(NASA-TM-78122) FILM CALIBRATION FOR THE SKYLAB/ATM S-056 X-RAY TELESCOPE (NASA) 35 p HC A03/MF A01 CSCL 03A

N77-29038

Unclas
G3/89 40706

NASA TECHNICAL MEMORANDUM

NASA TM-78122

FILM CALIBRATION FOR THE SKYLAB/ATM S-056 X-RAY TELESCOPE

By William Henze, Jr., Robert M. Broussard, James H. Underwood, James P. McGuire, Edwin J. Reichmann, and Jesse B. Smith, Jr.

July 1977

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

1. Report No.
NASA TM-78122

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle

Film Calibration for the Skylab/ATM S-056 X-Ray Telescope

5. Report Date
July 1977

6. Performing Organization Code

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8. Performing Organization Report No.

9. Performing Organization Name and Address

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

10. Work Unit No.

11. Contract or Grant No.

12. Sponsoring Agency Name and Address

National Aeronautics and Space Administration
Washington, D.C. 20546

13. Type of Report and Period Covered

Technical Memorandum

14. Sponsoring Agency Code

15. Supplementary Notes

Prepared by Space Sciences Laboratory, Science and Engineering

16. Abstract

The sensitometry and film calibration effort for the NASA-MSFC/The Aerospace Corporation Skylab/ATM S-056 X-Ray Telescope is summarized. The apparatus and procedures used by Sperry/MSFC and by Aerospace Corporation are described together with the two types of flight film used, Kodak SO-212 and SO-242. The sensitometry and processing of the flight film are discussed, and the results are presented in the form of the characteristic curves and related data. The use of copy films is also discussed.

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17. Key Words (Suggested by Author(s))

18. Distribution Statement

James P. McGuire
Unclassified — Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	36	NTIS

ACKNOWLEDGMENTS

W. Henze was supported by NASA contracts NAS8-26442 and NAS8-31908, R. M. Broussard by NAS8-29602, and J. H. Underwood by NAS8-29602 and NAS8-32263. J. B. Smith was supported by Government Work Order H-12261-B.

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I. INTRODUCTION

The purpose of this report is to summarize the sensitometry and film calibration effort for the NASA-MSFC/The Aerospace Corporation Skylab/Apollo Telescope Mount (ATM) S-056 X-Ray Telescope [1]. It includes descriptions of the films used, the sensitometry performed, the characteristic curves for the flight film, and the use of copy films. A brief summary of the history of the overall S-056 film calibration effort is given in this introduction.

Five rolls (or loads) of 35 mm film were exposed by S-056 during the three manned Skylab missions, four of black-and-white film (SO-212) and one of color-reversal film (SO-242). These rolls of film are referred to as flight film, originals, or first-generation film. Table 1 shows that one roll of black-and-white film was used on the first manned mission, SL2; two rolls were used on SL3; and one roll of black-and-white and one roll of color film were used on SL4. (Note that Load 5, the color film, was exposed before Load 4.)

Film tests and calibration were conducted by Sperry Support Services (Sperry Rand Corporation) and The Aerospace Corporation. As part of the S-056 hardware development program, a film testing and calibration facility was constructed at MSFC. This facility was used by Sperry to perform preflight and postflight sensitometry on the flight film as well as other film tests. Early in 1973, Aerospace became involved in the S-056 program and was directed to undertake a parallel sensitometric effort. In addition to general tests on the film, Aerospace made postflight calibration exposures on the flight film.

Section II presents a description of the apparatus and procedures used by Aerospace and Sperry. Section III describes the two types of flight films used, including the results of some of the tests made thereon. The sensitometry and processing of the flight films are described in Section IV. The resulting characteristic curves are given in Section V together with a description of the data reduction required to obtain the curves. Section VI covers the use of various copies that have been made of the flight film, including a description of the properties of the different types of copy films.

TABLE 1. S-056 FILM USAGE

MISSION	LOAD	FILM TYPE	DATES	DAY OF YEAR	FRAMES USED
SL2	1	SO-212 (B&W)	29 May 1973 - 18 Jun 1973	149 to 169	3998
SL3	2	SO-212 (B&W)	07 Aug 1973 - 24 Aug 1973	219 to 236	5653
	3	SO-212 (B&W)	24 Aug 1973 - 21 Sep 1973	236 to 264	5797
SL4	5	SO-242 (Color)	26 Nov 1973 - 25 Dec 1973	330 to 359	5029
	4	SO-212 (B&W)	26 Dec 1973 - 03 Feb 1974	360 to 34	6713
				TOTAL	27 190

II. SENSITOMETRY APPARATUS AND PROCEDURES

A. Sperry/MSFC

An X-ray sensitometer chamber, designed to place X-ray sensitometry on the S-056 film, was placed in operation at MSFC by Sperry in November 1972. A schematic of that facility is shown in Figure 1. The source of X-rays was a Henke tube. There were two other Henke tubes in the chamber as backups. The X-rays went through an exact duplicate mechanism as the camera on S-056, minus the optics. The filters used were also exact duplicates of the flight hardware.

A proportional counter, called the monitor counter, was placed just forward of the camera system, with its own set of duplicate flight filters, to monitor the X-ray source. Another counter, called the spectral proportional counter, was capable of being moved behind the camera filter wheel mechanism to measure the X-ray flux at the film plane. In this position, the counter took the place of the film. An Fe55 source was used as a calibration source for the pulse-height analyzer associated with the spectral proportional counter. The Fe55 source emitted Mn Kα X-rays at an energy of 5.9 keV (2.1 Å).

Various anode materials were used with the Henke tubes to produce X-rays at different wavelengths. The three primary lines used were Al Kα (8.34 Å), Cu Lα (13.3 Å), and Ti Lα (27.4 Å). The Henke tubes also

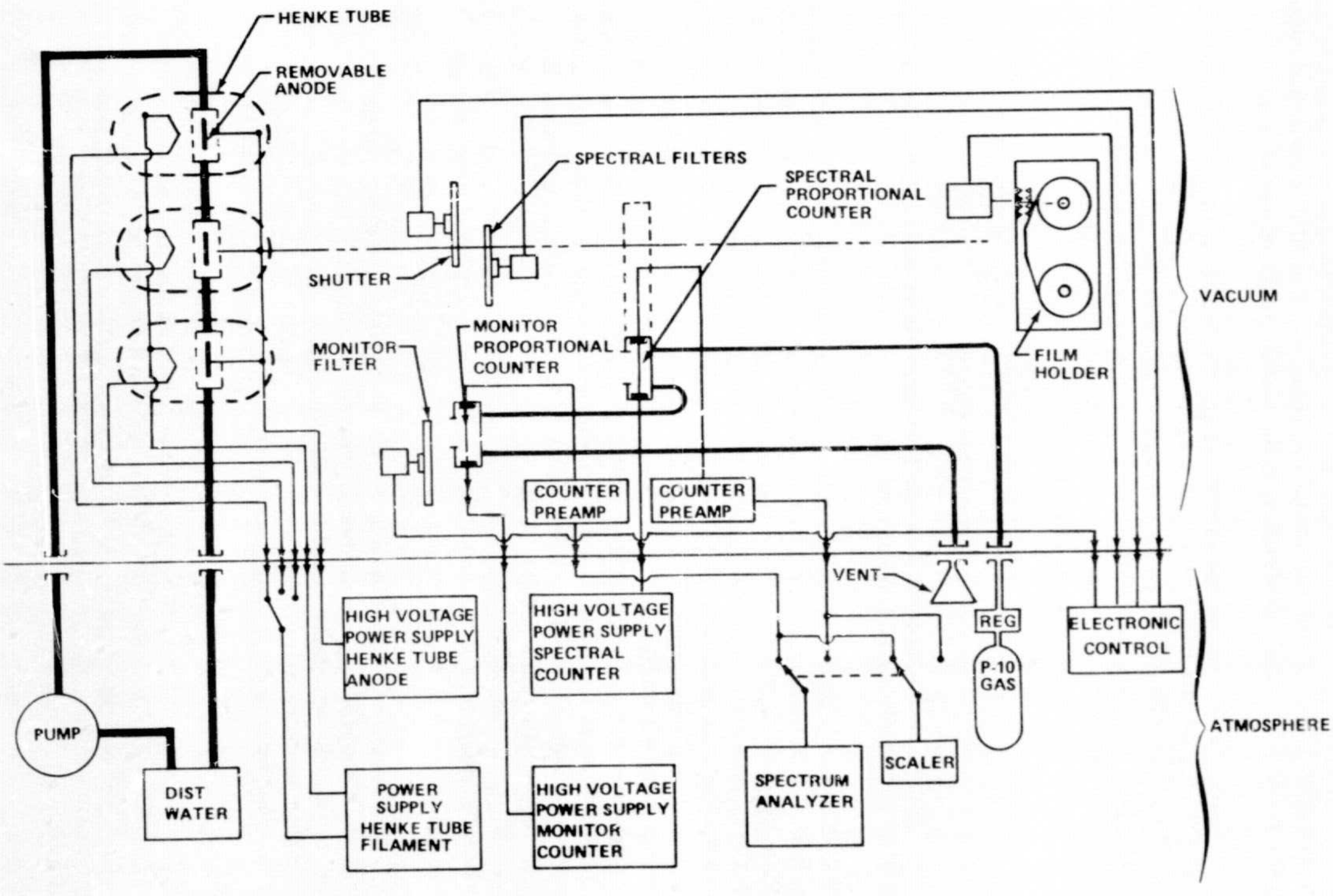


Figure 1. Schematic diagram of Sperry/MSFC X-ray sensitometry chamber.

emitted continuous radiation so that the X-rays produced were not monochromatic but contained both line and continuum components. The filters used then determined the final spectral distribution of the X-rays incident on the film.

Exposure times for the various steps of a set of sensitometric exposures ranged from 1 sec to 4 hr 33 min and 4 sec. During an exposure sequence, proportional counter readings were usually taken with the spectral counter before and after the sequence and sometimes between some of the individual exposures. Occasionally the monitor counter was used to take readings at the same time that individual exposures were being made.

B. Aerospace

The general film tests and sensitometric effort were completed at Aerospace on the apparatus shown in Figure 2.

The film under test was contained in the electrically driven Nikon camera. The lens of this camera was replaced by a tube whose outer end was covered by a filter to transmit X-rays of the desired wavelength and exclude visible light. The X-ray tube employed was specifically designed for that purpose. It was evacuated by a separate Vacion pumping system and isolated from the main tank by a very thin plastic window. In this way, contamination of the target by diffusion pump oil was held to a minimum, so that the characteristic lines of the target element were efficiently produced. Various target/filter combinations ensured that radiation of the desired wavelength reached the film. A proportional counter was used to detect the X-ray flux. For any exposure sequence, the counter was fitted with a window of exactly the same material as the filter covering the film. Pulse height analysis of the proportional counter pulses was employed to determine if the radiation reaching the film was of the correct wavelength.

The counter operated during the whole of each exposure, and the total counts were recorded. The number of photons reaching the film was then determined through a calculation based on the geometry. This required a knowledge of the counter aperture and distances of counter and film from the source. The source was assumed to be a point source so that the inverse square law applied.

In a typical sensitometric run (for example, those made for the postflight X-ray calibration strips), the exposures received by the film ranged between 5×10^6 and 1×10^{10} photons/cm^2. The flight sensitometry strips were exposed to X-rays of wavelengths 8.34 Å (Al K) and 13.3 Å (Cu L). Further tests on nonflight film were made at the wavelengths 5.4 Å (Mo L), 9.89 Å (Mg K), 16.0 Å (Co L), 27.4 Å (Ti L), and 44.6 Å (C K).

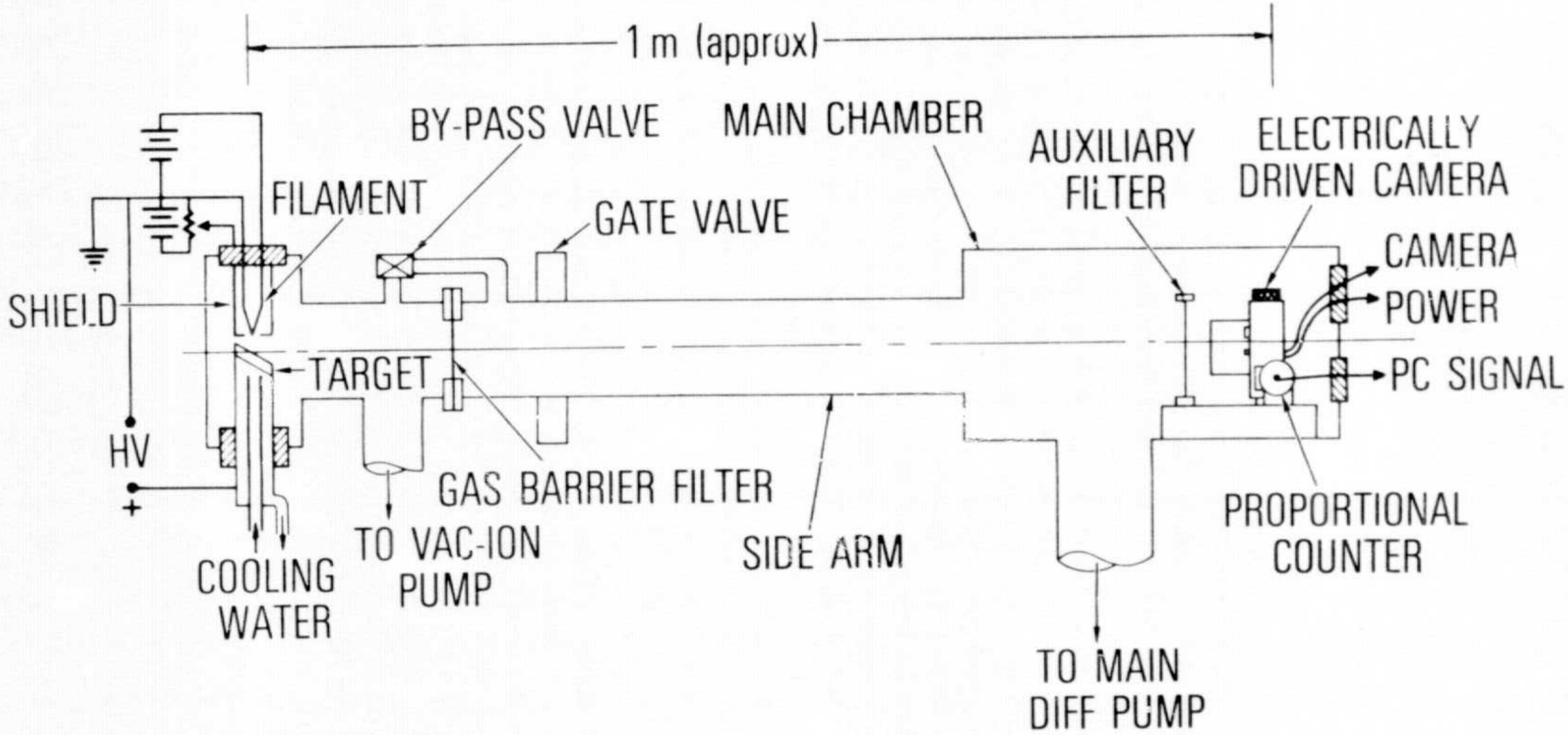


Figure 2. Schematic diagram of Aerospace X-ray sensitometry chamber.

III. PROPERTIES OF FLIGHT FILMS

A. SO-212 Film

The primary film used with the S-056 telescope was a black-and-white film, Kodak Type SO-212; four rolls were exposed during the three manned missions. The SO-212 film, developed by Kodak especially for the X-ray telescopes on Skylab, had a Panatomic-X emulsion but without a protective gelatin overcoat and with a Rem-Jet antistatic backing. This same film, in a 70 mm format, was used in the American Science and Engineering (AS&E) S-054 X-Ray Spectrographic Telescope on Skylab [2]. This section summarizes the history of the development of SO-212 film and then describes some of its properties.

Kodak Panatomic-X Aerial Film 3400 [3] possessed many of the characteristics of resolution, contrast, and sensitivity desired by the Skylab X-ray experimenters. A special version of this film, designated SO-114, was produced by Kodak without the normal protective gelatin overcoat. This film was tested by Sperry [4] and by AS& E [2]. The overcoat was omitted to eliminate absorption of the incident X-rays by the gelatin and thus increase the speed of the film. However, tests in a vacuum chamber indicated that the extreme drying of the film in the vacuum led to fogging of the film by static electrical discharges [4]. Two measures were taken to alleviate the problem of the discharges. First, a moisture source (potassium thiocyanate salt pads) was added to each magazine. Second, a Rem-Jet antistatic carbon backing was provided on the film which then was designated SO-212. The final film thus consisted of the emulsion mounted on Estar Thin Base with the Rem-Jet backing.

The X-ray response of the SO-212 film was extensively studied by Sperry, Aerospace, and AS&E. Tests conducted at Aerospace for the specific wavelengths mentioned in Section II.B indicated that the film response for wavelengths between 5.4 and 16 Å was identical when the exposures were plotted as a photon flux (in photons cm^{-2}) [5]. From this study it was concluded that the film acted as a photon detector. This result was used in subsequent S-056 analyses. In independent studies on the S-054 film, AS&E related the film density to the X-ray energy deposited on the film (in erg cm^{-2}) [6]. They found some variation of the film response with wavelength. The difference in the response of the S-056 and S-054 films, especially in the shoulder portion of the characteristic curve, may be caused by the difference in processing of the two films [6]. Work by Sperry at 8.3 and 27 Å suggested different values of gamma (contrast) at the two wavelengths; the value of gamma appeared to be lower at the longer wavelength.

Although study of the nature of the film response is continuing, the quantitative analyses of the S-056 films have thus far been based on the assumption that the film behaved as a photon detector with the same sensitivity for photons at all wavelengths. If the film acted as an energy detector at the longer wavelengths or showed a variation of gamma with wavelength, the results of the analyses would be changed somewhat. However, only those images taken through one of the S-056 filters (filter 3) would be significantly affected and, even then, only for low temperature solar features. The remaining four X-ray filters, though broadband [1], cover a wavelength range that is sufficiently narrow so that the analyses should remain reliable.

B. SO-242 Film

Although the black-and-white film, SO-212, was the primary film used with the S-056 telescope, one roll of color film, Kodak Type SO-242, was exposed on the third manned Skylab mission (SL4). The SO-242 film is an aerial color-reversal film [3,7] with slightly better resolution but slower speed than SO-212. The reason for using the color film was the realization that the color (visible light color) of an X-ray image depends on the spectral distribution of the X-rays incident on the film. This effect, discussed further later, is caused by the wavelength variation of the X-ray absorption coefficient of the emulsion. In principle, one should be able to infer information about the X-ray spectral distribution from color densitometry (or simple densitometry of black-and-white color-separation copies). In practice, the lack of good absolute sensitometry at a number of well-defined wavelengths combined with the complicated nature of the solar spectrum which must be folded into the film sensitivity curves for the different colors has made it difficult to utilize the color property of the film.

The overall properties of the SO-242 film and some of its test results have been described by Clune et al. [8]. Their paper forms the basis for much of the following discussion.

The film consists of eleven gelatin layers on a polyester base (Estar Thin Base) with a thin clear-gel backing. The gelatin layers consist of a protective overcoat, ultraviolet absorbing layer, green-sensitive emulsion, dye-absorbing layer, red-sensitive emulsion, dye-absorbing layer, blue-sensitive emulsion, three gelatin separation layers, and an antihalation coat. Because of absorption by the gelatin, all layers do not receive the same irradiance; i.e., the surface layers receive a higher exposure than the deeper layers. The major contributors to the absorption are carbon, oxygen, and nitrogen, with the absorption coefficient varying approximately as the cube of the wavelength except for abrupt decreases at absorption edges. The edges in the relevant spectral region are the K edges of C (43.7 Å), O (23.3 Å), and N (30.9 Å); however, even these edges would be significant only for S-056 Filter No. 3 with its long-wavelength window, and Filter No. 3 had developed a light leak and was generally unusable during the time that the SO-242 film (Load 5) was being exposed on Skylab. Thus, in the important spectral region from 6 to 18 Å, the absorption coefficient of the gelatin increases with wavelength so that the short wavelength photons are more likely to penetrate to the blue-sensitive emulsion layer. Therefore, one would expect that a hot solar event such as a flare with a harder spectrum would produce a bluer image than an active region with a cooler, softer spectrum.

Clune et al. [8] have presented data which verify the above qualitative discussion. They give H&D curves at two median wavelengths, 14.3 Å and 7.9 Å, where the blue, green, and red densities are plotted against the logarithm of the exposure. In the 14.3 Å case, the blue and green density curves are almost identical. At 7.9 Å, the blue density curve is approximately 0.8 in log exposure to the left of the green curve, thus showing a bluer image. These results and tests at other wavelengths were made with the MSFC/Sperry X-ray sensitometer. Because of the difficulty in getting absolute experimental data at more nearly monochromatic wavelengths which would then have to be folded into theoretical spectra, the calibration curves to be presented in Section V are for visible, white-light densities so that the color effects have been ignored. Thus far the color film has been treated the same as black-and-white film. However, the possibility of utilizing the color properties of the color film in the future has not been eliminated.

IV. FLIGHT FILM SENSITOMETRY AND PROCESSING

In this section, the various types of sensitometry performed on the flight films are described and the format and positions of the sensitometric sets are indicated. The processing of the flight films is also summarized.

A. Sensitometry

For calibration of the actual flight films, sets of sensitometry were placed on the films before and after each mission. Usually, the preflight sets were spliced onto the beginning (known as the "heads") of each roll, while the postflight sets were spliced onto the end (known as the "tails") of the roll. Tables 2 through 6 identify each set for each load, showing the order in which they are present and giving additional information concerning each set.

TABLE 2. LOAD 1, IDENTIFICATION OF SENSITOMETRY SETS

ORIGIN OF SENSITOMETRY SET	TYPE OF SENSITOMETRY	PRE OR POST FLIGHT	SOURCE OR λ(Å)	SET NO.	END OF SET WITH HIGH EXPOSURES	NUMBER OF STEPS (INTENDED OR ACTUAL)	REMARKS, STEP SIZE, OTHER FEATURES ON FILM
↑ HEADS END							
Sperry	X-Ray	Post	Ti	109	H	21	Each step 5/16 in. wide (along film), 1 1/2 in. from center to center
Sperry	X-Ray	Post	Ti	108	H	22	Same as Set 109
Sperry	X-Ray	Post	Al	107	H	21	Same as Set 109
							Trapezoidal piece of tape on flight film
Sperry	X-Ray	Post	Al	106	H	21	Same as Set 109
							Trapezoidal piece of tape on flight film
							~1 1/4 in. wide gate (highly exposed)
Sperry	Visible	Post	6400		T	21	Each step 3/8 to 1/2 in. wide, 5/8 in. from center to center
Sperry	Visible	Post	5200		T	21	Same as λ6400
Sperry	Visible	Post	4000		T	21	Same as λ6400
							1 in. wide gate (highly exposed)
Sperry	UV	Post	2600		T	21	Same as λ6400
Aerospace	X-Ray	Post	Al		T	28	
Aerospace	X-Ray	Post	Cu		T	15	
							15 3/4 in. highly exposed section
JSC	Photo	Pre	WL	1	T		
JSC	Photo	Pre	WL	2	T		Tick mark tenth step from Tails
Sperry	UV	Pre	2600		H	21	Each step 3/8 to 7/16 in. wide, 5/8 in. from center to center
Sperry	Visible	Pre	4000		H	21	Same as λ2600
Sperry	Visible	Pre	5200		H	21	Same as λ2600
Sperry	Visible	Pre	6400		H	21	Same as λ2600
Sperry	X-Ray	Pre	Al	1	T	27	Each step 5/16 in. wide, 1 1/2 in. from center to center; some overlapping steps
Sperry	X-Ray	Pre	Ti	2	T	24	Same step size and spacing as Set 1
Sperry	X-Ray	Pre	Al	3	T	24	Same as Set 2
Sperry	X-Ray	Pre	Ti	4	T	23	Same as Set 2
SOLAR IMAGES							
JSC	Photo	Post	WL	3	T		
JSC	Photo	Post	WL	4	T		
↓ TAILS END							

H = Heads; T = Tails; WL = White Light; UV = Ultraviolet Light; Photo = Photographic

TABLE 3. LOAD 2, IDENTIFICATION OF SENSITOMETRY SETS

ORIGIN OF SENSITOMETRY SET	TYPE OF SENSITOMETRY	PRE OR POST FLIGHT	SOURCE OR λ(Å)	SET NO.	END OF SET WITH HIGH EXPOSURES	NUMBER OF STEPS (INTENDED OR ACTUAL)	REMARKS, STEP SIZE, OTHER FEATURES ON FILM
↑ HEADS END							
Sperry	UV	Pre	2600		H	21	Each step 3/8 to 7/16 in. wide, 5/8 in. from center to center
							1 in. wide gate (highly exposed)
Sperry	Visible	Pre	4000		H	21	Same as λ2600
Sperry	Visible	Pre	5200		H	21	Same as λ2600
Sperry	Visible	Pre	6400		H	21	Same as λ2600
							1 3/8 in. wide gate (?), 1 1/2 in. wide gate (?)
Sperry	X-Ray	Pre	Al	047-I	T	21	Each step 5/16 in. wide, 1 1/2 in. from center to center
Sperry	X-Ray	Pre	Al	047-II	T	21	Same as Set 047-I
							6 in. highly exposed section
JSC	Photo	Pre	WL	1	T		
JSC	Photo	Pre	WL	2	T		
SOLAR IMAGES							
JSC	Photo	Post	WL	3	T		
JSC	Photo	Post	WL	4	T		
							1/2 in. splice, 1 in. wide gate
Sperry	Visible	Post	6400		T	21	Each step 3/8 to 1/2 in. wide, 5/8 in. from center to center
Sperry	Visible	Post	5200		T	21	Same as λ6400
Sperry	Visible	Post	4000		T	21	Same as λ6400
Sperry						1	Step is centered in 1 in. wide, lightly exposed section (gate ?)
Sperry	UV	Post	2600		T	21	Same as λ6400
							1 in. wide gate, ~3 1/2 in. highly exposed section
Sperry	X-Ray	Post	Ti	165			Messed up, steps superimposed
Sperry	X-Ray	Post	Al	164	H	22	Many touching or overlapping steps, close to Set 165
Sperry	X-Ray	Post	Ti	163	H	21	Each step 5/16 in. wide, 19/32 in. normal center to center
Sperry	X-Ray	Post	Al	162	H	21	Same as Set 163
							12 in. long, ~10 1/2 in. long highly exposed sections
Aerospace	X-Ray	Post			H	2	
Aerospace	X-Ray	Post	Al		H	17	
Aerospace	X-Ray	Post				1	Very faint
Aerospace	X-Ray	Post			H	17	
Aerospace	X-Ray	Post			T	2	
↓ TAILS END							

TABLE 4. LOAD 3, IDENTIFICATION OF SENSITOMETRY SETS

ORIGIN OF SENSITOMETRY SET	TYPE OF SENSITOMETRY	PRE OR POST FLIGHT	SOURCE OR λ(A)	SET NO.	END OF SET WITH HIGH EXPOSURES	NUMBER OF STEPS (INTENDED OR ACTUAL)	REMARKS, STEP SIZE, OTHER FEATURES ON FILM
↑ HEADS END							
Sperry	UV	Pre	2600		H	21	Each step 3/8 to 1/16 in. wide, 5/8 in. from center to center
							1 in. wide gate (highly exposed)
Sperry	Visible	Pre	4000		H	21	Same as λ2600
Sperry	Visible	Pre	5200		H	21	Same as λ2600
Sperry	Visible	Pre	6400		H	21	Same as λ2600
							1 1/2 in. wide gate (?)
Sperry	X-Ray	Pre	Al	048-I	T	22	Each step 5/16 in. wide, 1 1/2 in. from center to center
Sperry	X-Ray	Pre	Al	048-II	T	20	Same as Set 048-I
							~2 1/4 in. highly exposed section, 1/2 in. splice
JSC	Photo	Pre	WL	1	T		
JSC	Photo	Pre	WL	2	T		
SOLAR IMAGES							
JSC	Photo	Post	WL	3	T		
JSC	Photo	Post	WL	4	T		
							1/2 in. wide splice, 1 in. wide gate
Sperry	X-Ray	Post	Al	166	T	21	Each step 5/16 in. wide, 5/8 in. normal from center to center, many steps touching
Sperry	X-Ray	Post	Ti	167	T	9	Same step size, normal spacing as Set 166
							1 in. wide gate
Sperry	UV	Post	2600		H	21	Each step 3/8 to 7/16 in. wide, 5/8 in. total spacing
Sperry		Post				1	
Sperry	Visible	Post	4000		H	21	Same as λ2600
Sperry	Visible	Post	5200		H	21	Same as λ2600
Sperry	Visible	Post	6400		H	21	Same as λ2600
							1 in. wide gate, 1/2 in. splice, 1/2 in. splice
Aerospace	X-Ray	Post					Messed up, steps overlapping
↓ TAILS END							

TABLE 5. LOAD 4, IDENTIFICATION OF SENSITOMETRY SETS

ORIGIN OF SENSITOMETRY SET	TYPE OF SENSITOMETRY	PRE OR POST FLIGHT	SOURCE OR λ(A)	SET NO.	END OF SET WITH HIGH EXPOSURES	NUMBER OF STEPS (INTENDED OR ACTUAL)	REMARKS, STEP SIZE, OTHER FEATURES ON FILM
↑ HEADS END							
Sperry	UV	Pre	2600		H	21	Each step 3/8 to 7/16 in. wide, 5/8 in. from center to center
							~1 1/8 in. wide gate (?) (highly exposed)
Sperry	Visible	Pre	4000		H	21	Same as λ2600
Sperry	Visible	Pre	5200		H	21	Same as λ2600
Sperry	Visible	Pre	6400		H	21	Same as λ2600
							~2 in. wide, highly exposed section, 1 7/8 in. wide gate (?)
Sperry	X-Ray	Pre	Al	045-I	T	21	Each step 5/16 in. wide, 1 1/2 in. from center to center
Sperry	X-Ray	Pre	Al	045-II	T	21	Same as Set 045-I
							~7 in. highly exposed section
JSC	Photo	Pre	WL	1	T		
JSC	Photo	Pre	WL	2	T		
SOLAR IMAGES							
JSC	Photo	Post	WL	3	T		
JSC	Photo	Post	WL	4	T		
							1/2 in. wide splice, 6 1/2 in. highly exposed section, 1 in. wide gate
Sperry	X-Ray	Post	Al	256	T	22	Each step 5/16 in. wide, 1 1/2 in. from center to center
Sperry	X-Ray	Post	Cu	257	T	22	Same as Set 256
Sperry	X-Ray	Post	Ti	258	T	22	Same as Set 256
							1 1/4 in. wide gate
Sperry	UV	Post	2600		H	21	Each step 3/8 to 7/16 in. wide, 5/8 in. from center to center
Sperry	Visible	Post	4000		H	13	Same as λ2600
Sperry	Visible	Post	4000		H	21	Same as λ2600
Sperry	Visible	Post	5200		H	21	Same as λ2600
Sperry	Visible	Post	6400		H	21	Same as λ2600
							1 in. wide gate; "Marshall Sensi" 1/2 in. splice; "Aerospace Sensi"
Aerospace	X-Ray	Post	Cu	3	H	17	
Aerospace	X-Ray	Post	Al	2	H	17	Two lowest exposure steps overlap
Aerospace	X-Ray	Post	Al	1	H	16	
↓ TAILS END							

TABLE 6. LOAD 5, IDENTIFICATION OF SENSITOMETRY SETS

ORIGIN OF SENSITOMETRY SET	TYPE OF SENSITOMETRY	PRE OR POST FLIGHT	SOURCE OR λ(A)	SET NO.	END OF SET WITH HIGH EXPOSURES	NUMBER OF STEPS (INTENDED OR ACTUAL)	REMARKS, STEP SIZE, OTHER FEATURES ON FILM
↑ HEADS END							
JSC	Photo	Pre	WL	1	T		
JSC	Photo	Pre	WL	2	T		
SOLAR IMAGES							
JSC	Photo	Post	WL	3	T		
JSC	Photo	Post	WL	4	T		
							1/2 in. wide splice, "Marshall Sensi", highly exposed mark (made by tape on flight film), 1 in. wide gate
Sperry	Visible	Post	6400		T	21	Each step 3/8 to 7/16 in. wide, 5/8 in. from center to center
Sperry	Visible	Post	5200		T	21	Same as λ6400
Sperry	Visible	Post	4000		T	21	Same as λ6400
Sperry	UV	Post	2600		T	21	Same as λ6400
							1 in. wide gate
Sperry	X-Ray	Post	Ti	255	H	22	Each step 5/16 in. wide, 1 1/2 in. from center to center
Sperry	X-Ray	Post	Cu	254	H	22	Same as Set 255
Sperry	X-Ray	Post	Al	253	H	21	Same as Set 255
							1 in. wide gate, 10 in. highly exposed section, 1/2 in. wide splice, "Aerospace Sensi"
Aerospace	X-Ray	Post	Al	1	T	21	
Aerospace	X-Ray	Post	Cu	2	T	18	
Aerospace	X-Ray	Post	Cu	3	T	13	
							2 1/2 in. long, medium exposed section, 1/2 in. wide splice, "227"
Sperry	X-Ray	Test	Al	227	H	12	
							1/2 in. wide splice, "226"
Sperry	X-Ray	Test	Al	226	H	12	
↓ TAILS END							

Test = Sensitometry set made on film which did not fly on Skylab.

As can be seen from the tables, the films contain several different types of sensitometry. In addition to the X-ray sensitometry performed by Sperry and Aerospace, there are visible light (Vis) and ultraviolet (UV) sets provided by Sperry and photographic white-light (WL) wedges exposed by the NASA/Johnson Space Center (JSC). The purpose of the JSC wedges was to monitor changes in film properties as a result of exposure to the space environment. The appearance of a typical step for each type of sensitometry is shown in Figure 3. Some second or third generation copies may also have additional photographic wedges at the very beginning and end; these were provided to monitor the constancy of the duplicating process. The numbering of the X-ray sets is based on the numbers assigned or used by Sperry and Aerospace. Numbers for other sets, if given at all, were assigned simply for convenience.

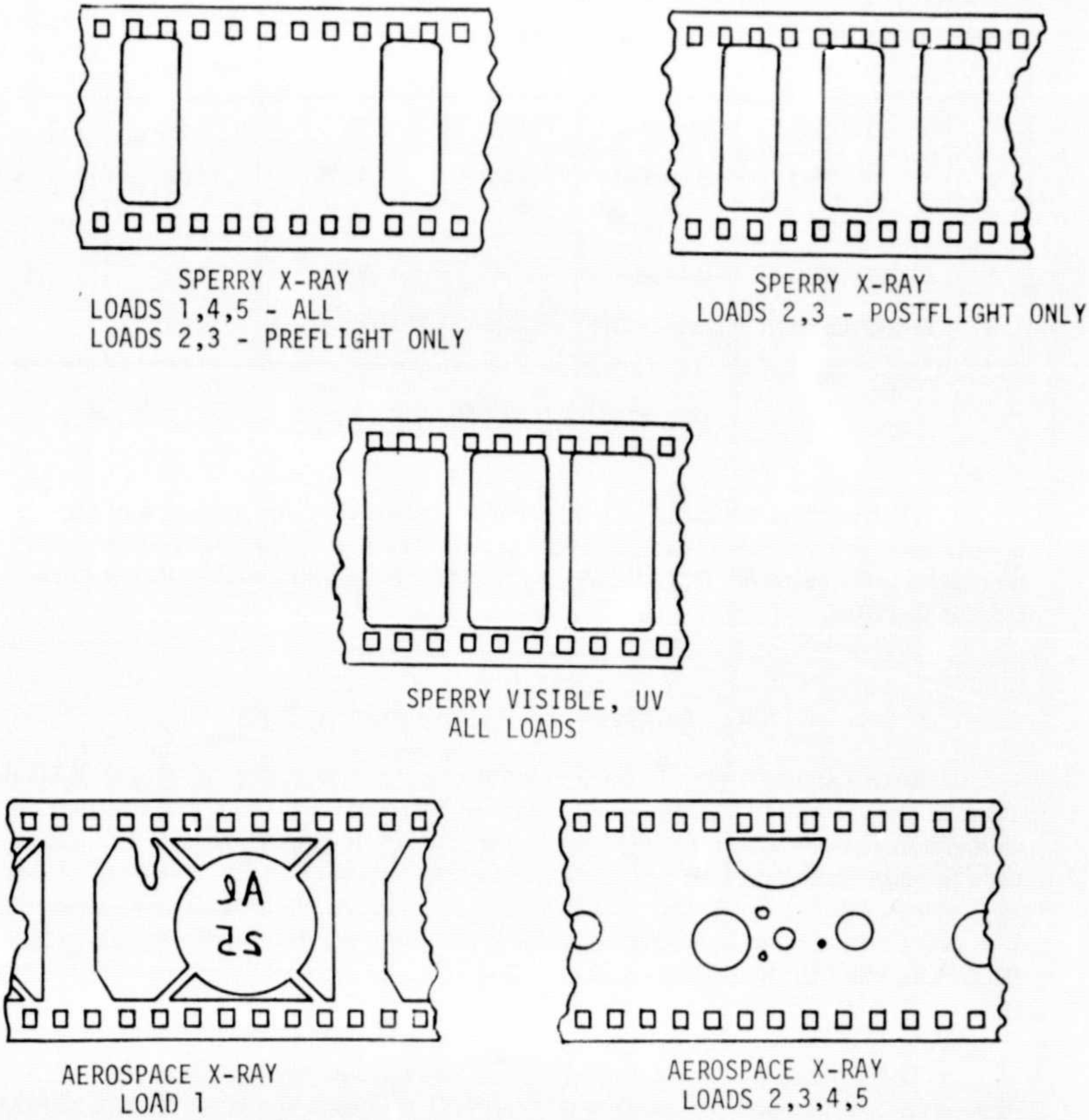
The preflight X-ray sensitometry was performed only by Sperry and is available for Loads 1 through 4. No preflight sensitometry was spliced onto Load 5, the color film. However, two test sets were exposed on the color film as part of a group of environmental simulation test samples. The test sets were made by Sperry after the SL4 mission had been launched; therefore, the samples of film used did not fly on Skylab although they were stored and then spliced onto and processed with the Load 5 flight film.

Sperry and Aerospace performed postflight sensitometry for all five loads. However, the Aerospace sensitometry on Load 3 is not usable because of overlapping exposures, apparently caused by film advance problems. In addition, some of the Sperry sets, especially postflight on Load 2, also had overlapping steps and were not completely usable.

B. Film Processing

Each of the loads of flight film was processed at JSC, typically approximately 2 weeks after splashdown for each mission. Before processing, segments of film were cut from each load, sent to MSFC and Aerospace for postflight sensitometry, and then returned to JSC and spliced back onto the rolls of film. Considerable effort was expended to guarantee uniform, high-quality development of the film. Information concerning the processing conditions for the film is given in Table 7.

After Load 1 was developed, a decision was made to develop the later loads of black-and-white film to a lower contrast. This accounts for the change in developing conditions for the SO-212 film shown in Table 7. Loads 2 and 3 were processed at the same time.



EMULSION IS DOWN ON FLIGHT FILM AND THIRD-GENERATION COPY, UP ON SECOND-GENERATION COPY. TAILS IS TO THE RIGHT IN ALL CASES EXCEPT AEROSPACE X-RAY LOAD 4 WHERE HEADS IS TO THE RIGHT.

Figure 3. Appearance of typical sensitometry sets.

TABLE 7. S-056 FILM PROCESSING

LOAD	FILM TYPE	PROCESSOR	CHEMISTRY	TEMPERATURE (F)	DEVELOPING TIME (min:sec)	RATE (ft/min)
1	SO-212(B&W)	High-Speed	D-76	76	8:50	4
2	SO-212(B&W)	High-Speed	D-76	72	8:50	4
3	SO-212(B&W)	High-Speed	D-76	72	8:50	4
4	SO-212(B&W)	High-Speed	D-76	75	7:58	3.75
5	SO-242(Color)	Versamat 1811	EA-5	110(1st Dev.)	2:00	6

V. CALIBRATION RESULTS

This section contains an outline of the reduction and analysis of the sensitometric data described in Section IV and then presents the resulting characteristic curves. Only the X-ray sensitometry was used in the calibration of the film.

A. Analysis of Sensitometric Data

Each exposure step in each sensitometry set was measured with a Macbeth TD-504 densitometer to obtain the doubly diffuse density. The rolls of black-and-white film (Loads 1 through 4) were measured at Aerospace with a 2 mm diameter aperture in the central portion of each step. Several measurements of each step were made to verify that the exposure and development had been uniform. The color film (Load 5) was measured at JSC with a 3 mm aperture; no color filter was used in the densitometer so that the density was measured with "white light."

The density readings were then plotted against the logarithm of the exposures (in photons per square centimeter) to obtain the conventional characteristic (H&D) curve plots. The photon flux was determined from the count rates measured by the proportional counters during the exposures in the sensitometer chambers. To convert count rate to photon flux, the counter aperture area and the distances between the X-ray source, counter, and film must be known.

All available X-ray data were plotted together for each load of film. In comparisons of the various sets of data, the aluminum (8.3 Å) data seemed to be the most consistent and reliable. There were, however, systematic differences between the Sperry and Aerospace data in that the Aerospace points lay to the right (toward higher exposures) of the Sperry points. Because the Aerospace proportional counters were operating continuously throughout their calibration exposures and because the Aerospace data for sources emitting different wavelengths were more consistent, it was decided to base the absolute calibration on the Aerospace sensitometry. The Sperry data covered a more extensive range of exposures and defined the shape of the curve better at high and low densities. Therefore, the procedure was to first draw a curve for each load based on the Sperry aluminum sensitometry and then to shift the curve to the right to agree with the Aerospace absolute values. The amount of the shift for a given load was calculated as the average displacement (in the logarithm of the exposure) between the Sperry curve and those Aerospace data points that were in or near the straight-line portion of the curve. Thus, the final characteristic curves are a composite of the Sperry and Aerospace sensitometry, with the shape of the curves being based on the Sperry data while the absolute values of the photon fluxes were derived from the Aerospace work.

B. Characteristic Curves and Related Data

The characteristic curves resulting from the analyses described in the preceding section are presented here in two forms. First, values of the logarithm of the exposure were read off the curves for many values of the density; these points are given in Tables 8 and 9. (Because Loads 2 and 3 were processed at the same time, the same curve applied to both loads.) In the toe and shoulder portions of the curves, the points are very closely spaced. In the straight-line portion of the curves, only the two end-points are given; thus, the positions and ranges of the straight-line regions are obvious from the large gap in data points. Linear interpolation can be used to calculate the logarithm of the exposure at any intermediate value of the density.

The second form of presentation of the curves consists of the plotted curves themselves as shown in Figures 4 through 7. The crosses are the points from Tables 8 and 9 except that additional points are shown in the straight-line regions.

TABLE 8. CHARACTERISTIC CURVES, LOADS 1, 2, 3, AND 4

FLIGHT FILM DENSITY	log E (photons cm^{-2}) LOAD 1	LOADS 2 AND 3	LOAD 4
0.30	7.21		
0.32	7.51	6.645	
0.33		6.995	
0.34	7.71	7.165	
0.35		7.275	
0.36	7.84	7.355	
0.37		7.43	
0.38	7.93	7.49	
0.39		7.55	
0.40	8.01	7.605	
0.42		7.695	6.66
0.43			6.94
0.44		7.775	7.155
0.45	8.172		7.285
0.46		7.84	7.38
0.48		7.905	7.525
0.50	8.298	7.965	7.635
0.52		8.015	7.74
0.54			7.825
0.55	8.390	8.085	
0.56			7.885
0.58			7.945
0.60	8.468	8.185	7.995
0.62			8.045
0.64			8.09
0.65	8.538	8.268	
0.66			8.13
0.68			8.17
0.70	8.601	8.343	8.21
0.75	8.660	8.407	8.30
0.80	8.714	8.464	8.378
0.85	8.767	8.517	8.442
0.90	8.814	8.566	8.503
0.95		8.612	8.557
1.00	8.895	8.655	8.607
1.05		8.695	8.652
1.10	8.968	8.734	8.695
1.20	9.033	8.806	8.777
1.30	9.095		
1.40	9.153		
1.50	9.210		
2.40		9.636	9.664
2.50		9.710	9.745
2.60		9.788	9.828
2.70		9.872	9.918
2.80		9.963	10.017
2.90		10.062	10.123
3.00	9.993	10.173	10.234
3.05		10.233	10.292
3.10	10.046	10.296	10.352
3.15		10.364	10.411
3.20	10.107	10.435	10.472
3.25		10.516	10.533
3.30	10.174	10.609	10.60
3.35	10.210	10.715	10.67
3.40	10.248	10.847	10.745
3.45	10.291	11.007	10.795
3.47		11.082	
3.50	10.336		10.93
3.55	10.382		
3.56			11.10
3.60	10.433		
3.64			11.65
3.65	10.488		
3.70	10.551		
3.75	10.623		
3.80	10.702		
3.85	10.80		
3.90	10.94		

TABLE 9. CHARACTERISTIC CURVE, LOAD 5 (COLOR FILM)

FLIGHT FILM DENSITY*	log E (photons cm^{-2})	FLIGHT FILM DENSITY*	log E (photons cm^{-2})
2.47	7.668	0.65	9.818
2.46	7.833	0.60	9.866
2.45	7.938	0.55	9.919
2.44	8.013	0.50	9.973
2.42	8.122	0.45	10.033
2.40	8.199	0.40	10.097
2.38	8.264	0.35	10.171
2.36	8.320	0.30	10.252
2.34	8.373	0.28	10.285
2.32	8.415	0.26	10.321
2.30	8.457	0.24	10.359
2.25	8.545	0.22	10.404
2.20	8.616	0.20	10.447
2.15	8.680	0.18	10.502
2.10	8.738	0.16	10.558
2.05	8.791	0.14	10.623
2.00	8.839	0.12	10.702
1.90	8.926	0.10	10.792
1.80	9.005	0.09	10.853
1.70	9.078	0.08	10.913
1.00	9.537	0.07	10.992
0.90	9.608	0.06	11.105
0.80	9.686		
0.75	9.728		
0.79	9.772		

*Measured with no filter in densitometer.

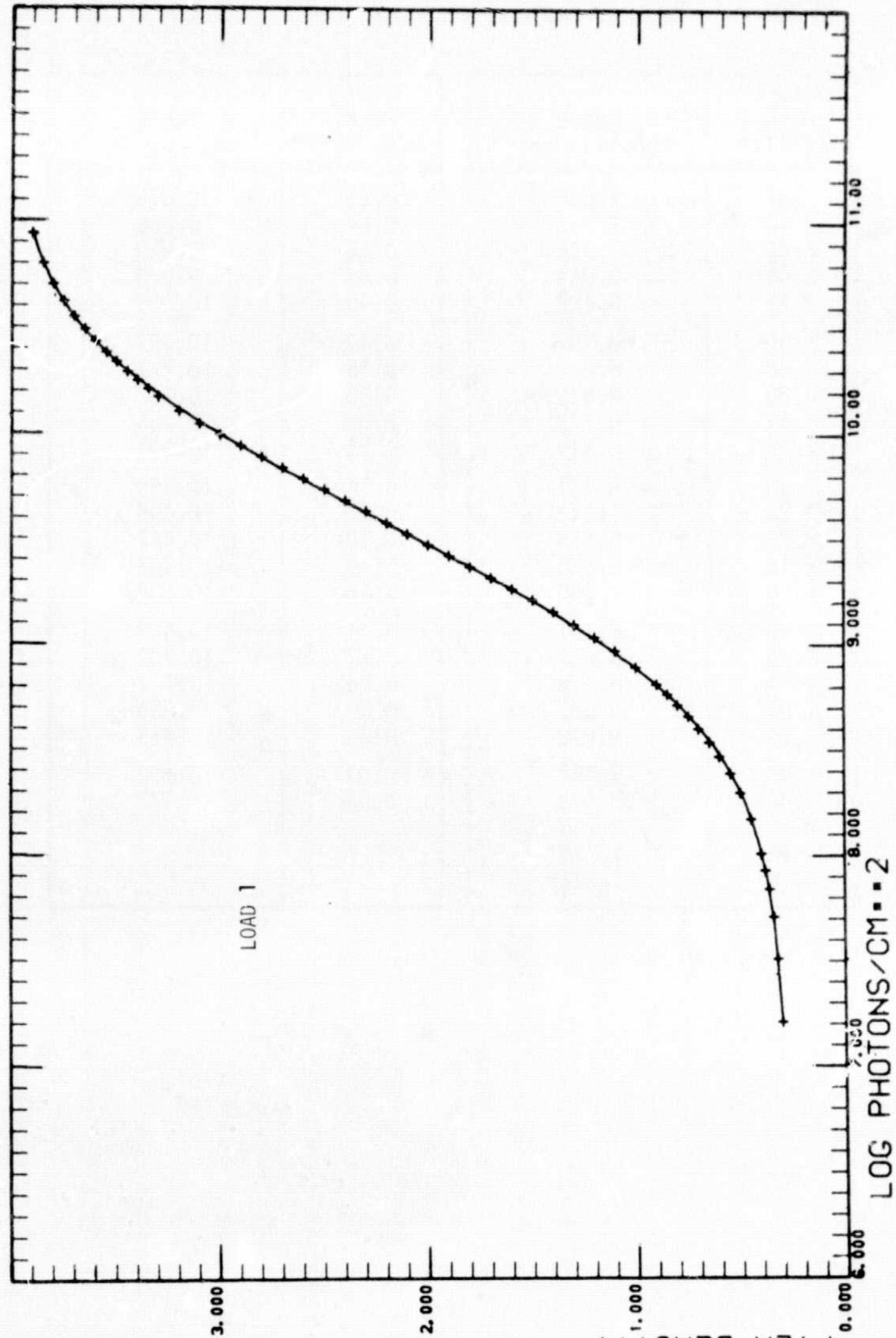


Figure 4. Characteristic curve, Load 1.

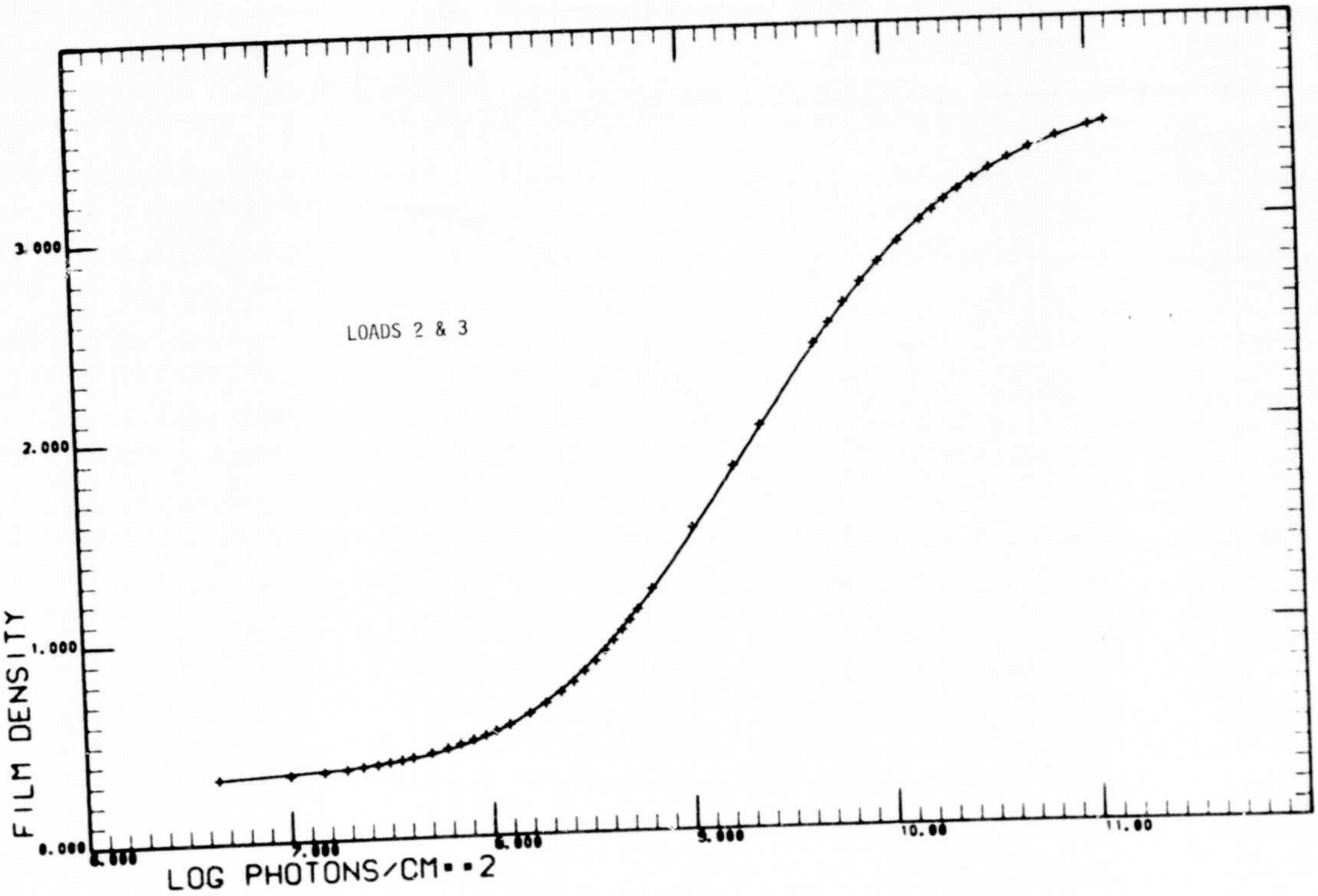


Figure 5. Characteristic curve, Loads 2 and 3.

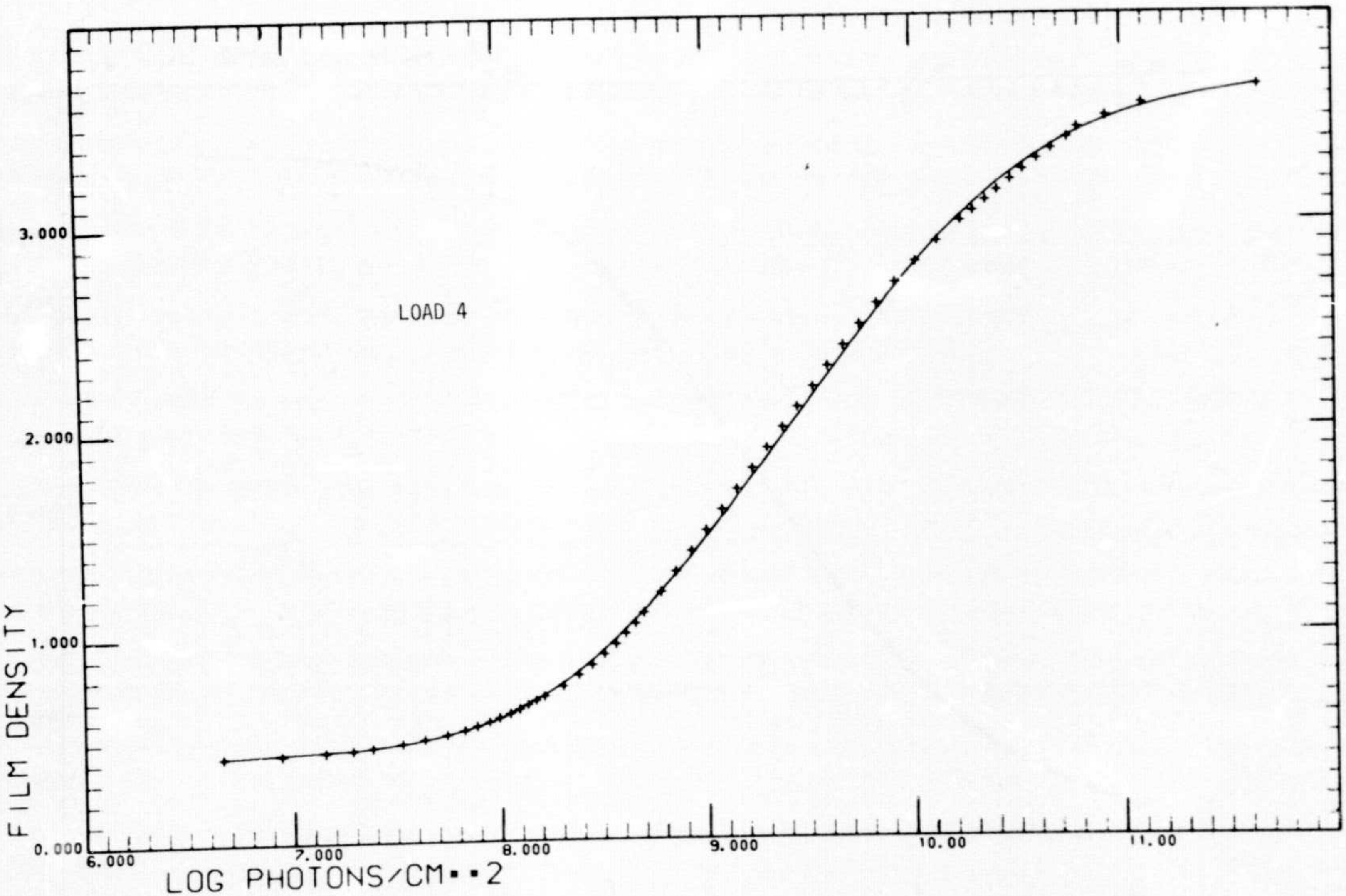


Figure 6. Characteristic curve, Load 4.

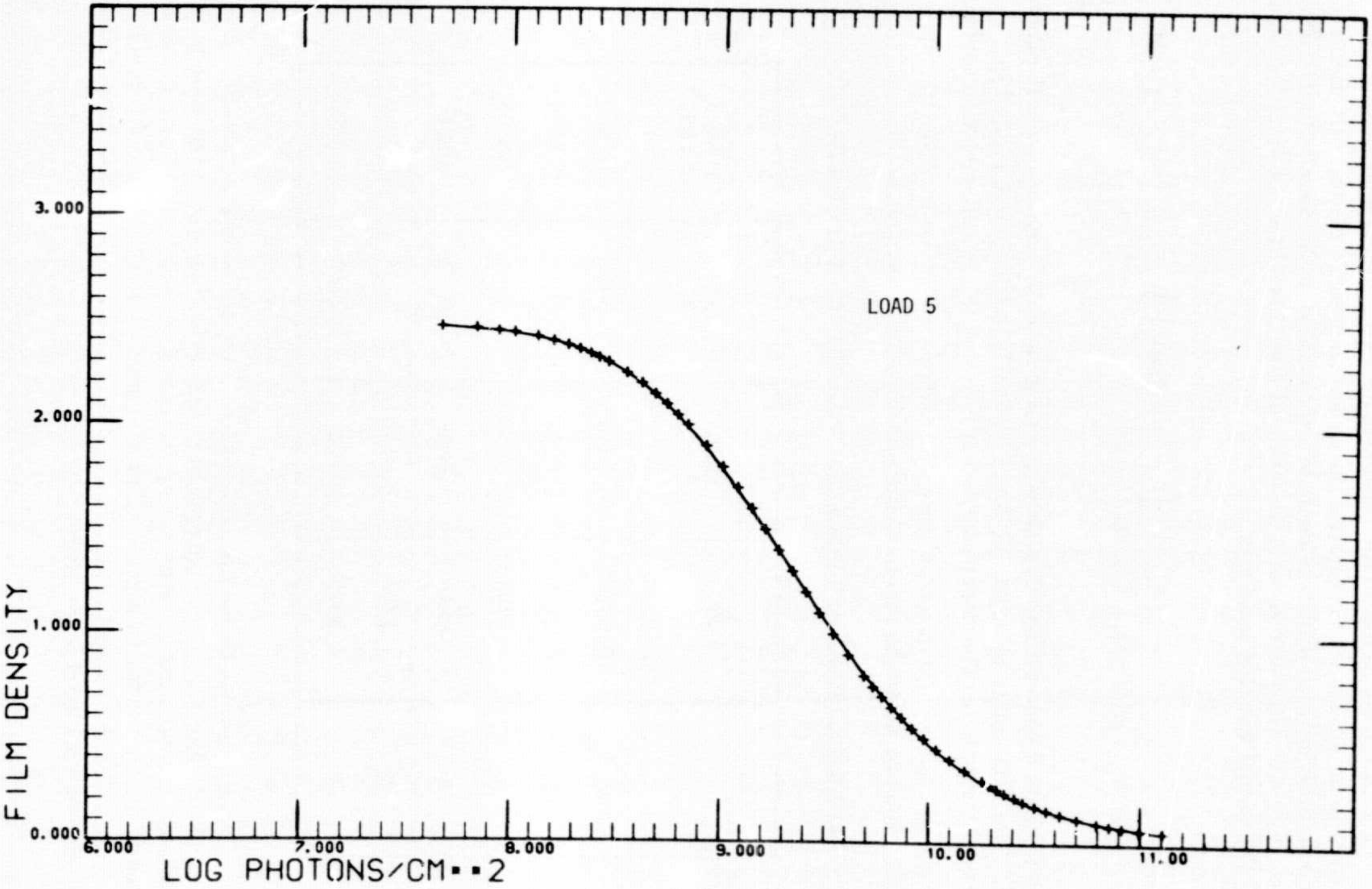


Figure 7. Characteristic curve, load 5 (color film).

In the analysis of the X-ray photographs, it is often useful to have an analytical form for the characteristic curve for each roll of film. An attempt was made to fit several different kinds of expressions to the sensitometric data; the best formula was found to be a variation of that given by Green and McPeters [9]. The actual function used was

$$\log E = \log E_o + N(D - D_1) + K \log\left[1 - 10^{-(D-D_1)}\right] - M \log\left[1 - 10^{-(D_u-D)}\right] ,$$

where D is the doubly diffuse film density and E is the X-ray exposure in photons cm^{-2}. The data points to which the function was fitted are those plotted in Figures 4 through 7. The parameters, $\log E_o$, D_1, D_u, N, K, and M, resulting from the nonlinear least-squares fitting techniques are given in Table 10. The fitted curves are shown as the solid lines in Figures 4 through 7.

TABLE 10. PARAMETERS FOR CHARACTERISTIC CURVE FITS

	LOAD 1	LOADS 2 & 3	LOAD 4	LOAD 5 (COLOR)
$\log E_o$	8.6410	8.3349	8.3063	10.0626
D_u	4.0122	3.6934	3.6996	2.4856
D_1	.2756	.3080	.4113	.0094
N	.4846	.6047	.6873	-.5611
K	1.1383	1.0632	.9787	-1.0959
M	.8515	2.1066	1.2374	-.6946

Certain commonly used parameters relating to the characteristic curves are listed in Table 11. These parameters include the background or base plus fog density, the contrast (gamma), and the speed of each load. For the black-and-white loads, the fog is highest on Load 4 which was exposed to the Skylab environment for the longest time. The speed is given according to three different definitions as explained in the table.

TABLE 11. CHARACTERISTIC CURVE PARAMETERS

	LOAD 1	LOADS 2 & 3	LOAD 4	LOAD 5 (COLOR)
Gamma	1.92	1.45	1.35	-1.53
Base + Fog Density	.29	.31	.41	2.48
Speed(0.1)	1.07(-8)	2.24(-8)	2.04(-8)	5.45(-9)
Speed(1.0)	8.15(-10)	1.31(-9)	1.17(-9)	5.99(-10)
Speed(B+F)	2.64(-9)	6.45(-9)	6.41(-9)	2.71(-9)

The speeds are defined as the reciprocal of the exposure in photons per square centimeter at the points:

(0.1) - on the curve at a density of 0.1 above* base plus fog,
(1.0) - on the curve at a density of 1.0 above* base plus fog,
(B+F) - at the intersection of the straight-line portion (extrapolated downward) with the base plus fog level.

* Below base plus fog for Load 5.

To simplify the transfer of the calibration results from the flight films to any copies that may be used, we have selected a "standard" sensitometry set for each load and have provided the appropriate exposure values in Table 12. Each standard set is a Sperry set, and its location may be found with the aid of Tables 2 through 6. The densities of the steps in each standard set may be measured in any system or by any device as long as the same system or device is used for the measurement of the solar images. Use of Table 12, thus, does not depend on any particular copy, in contrast to Tables 8 and 9 or Figures 4 through 7, which apply only to the flight films themselves.

All of the preceding data are given in units of photons per square centimeter for the X-ray exposure of the film, independent of the wavelength, as was discussed in Section III. A. Because the final absolute calibration was tied primarily to the aluminum (8.34 Å) exposures, the photon flux (photons/cm^2) can be converted to energy flux (ergs/cm^2) by simply multiplying each exposure value in photons by 2.382×10^{-9} (the number of ergs per photon at 8.34 Å).

TABLE 12. EXPOSURE VERSUS STEP NUMBER FOR STANDARD SENSITOMETRY SETS

STEP NO. FROM HIGH EXPOSURE END	EXPOSURE (photon cm^{-2})				
	LOAD 1 SET 106	LOAD 2 SET 047-I	LOAD 3 SET 048-I	LOAD 4 SET 256	LOAD 5 SET 253
	↑ HEADS	↑ TAILS	↑ TAILS	↑ TAILS	↑ HEADS
1	5.97(10)	3.05(10)	4.06(10)	3.31(11)	1.30(11)
2	2.99(10)	1.81(10)	2.10(10)	1.66(11)	6.49(10)
3	1.49(10)	8.99(9)	9.62(9)	8.28(10)	3.24(10)
4	7.46(9)	4.12(9)	4.79(9)	4.14(10)	1.62(10)
5	3.76(9)	2.15(9)	2.40(9)	2.07(10)	8.11(9)
6	1.81(9)	1.05(9)	1.15(9)	1.04(10)	4.06(9)
7	1.38(9)	7.38(8)	8.26(8)	4.97(9)	2.87(9)
8	9.29(8)	5.22(8)	5.89(8)	3.64(9)	1.97(9)
9	6.53(8)	3.76(8)	4.09(8)	2.50(9)	1.39(9)
10	4.65(8)	2.62(8)	2.91(8)	1.72(9)	9.93(8)
11	3.27(8)	1.85(8)	2.06(8)	1.22(9)	6.98(8)
12	2.32(8)	1.31(8)	1.46(8)	8.55(8)	4.97(8)
13	1.67(8)	9.40(7)	1.05(8)	6.08(8)	3.56(8)
14	1.16(8)	6.53(7)	7.31(7)	4.40(8)	2.48(8)
15	7.98(7)	4.49(7)	5.04(7)	3.10(8)	1.71(8)
16	5.81(7)	3.27(7)	3.66(7)	2.15(8)	1.24(8)
17	4.36(7)	2.92(7)	2.74(7)	1.57(8)	9.31(7)
18	2.90(7)	2.60(7)	1.83(7)	1.17(8)	6.21(7)
19	2.18(7)	1.22(7)	1.37(7)	7.82(7)	4.66(7)
20	1.45(7)	8.17(6)	9.14(6)	5.87(7)	3.10(7)
21	7.26(6)	4.08(6)	9.14(6)	3.91(7)	1.55(7)
22			4.57(6)	1.95(7)	
	↓ TAILS	↓ HEADS	↓ HEADS	↓ HEADS	↓ TAILS

VI. USE OF COPY FILMS

To avoid damage to the original flight film, it has not been used for scientific analyses except in a limited number of cases. Instead, copies have been produced for scientific analyses of the solar images and for submission to the National Space Science Data Center (NSSDC). The analyses include densitometry for quantitative work and the preparation of photographic prints.

The first attempts at copying the black-and-white film at JSC met with difficulty, primarily because of the large density range on the original (with densities up to almost 4.0). The copies, and the prints and transparencies made from them, showed only the features with intermediate exposure; the high and low intensity features were lost. Therefore, a series of tests of candidate copy materials and methods of development was undertaken at Aerospace. The desired properties were low contrast and a large exposure range. The film finally chosen for the second-generation copies of the black-and-white film (Loads 1 through 4) was Kodak Type 5235, a panchromatic separation film; these copies are positives and were made at Aerospace. Unfortunately, the film still could not be made to yield the required range of exposure in a single copy. Two different versions were made, a high-exposure copy for bright X-ray features and a low-exposure copy (with exposure approximately 4 stops less than that received by the high-exposure copy) for faint features. These two different exposure copies are therefore known as bright-feature and faint-feature versions. The two copies also differ in the contrast (γ) to which they were developed. The bright-feature copy was developed to $\gamma \approx 0.7$ so as not to saturate the high intensity areas, and the faint-feature copy was developed to $\gamma \approx 1.0$ to enhance the contrast of the faint features.

Many third-generation negative copies of Loads 1 through 4 have also been made, at Aerospace and JSC. These copies have been made on several films, including Kodak Types 5366, 5234, and 5235. They are not used for quantitative work but are very convenient for examination or any use where extremely careful handling is not required.

Black-and-white and color copies have been made of the color film (Load 5), primarily at JSC. Because the flight or first-generation film was a color-reversal film, the second generation black-and-white copies are negative copies. Again, bright-feature and faint-feature versions were made. The film was Kodak Type 2402, a Plus-X aerographic film with a panchromatic emulsion having extended red sensitivity. Third-generation positive copies were then made on Kodak Type 5366, a duplicating positive film. The third-generation copies were normally exposed copies of each of the bright-feature and faint-feature versions of the second-generation films.

In addition to the ordinary black-and-white copies of Load 5, color-separation copies were made by Technicolor. The second-generation color-separation copies are black-and-white negatives made on Kodak Type 5234, a duplicating panchromatic negative film. Three separate copies were made with cyan, yellow, and magenta filters. The primary reason for making the color-separation copies was to preserve the color information on the color film. Initially, it appeared that the densities on the original were changing; however, this problem has been alleviated with the storage of the original color film in a dry, refrigerated environment.

Color copies have also been made of Load 5. Second and third generation copies were made on Kodak Type 5389, an Ektachrome R color-reversal print film. Copies with a number of different exposures were made to show the entire range of exposures on the original.

The copies of each of the five loads that have been sent to NSSDC are black-and-white positives in the bright-feature and faint-feature versions. For Loads 1 through 4, they are second-generation copies; for Load 5, they are third-generation.

REFERENCES

1. Underwood, J. H.; Milligan, J. E.; deLoach, A. C.; and Hoover, R. B.: S056 X-Ray Telescope Experiment on the Skylab Apollo Telescope Mount. Applied Optics, vol. 16, 1977, pp. 858-869.

2. Haggerty, R.; Simon, R.; Golub, L.; Silk, J. K.; Timothy, A. F.; Krieger, A. S.; and Vaiana, G. S.: Soft X-Ray Imaging on Photographic Film. AAS Photo-Bulletin, no. 10, 1975, pp. 8-14.

3. Kodak Aerial Films and Photographic Plates. Eastman Kodak Co. Publication No. M-61, Rochester, New York, 1975.

4. Light, R. L., and Lollar, H. W.: Summary Report of Photographic Film Testing for ATM Experiment S-056. Technical Report No. SP-580-0501, Sperry Rand Corporation, Space Support Division, Huntsville, Alabama, 1971.

5. Underwood, J. H.: NASA Final Report on the Scientific and Technical Support for ATM Experiment S-056. Aerospace Report No. ATR-76(7405)-6, Aerospace Corporation, El Segundo, California, 1976.

6. Simon, R.; Haggerty, R.; Golub, L.; Krieger, A. S.; Silk, J. K.; Timothy, A. F.; and Vaiana, G. S.: Response of Photographic Film to Soft X-Ray Radiation. American Science and Engineering Report No. ASE-3775, Cambridge, Massachusetts.

7. Kodak Aerial Color Film (Estar Thin Base) SO-242, Kodak Aerial Color Film (Estar Ultra-Thin Base) SO-255. Eastman Kodak Co. Publication No. M-74, revision, Rochester, New York, 1973.

8. Clune, L. C.; Waite, W. F.; and Gordon, J. A.: Measurement of Soft X-Ray Photon Energies with Color Photographic Film. AAS Photo-Bulletin, no. 10, 1975, pp. 3-7.

9. Green, A. E. S., and McPeters, R. D.: New Analytic Expressions of Photographic Characteristic Curves. Applied Optics, vol. 14, 1975, pp. 271-272.

APPROVAL

FILM CALIBRATION FOR THE SKYLAB/ATM S-056 X-RAY TELESCOPE

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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