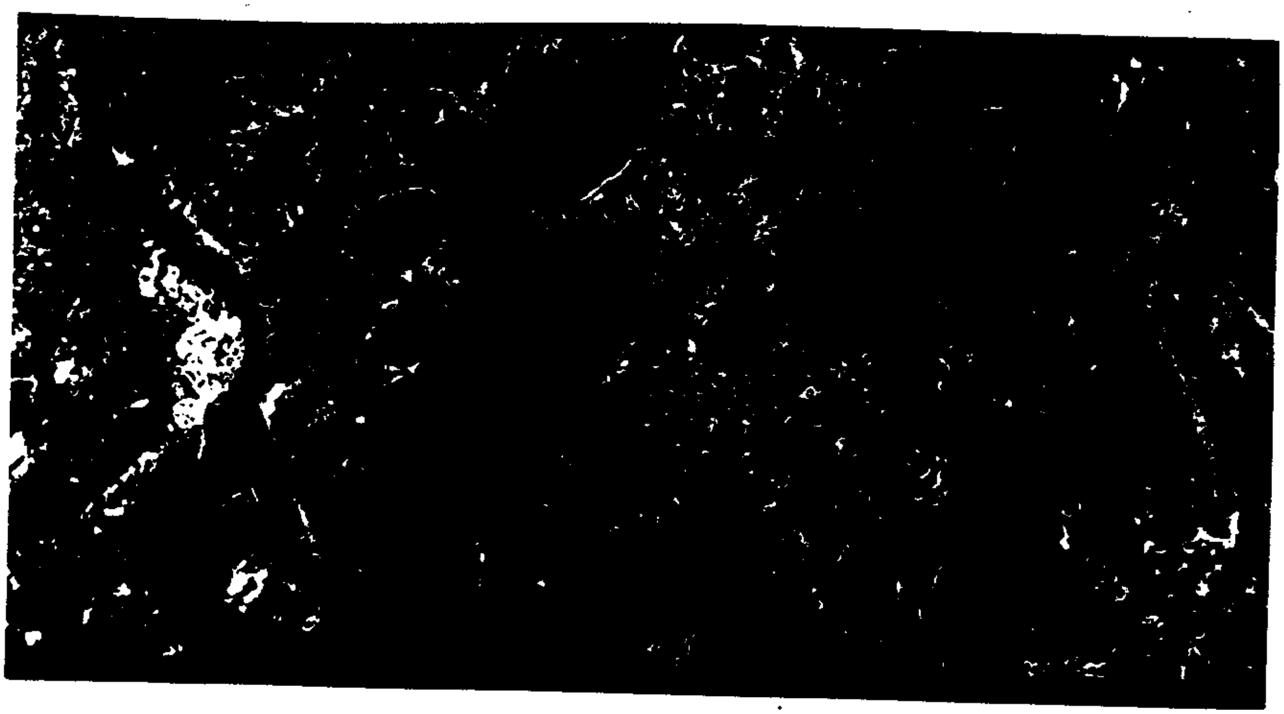
(b) 3404 rev D-203-065 AFT

Fig. 5-7 — 1.5× enlargements of mineral washout in Sinai Desert

[redacted]



(a) SO-180 rev D-201-031 FWD



(b) 3404 rev D-201-038 AFT

Fig. 5-8 — 1.5× enlargements of tundra in Northern Russia

(a) 3404 rev D-200-034 AFT

(b) SO-180 rev D-200-028 FWD

(c) 3404 rev D-200-033 AFT

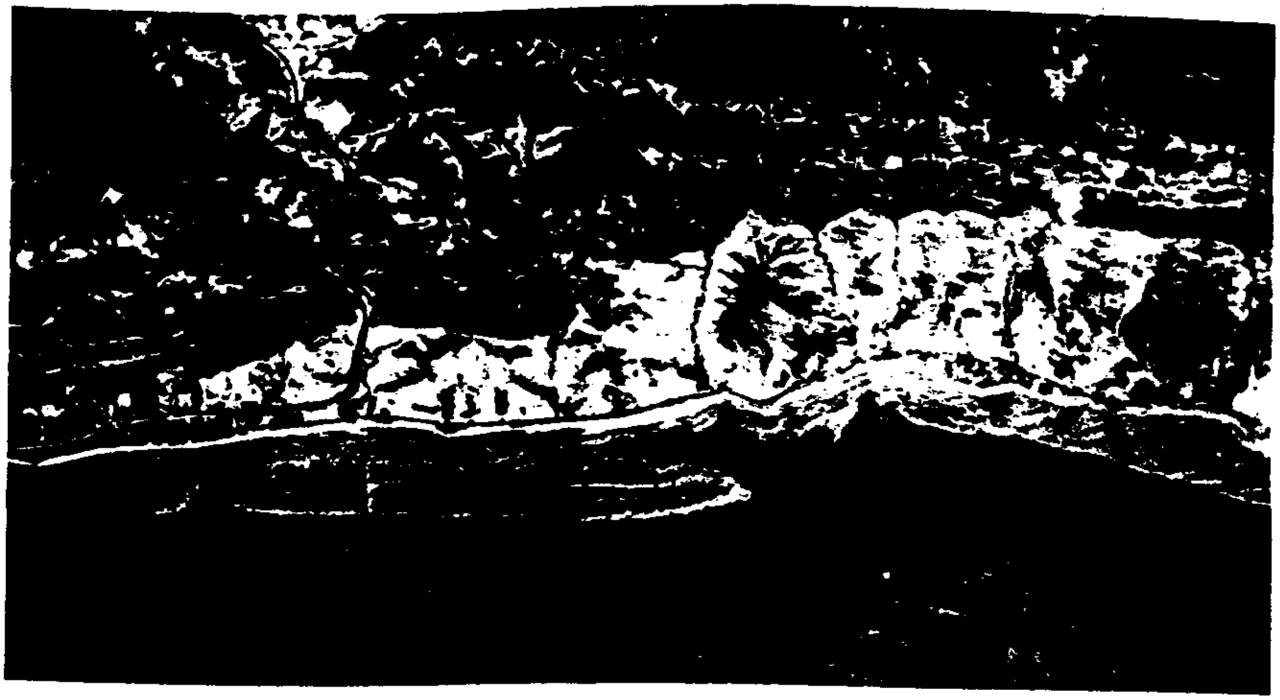
(d) SO-180 rev D-200-027 FWD

(e) 3404 rev D-200-036 AFT

(f) SO-180 rev D-200-030 FWD

Fig. 5-9 — 5× enlargements of three different river intersections in Vietnam

[redacted]

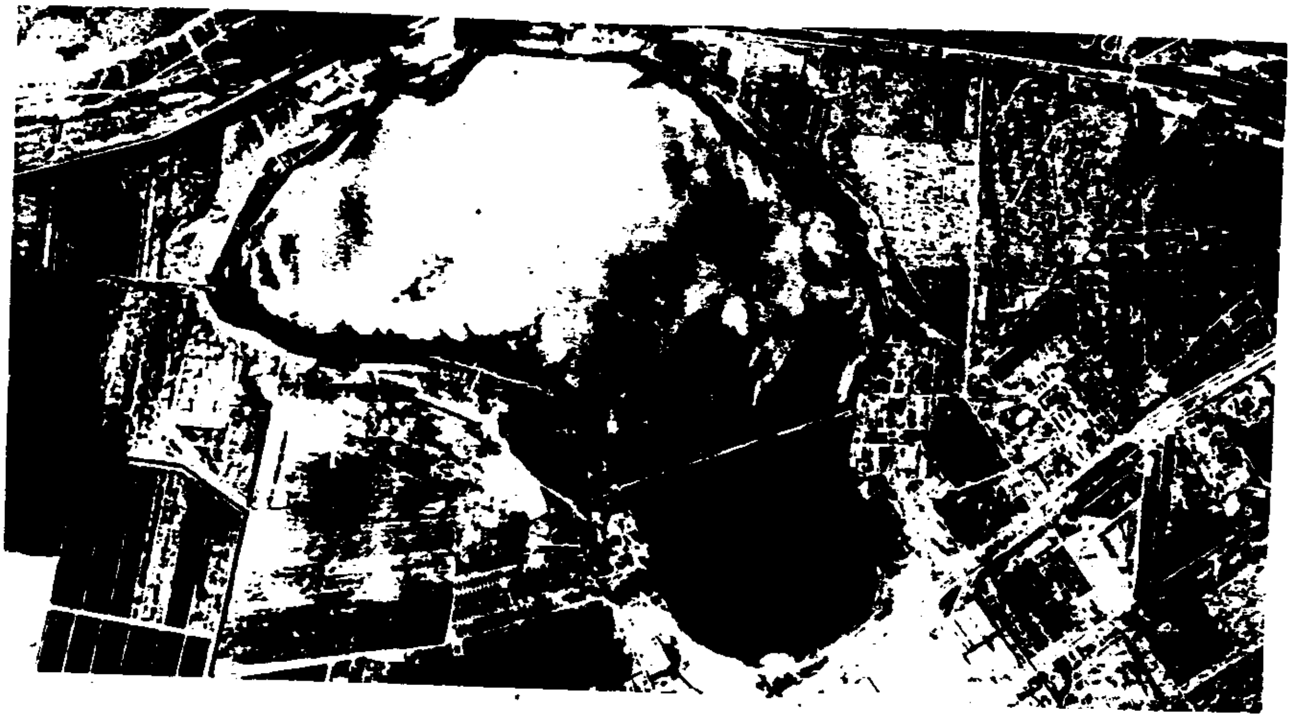


(a) SO-180 rev D-210-015 FWD

(b) 3404 rev D-210-021 AFT

Fig. 5-10 — 3× enlargements of kelp beds off California coast

(a) SO-180 rev D-203-012 FWD



(b) 3404 rev D-203-018 AFT

Fig. 5-11 — 5× enlargements of water pollution in the Soviet Crimea

[redacted]

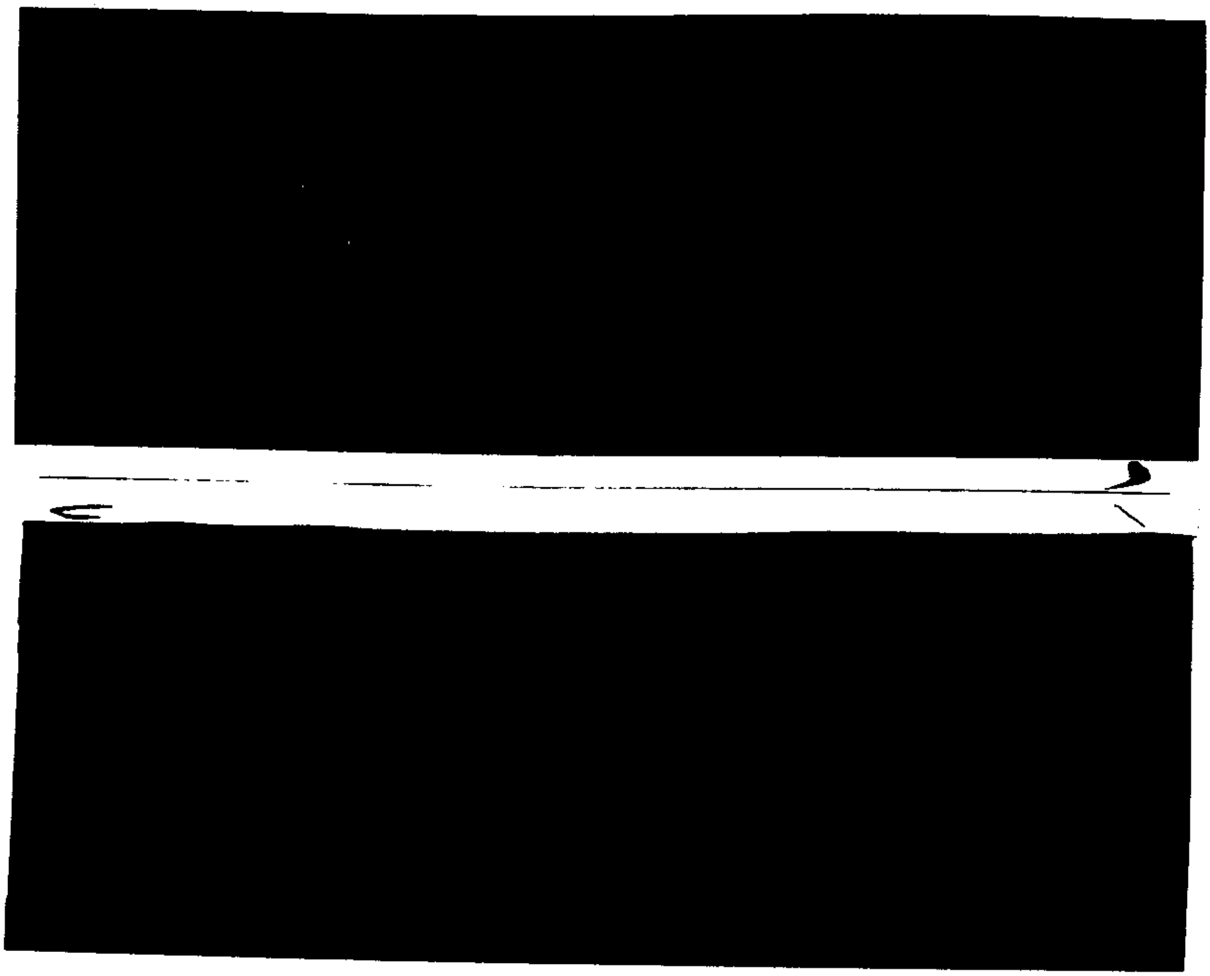


Fig. 5-12 — Transparency of severe corona static with filters attached (rev D-199-021 FWD)

5.2.7 Summary

The fact that the SO-180 resolution is lower than that of the 3404 does not necessarily imply less total information content. On the contrary, improved information content is the primary objective of using the color translation material. It is a matter of specifying the purpose for the required information. That is, a visual color film (like SO-121) has the capacity (if used properly) to record information that a high definition panchromatic film (like 3404) is incapable of. Moving a step further, a color translation film (like SO-180) has the capacity (if used properly) to record information that a visual color film (like SO-121) is incapable of. Thus, SO-180 film is a valuable tool for the collection and presentation of information by photographic means in that part of the electromagnetic spectrum beyond the red sensitivity of panchromatic films.

From the foregoing section dealing with specific areas of interest and activity, it is conclusive that the film is not particularly useful for some subjects and of exceptional value for others.

Cultural and military objects are, in the majority of instances, best photographed in the KH-4B camera system on 3404 film. In these categories, resolution is of paramount importance for detail rendition, and the dominant color is essentially gray anyway. In the graphic presentation summary of subjective ranking (Fig. 5-12), the categories of "culture" and "military" have the lowest SO-180 rankings, 3 and 4.

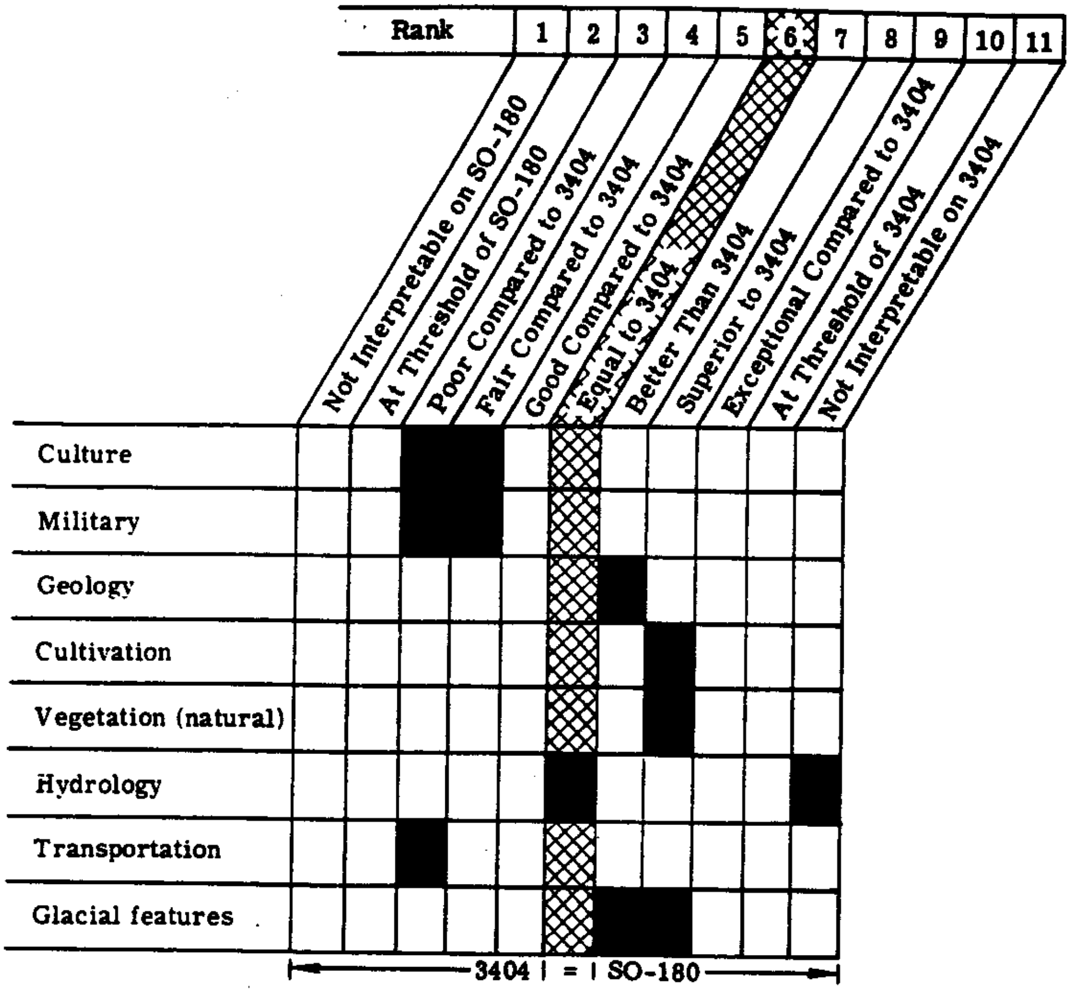
The recording of geological information on SO-180 is good, and when used in stereo with high resolution black-and-white, it is particularly impressive. Stereopsis is good, but mensuration accuracy and pointing capability are degraded by the SO-180.

Vegetative cover, both cultivated and natural, is superior on SO-180 as compared with 3404, and the capabilities of determining the state of being as well as the extent of growth could be of great economic worth. This fact is reflected by the rank 8 in the summary Fig. 5-13.

Hydrology shows exceptional response on SO-180, and, as has been found in evaluations independent of this study, constitutes one of the greater areas for exploitation. Note the extension from rank 6 to rank 11 in Fig. 5-13.

Transportation, being essentially a cultural feature, exhibits about the same ranking. In Fig. 5-13, it is located on the scale at rank 3. The implication is that transportation facilities are more advantageously imaged on 3404 rather than SO-180 in the KH-4B system.

Generally, it is concluded that the most valuable uses for SO-180 film are in the fields of geology, forestry, agronomy, and hydrology.



NOTE: This figure is intended solely as a rapid assessment presentation and specific targets or features within each subject category may vary from the ranking shown. Hydrologic features, for instance, are generally equal to 3404; but there are two instances where information is presented on the SO-180 record that is not interpretable on the 3404 record. Reference is made, therefore, to the text for definitive information regarding any item.

Fig. 5-13 — Graphic presentation of the general results of the subjective relative interpretability ranking

6. CONCLUSIONS

1. Despite the limited film footage, the extensive cloud cover, the cyan cast, and the electrostatic discharge fogging, a sufficient amount of good imagery was acquired on the mission 1104 SO-180 film to support a reliable engineering evaluation and analysis of interpretability. At the same time, Infrared Ektachrome Aerial has not yet been completely demonstrated to be an acceptable film for use with the KH-4B camera system because there are technical difficulties to be overcome.

2. Differential degrees of cyan cast over most of the SO-180 footage resulted from speed losses in the cyan dye-forming layer. Because of this, realization of the full potential of orbital color translation imagery has been precluded to date. These cyan dye-forming layer speed losses are attributable to moisture content depletion in the SO-180 due to the low pressure, dry capsule environment.

3. Corona static discharge fogging was caused by a failure in the regulator of the PMU that generated an internal capsule pressure above the 20-micron window for SO-180. However, not all the corona fogging was detrimental to information extraction. There are instances where low level fogging enhances vegetation information content.

4. Despite the poorer resolving power of SO-180 as compared with the 3404 film, there are instances in which the SO-180 record contains information that is absent on the 3404 comparative coverage.

5. In cases where the corona fog is not present in all three of the sensitive layers, black and white duplication through selective filtering can be used to eliminate the fog and retrieve gray-scale tonal information.

6. The magenta layer imagery has superior image quality to either of the other dye layers or any combination of the three dye layers. Black and white reproduction of this SO-180 layer can thus be used to advantage in a stereo mode with comparative 3404 coverage.

7. There is a higher potential in the mission 1104 SO-180 photography for economic intelligence and earth resources rather than for military intelligence.

8. The unusual color contrasts on SO-180, produced by the spectral shift, afford potential for rapid scanning exploitation.

7. RECOMMENDATIONS

1. SO-180 film should be flown again in the KH-4B system as a tag-on to 3404 with a well-coordinated effort to acquire coverage of target areas beneficial to specific color translation information requirements with imagery unimpeded by corona fogging or cyan cast.

2. SO-180 preconditioning, wrapping tensions, and supply spool/cassette modifications should be investigated to optimize moisture retention or uniform moisture depletion for future KH-4B missions.

3. On upcoming KH-4B missions, it would be valuable to monitor the pressures sustained inside the supply cassette along with those within the instrument barrel.

4. In situ vacuum sensitometry under various conditions of pressure, humidity, temperature, and time should be carried out in the Thermal Optical Research Facility (TORF).

5. Additional SO-180 acquisition is needed for times of the year other than August in order to exploit the unique advantages of synoptic color translation photography on a time base.

6. The possibilities of hypersensitization of SO-180, i.e., improved cyan tone renditions for near-infrared objects with pre-or post-near-infrared fogging at weak levels should be pursued.

7. A study program should be established for a single information extraction application from a specific set of targets that will define exposure and color balance in both the acquisition and duplication stages.

Appendix A

MISSION 1104 PMU FAILURE

External on-orbit pressures range from 10^{-4} to 10^{-5} micron, while internal payload vehicle pressures range from 1 to 10 microns. Self-determining capsule pressures are somewhat higher than extra-atmospheric pressures due to outgassing from the film and other components. Low environmental pressures create a variety of problems for KH-4B system films. The germane problem, however, is the twofold one of increased friction resulting from dried-out film enhancing electrostatic charge separation together with increased ease of ionization and subsequent discharge as a product of the rare environment.

Early in the program it was learned that electrostatic discharge can be inhibited by artificially increasing the payload vehicle internal pressure. However, instead of a threshold pressure level as might be expected, nondischarge pressures come in a series of "windows," the pressure levels of which have not yet been pinned down by a convenient model. The pressures at which corona marking occur in KH-4B panoramic camera systems are functions of the individual instrument or component of that instrument. Therefore, the primary means for reducing or eliminating corona is in the control of components as corona sources, which is carried out in premission testing.

Although the pressure levels of corona-free windows depend upon the photographic film type involved, when different films are used in a given instrument, there is a tendency for them to mark at the same pressures. When this is the case, faster films mark to a higher density and can thus produce detectable marking over a much greater range of pressures. Once an instrument is "cleaned up," as can be done by replacing corona discharge source components, what is required for corona-free performance is maintenance of specifiable window pressures. This job is the responsibility of the pressure makeup unit (PMU).

The PMU system consists of a 231-cubic-inch titanium pressure vessel containing dry nitrogen at 3,200 psi (initial fill pressure),* a pressure regulator,† two solenoid-actuated valves, and two orifices of different size, along with control and instrumentation electronics. A schematic diagram of the PMU is shown in Fig. A-1. Empty weight of the PMU is 11.1 pounds which, when initially filled with 2.3 pounds of dry nitrogen gas, weighs 13.4 pounds.

---

*This pressure can decrease to 2,880 psi by launch time. In operation, pressure decreases functionally down to a marginal 100 psi. At approximately 50 psi, the regulator is rendered ineffective.

†The output pressure is reduced from the supply bottle pressure by a single stage regulator to approximately 15 psi.

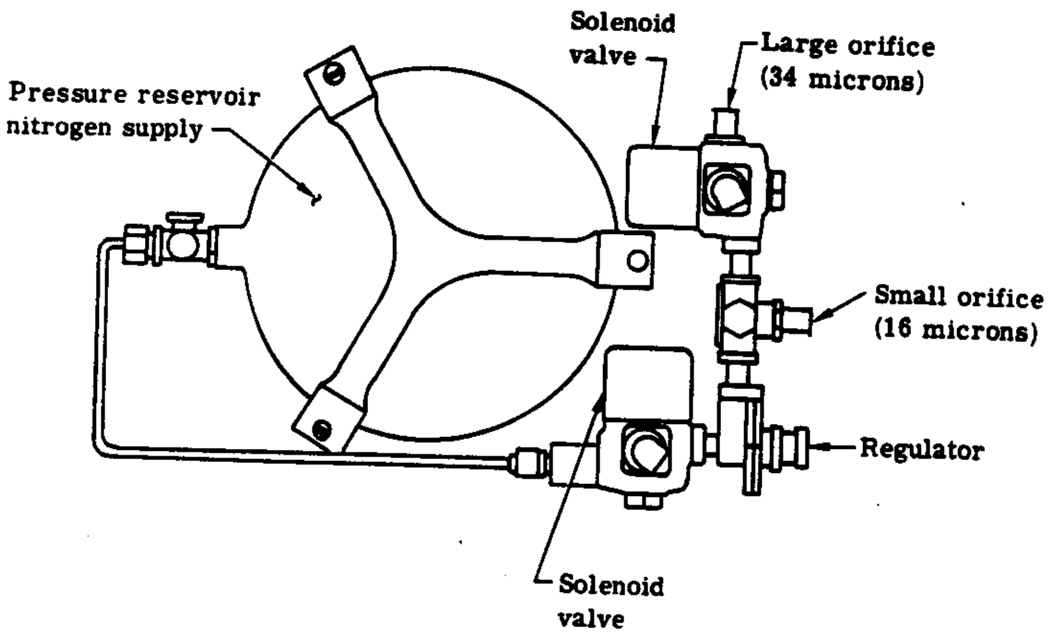


Fig. A-1 — Schematic diagram for CR-4 PMU

In serving a photographic mission, the PMU's basic functional objective is to provide a specifiable internal pressure within the payload vehicle during camera operations. For the most part, the history of the PMU has been a successful one. On mission 1104, however, PMU failure is held responsible for the excessive corona fogging on SO-180 film. Explanation and analysis are the concerns of this section.

The PMU utilizes a two-orifice discharge system design. A large (0.04-inch diameter) surge orifice discharges gas after the CR CAMERA ON command to provide a fast vehicle pressure buildup. The Agastat time delay relay is adjustable and is usually preset to shut off in 3 seconds. It is required that proper pressure levels be obtained within 3 seconds at the startup of each photographic operation. This constraint is imposed on KH-4B system because the CR instruments attain constant speed in one photographic cycle. A small (0.02-inch diameter) sustaining orifice also begins discharging gas (at a rate equal to the vehicle leakage) with the CR CAMERA ON command. Fig. A-2 illustrates how the two-orifice design achieves the desired internal payload vehicle pressures in time. The PMU is not activated during DISIC operate only.

Thus, the PMU is automatically activated with the CR CAMERA ON command. Similarly, deactivation of the unit is automatic with the CR CAMERA OFF command. However, the CR CAMERA ON signal to the PMU can be disabled by a real-time command. This alternative, in fact, was elected during mission 1104, and the situation is described later. The CR-4 PMU serial number was 1005.

Missions 1101, 1102, and 1103 used PMU's, each with two orifices set for a single fixed regulated pressure of 50 microns, as described above. The mission 1104 PMU, however, was modified to accommodate the SO-180 experiment. Whereas the optimum corona-free pressure window for 3404 film is above 45 microns, the SO-180 film experiences corona fogging in the KH-4B camera system at these pressures. Instead of the 50-micron design level, the color film's corona-free pressure window ranges from 12 to 22 microns. Using the PMU as designed, both pressures (50 microns and 16 microns) could not be provided.

HIVOS tests conducted with the CR-4 instrument, however, revealed that units numbered 308 and 309 were unusually clean with regard to electrostatic discharge characteristics. For this reason, it was elected to sacrifice the quick buildup burst supplied by the large orifice and modify the CR-4 PMU to a dual fixed mode. In this mode, the two orifices would build slowly to and maintain a pressure of 50 microns for 3404 film operations in the FWD-looking camera. The fact that the first eight or nine frames would be transported and imaged in a noncorona-free window environment was not expected to induce detrimental corona glow in these particular cameras. On a signal triggered by the MCD, the large orifice (contributing 34-micron pressure) was wired to cut out, allowing the small orifice to continue alone with its contribution of 16 microns. This small orifice would then maintain a 16-micron pressure suitable for the SO-180 material. This pressure would not excessively endanger the 3404 film running through the AFT-looking camera during this time because 3404 film does have a 10 to 20-micron corona-free window. Normally it is not advisable to use it because of its tight tolerance. This planned performance for the CR-4 PMU, however, was not realized on the mission.

Pressure profiles for three early passes accessible to the [redacted] Tracking Station appear in Fig. A-3. Rev 09 was a 17-frame ascending node engineering operation during which the internal pressure apparently climbed from 24 to 75 microns. Rev 16 was a 16-frame descending node operation during which the internal pressure at the CR CAMERA ON command was already 60 microns and the PMU activation raised this pressure a little to 66 microns. Rev 32 was a

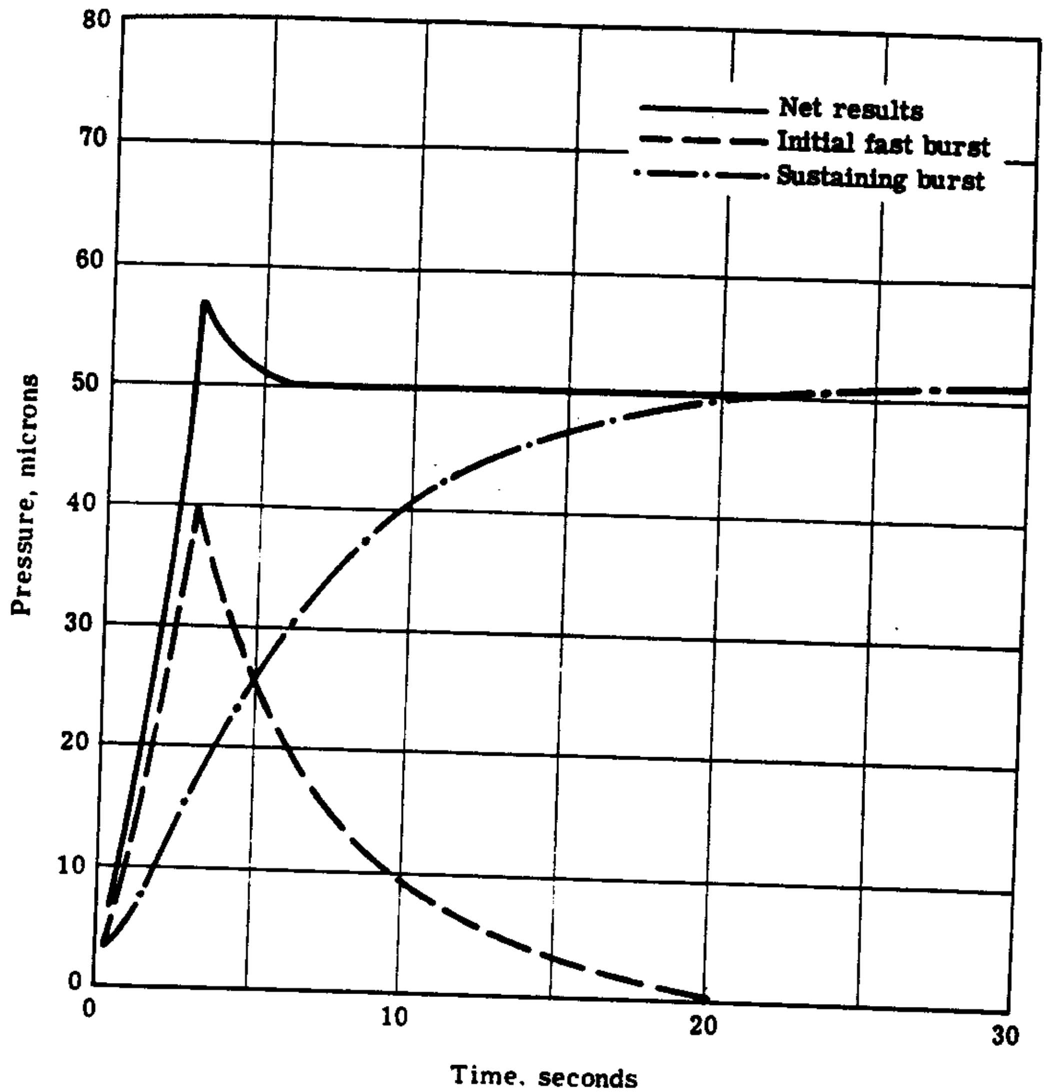


Fig. A-2 — Two-orifice typical pressure profile for 3404 film camera operate

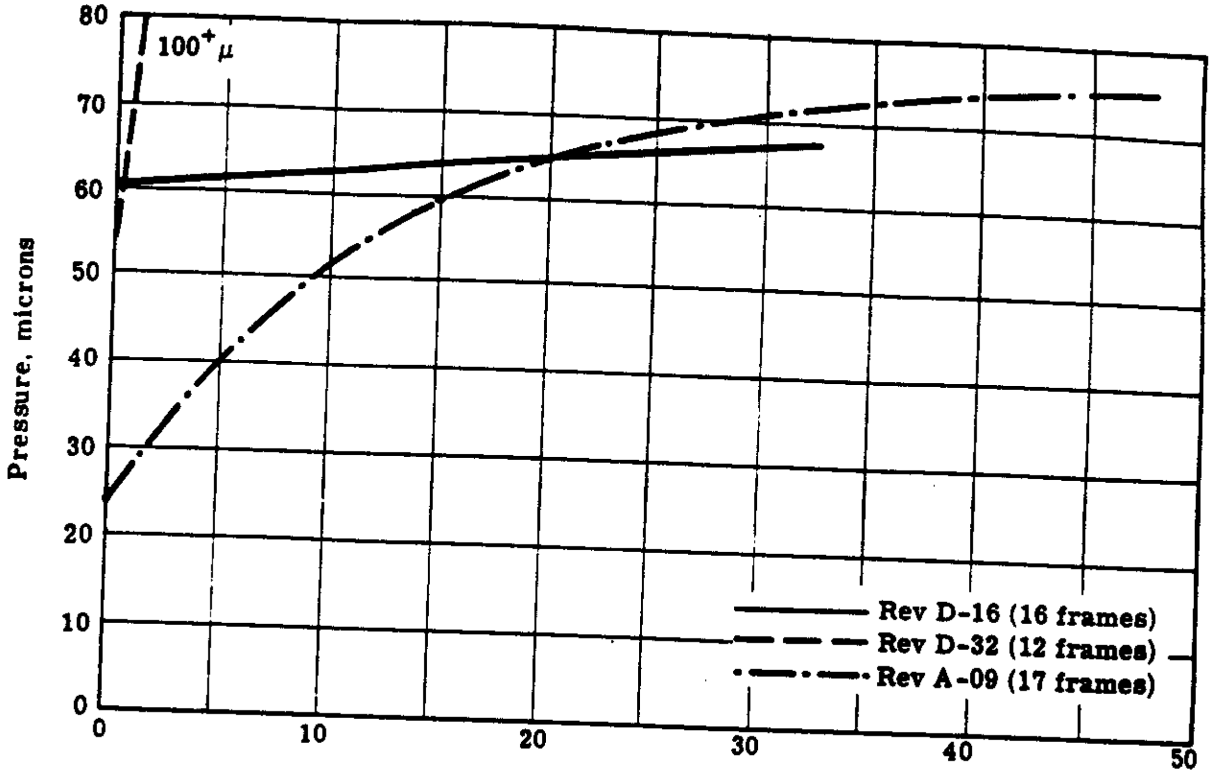


Fig. A-3 — Payload vehicle internal pressure history for three early California passes obtained with real-time telemetry

12-frame descending node operation during which the initial indicated pressure of 53 microns skyrocketed. The unusually high pressures in the vehicle indicated at the start of these CR/PMU operations imply that there was gas leakage during the sit periods. The PMU activation pressure increases above the designed 50 microns imply improper regulation. The rev 32 anomaly reveals malfunction of the PMU.

Additional abnormalities associated with the PMU system were observed during mission 1104. These abnormalities include a variety of stabilized pressures exceeding 50 microns during some operates, internal pressure fluctuations during other operates, and pressure buildup on occasion exceeding 100 microns (gauge limit) within 2 seconds. The nature of these pressure anomalies suggests sporadic failure, indicative of contamination in the regulator, rather than fracture or rupture. A foreign particle in any one of the following three places could have caused the failure in the regulator:

1. Between the ball and the seat
2. Between the plunger shaft and the side of the shaft hole
3. Inside the pressure-sensing port which permits gas to flow to the diaphragm.

While monitoring mission progress, malfunction of the PMU was first noticed during rev 32 when pressure dropped 310 psi in 3.5 minutes of instrument operate time (see Fig. A-4). This was a pressure loss of 90 psi per minute, which is an abnormally high rate.

After a drastic loss in PMU bottle pressure, in order to conserve gas for the SO-180 tag-on, the PMU was disabled during rev 124, after 130 minutes of operate time (Fig. A-4), with a pressure of approximately 350 psi remaining. The system was re-enabled during rev 200 (when SO-180 had come in) and remained on for the balance of the mission.

Because the telemetry signals are readable only to the nearest 0.05 volt, accurate determination of low bottle pressures is impossible. In fact, fluctuations in voltage readings ± 0.05 are evident in the mission 1104 telemetry records which correspond to inaccuracies on the order of ± 25 psi at the pressures existing during the SO-180 operations. Keeping this inaccuracy in mind, on rev 201 the bottle pressure was down (25 psi) to approximately 325 psi; it dropped further (75 psi) to approximately 250 psi during the next camera operate on rev 203, and must have been less than this (approximately 225 psi) on rev 210, although the data does not reflect it. The PMU was disabled during rev 211. After the rev 220 and 236 operations, the supply pressure remaining (at the end of the mission) was 200 psi, which indicates that these two final, relatively long operates discharged only a small amount of gas (~25 psi). All of this data gives only an indication as to how much gas was expelled incrementally, but cannot be transcribed with any confidence into internal payload vehicle pressures.

Internal payload vehicle regulated pressures are monitored by a vacuum gauge located above the exposure control box in the KH-4B system main instrument barrel. The vacuum gauge has a low sensor, designed for pressures below 10 microns, that was of no value in the mission 1104 pressure anomaly. The high sensor, reliable in the 10- to 100-micron region, provided data with which to reconstruct pressure profiles during camera operations.

The following telemetry monitors are provided for diagnostic, status, and command verifications of the PMU system:

1. Reservoir pressure (0 to 5 volts)
2. Reservoir temperature (0 to 5 volts)
3. Regulated pressure (switch 1.5 to 2.5 volts).

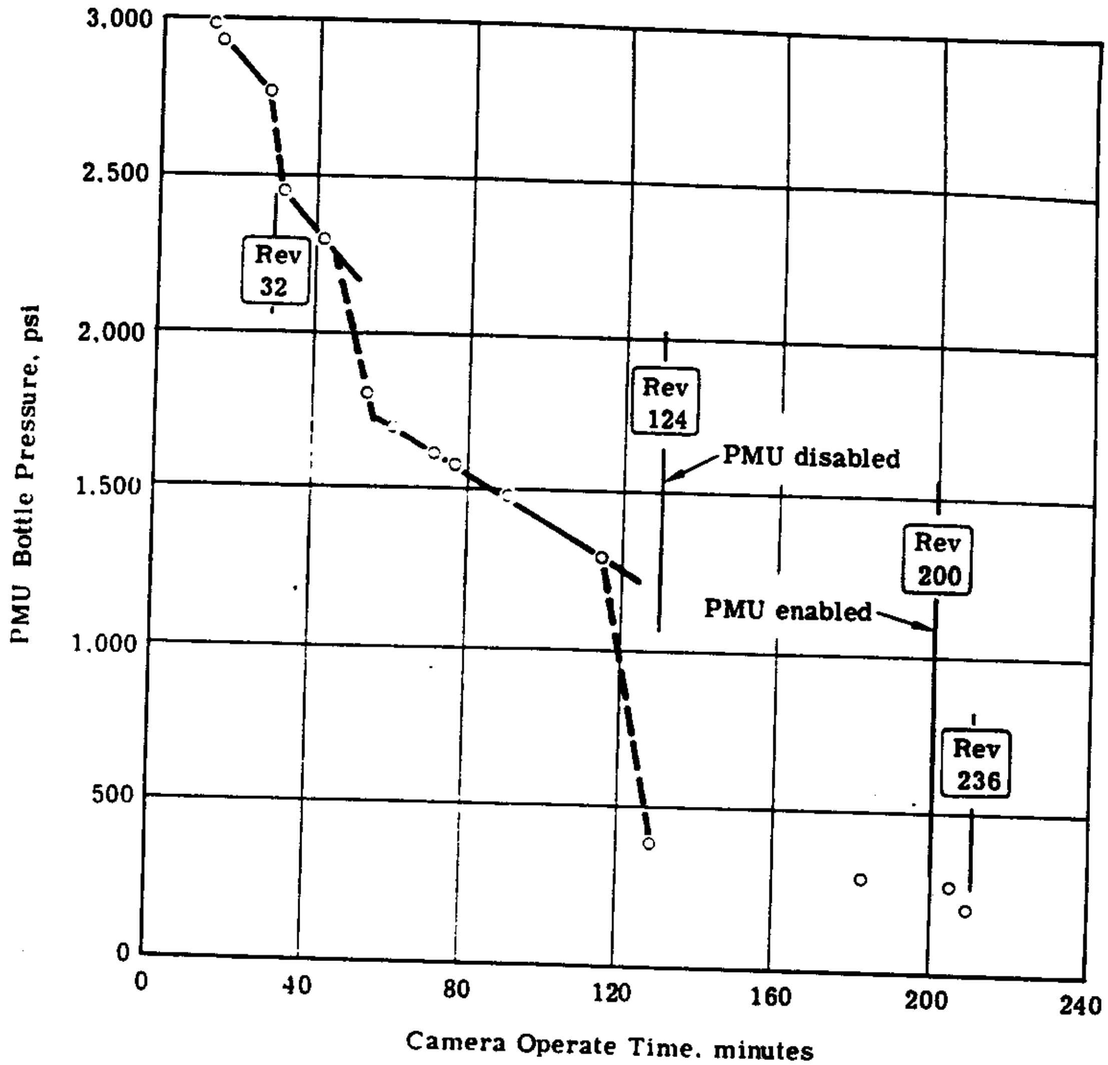


Fig. A-4 — Mission 1104 PMU gas supply consumption

These outputs are commutated and transmitted redundantly over telemetry links 1 and 2. The purpose of the telemetry system is to obtain operational and performance data for use in the evaluation of payload vehicle performance, as expressed in real time or as recorded. Real time telemetry from the satellite is achieved only over [redacted] Tracking Station at [redacted] For all other passes, digital tape recorders (288×10^6 bits storage capacity) are located in each SRV, with the capability of recording on-orbit data during CR instrument operations. However, because the B-SRV T/R subsystem failed to record* after the first two operations of mission 1104-2, PMU diagnostic information was not achieved after rev 103.

Analysts at NPIC produced an SO-180 frame-by-frame subjective estimation of format area percentage fog degradation.† Average values from this analysis for each pass appear in Table A-1. Because the type and degree of electrostatic discharge fogging on the SO-180 is so variable, it would be advantageous to know how the internal payload vehicle pressure varied during the SO-180 image acquisition. Some sort of meaningful correlation could be expected. However, because of the unanticipated B-SRV T/R failure, the pressure profiles for the seven foreign area passes are not available to us. Even if best guess estimations are made of what the artificial pressure environment was for each of the color acquisition operations based on the PMU bottle depletions and lengths of time for camera operate, there is no correlation with low percentage markings on revs 200, 201, and 203. The only correlation that can be made is that these three passes each consisted of two operations.

Only on the California coverage (D-210) was the pressure profile obtained by direct telemetry by [redacted] This information is presented in Fig. A-5. From this we see that the pressure was climbing during the first half of the coverage until it stabilized at 77 microns for the remaining frames. The fact that the indicated pressure at the time of the CR CAMERA ON command was 1 micron implies that there were sit periods during which there was no gas leakage from the PMU system.

Whatever the pressure was during rev 203, it was good in that it produced only minimal corona fogging. But the pressure profile as we have it for rev 210 is not desirable because the fogging on most of this pass is severe. The last frames of D-203 and the first five frames of D-210 are all "light" corona (1 to 15 percent). The next four frames are "medium" corona (16 to 50 percent), and the remainder of the pass is "heavy" corona (51 to 80 percent). The indication is that film transport under pressures from 9 to 40 microns caused light corona, pressures from 40 to 70 microns caused medium corona, pressures from 70 to 77 microns caused heavy corona. Passage through the 12 to 22-micron window took place in approximately 1 second, so that it was no help to the situation.

Early testing of SO-180 on QR-2 in the HIVOS chamber indicated that corona marking decreases at high pressures, disappearing entirely at 160 microns. Marking is very severe at very low pressures, (1 micron or less). Thus, we were probably better off, in general, in having excessive pressures with the regulator discharging gas than if the regulator had been stuck closed. The 3404 film did not suffer from the PMU failure as did the SO-180 film.

> "NO CORRELATION WAS OBSERVED BETWEEN PMU ON/OFF TIMES AND INCIDENCE OF CORONA MARKING ON 3404. DURING PRE-FLIGHT HIVOS TESTING, THE 3404 FILM WAS FREE OF MARKING WHEN THE PMU WAS OFF."‡

---

* Postrecovery testing was not conclusive, but indicated that failure occurred in either the peripheral power or control systems rather than the T/R subsystem itself.

† Photographic Evaluation Report Mission 1104, [redacted]

‡ NPIC Message no. [redacted] 16 Sept 1968.

Table A-1 — Average Extent of Corona Fog Over Each SO-180 Pass in Percent

Pass	Fog, percent	Number of Frames
199	36	9
200	2	41
201	6	71
203	5	69
210	41	25
211	18	20
220	30	40
236	54	31

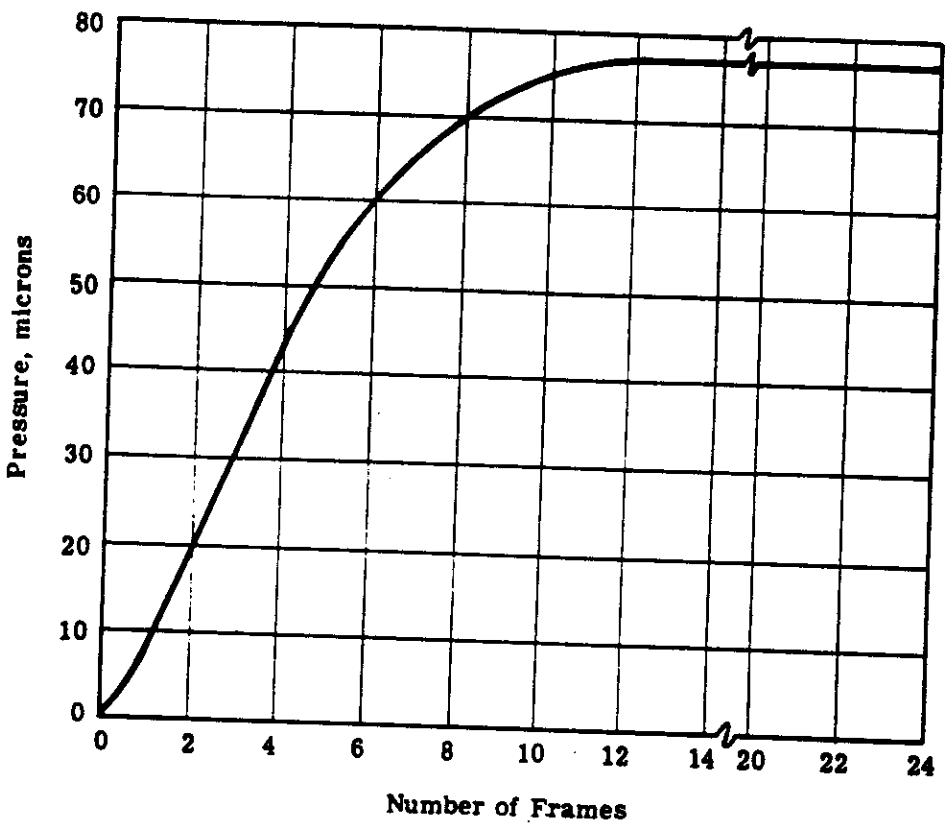


Fig. A-5 — Payload vehicle internal pressure history for rev 210 obtained with real-time telemetry

There is a strong possibility that electrostatic discharge in the KH-4B camera system during operation could be more effectively suppressed than it is now. Rather than providing a pressure environment within the entire payload vehicle, it has been suggested that optimum pressure environments be provided locally to the input metering rollers and the frame metering rollers, which are the two prime sources of discharge. One means of implementing this concept that could be tested is illustrated in Fig. A-6. Here, the rollers are individually housed to contain the gas at a desired pressure environment, as shown in the cross section view. In the vertical view, gas supply lines, flowmeter, and gas entry ports are shown. To date, no hardware is available to test this concept.

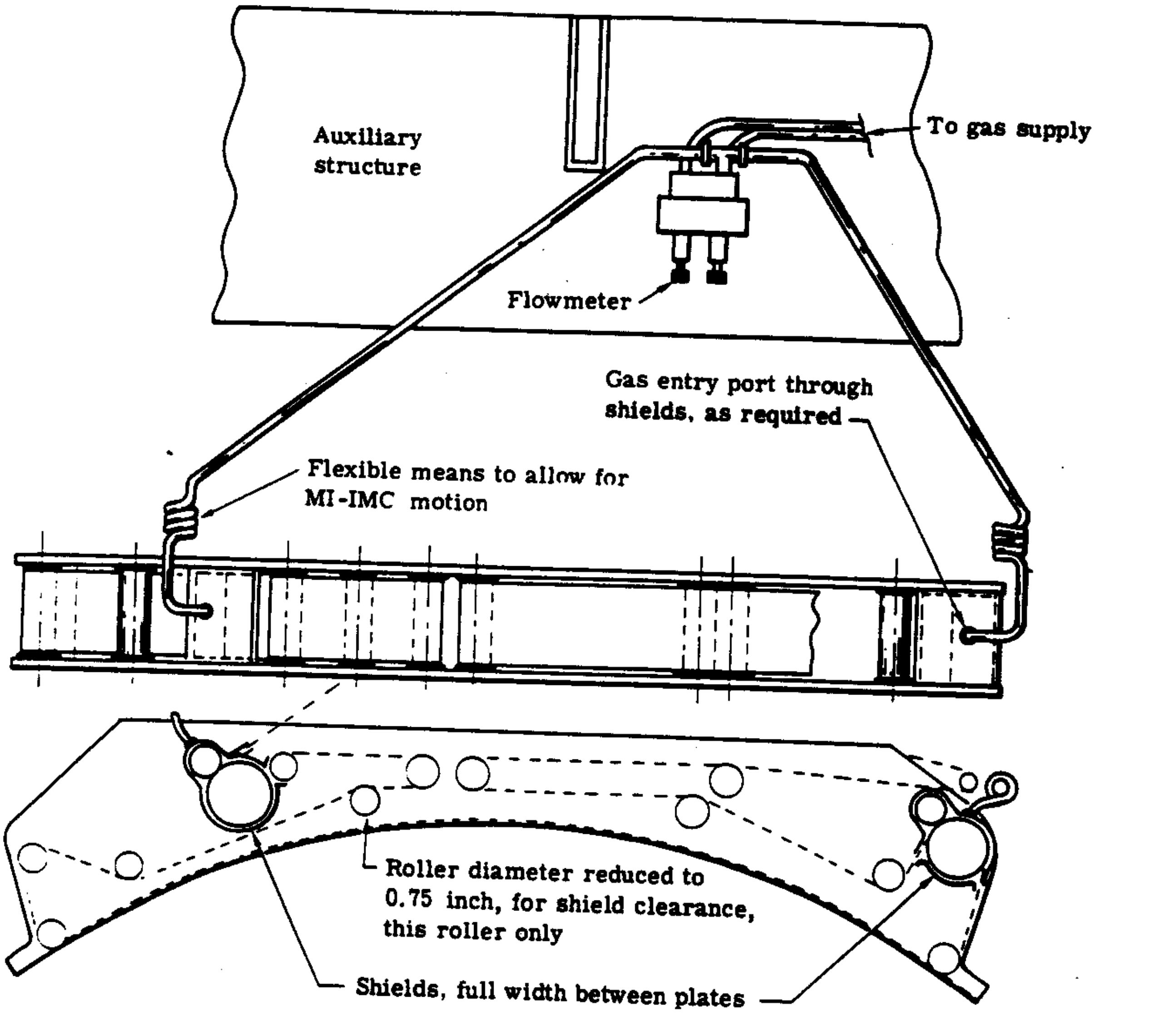


Fig. A-6 — Concept for localized pressure makeup with individual roller housings

Appendix B

RELATIVE INTERPRETABILITY RANKING

The following numerical ranking is used in conjunction with subjective evaluation for an orderly and definitive comparison between SO-180 and 3404 imagery.

Quality Rank	Criteria
1	Image on SO-180 is not interpretable.
2	Image on SO-180 is at threshold of interpretability.
3	Image on SO-180 is poor compared with the 3404 image.
4	Image on SO-180 is fair compared with the 3404 image.
5	Image on SO-180 is good compared with the 3404 image.
6	Image on SO-180 is equal to the 3404 image.
7	Image on SO-180 is better than the 3404 image.
8	Image on SO-180 is superior to the 3404 image.
9	Image on SO-180 is exceptional compared with the 3404 image.
10	Image on 3404 is at threshold of interpretability.
11	Image on 3404 is not interpretable.

These evaluations are subjective in nature and are based on the observer's judgment in which all those factors applicable to the particular subject are weighed. Such factors may not be applicable in other cases, and no attempt was made to execute a "forced fit" for the sake of uniformity or conformity.