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MSFC SKYLAB APOLLO TELESCOPE MOUNT EXPERIMENT SYSTEMS MISSION EVALUATION

NASA

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

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16. ABSTRACT

This report presents a detailed evaluation of the Skylab Apollo Telescope Mount (ATM) experiments performance throughout the eight and one-half month Skylab Mission. Descriptions and the objectives of each instrument are included. Also included is a discussion of the anomalies experienced, the causes, and corrective actions taken. Conclusions, based on evaluation of the performance of each instrument, are presented. Examples of the scientific data obtained, as well as a discussion of the quality and quantity of the data, are presented. This report shows that the ATM instruments, individually larger and more complex than any previous instruments flown on satellites, surpassed all performance expectations. In many cases the instruments greatly exceeded their design operating life. The spatial resolution of each instrument was an order of magnitude better than any similar instrument flown on previous satellites. This report also shows that, as never before, it was possible to simultaneously collect multispectral data of specific solar phenomena. This report clearly demonstrates the major advantage of Man to point the instruments precisely at small targets and immediately react to unpredictable events. As a result of the data obtained by the ATM instruments, many theories of solar physics will undergo significant revisions.

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DEFINITION OF SYMBOLS

α	alpha
Å	angstrom
$\widehat{\text{min}}$	arc-minute
$\widehat{\text{sec}}$	arc-second
D_o	diameter
f/number	f stop number
L_λ	long wavelength
R_o	radii
S_λ	short wavelength
$\lambda/\Delta\lambda$	Spectral resolution (reference S054 Section V)

UNUSUAL TERMS

Manned	Mission periods beginning with the launch of crewmen and ending with CSM undocking.
Unmanned	Mission periods beginning with the crewmen undocking the CSM until the launch of the next crew.
Unattended	ATM experiment operation via ground command during a manned mission.
Attended	ATM experiment operation by the crew.

NON-STANDARD ABBREVIATIONS

AGC	automatic gain control
AM	Airlock Module
ATM	Apollo Telescope Mount
BB	building block
°C	degrees Celsius
C&D	control and display
CRT	cathode ray tube
CSM	Command and Service Module
dc	direct current
DOY	day of year
EVA	extravehicular activities
°F	degrees Fahrenheit
FRC	frames remaining counter
GMT	Greenwich Mean Time
H-alpha	hydrogen-alpha
IAS	internal alignment system
IU	Instrument Unit
JOP	joint observing program
MDA	Multiple Docking Adapter
Min	minute
MHz	megahertz
MRS	movable reticle system

NON-STANDARD ABBREVIATIONS (Continued)

NOAA	National Oceanic and Atmospheric Agency
OA	Orbital Assembly
OWS	Orbital Workshop
PDU	photomultiplier detector unit
PES	pointing error system
PHA	pulse-height analyzer
PI	Principal Investigator
PRS	pointing reference system
pwr	power
sec	second
SAA	South Atlantic Anomaly
SWS	Saturn Workshop
TCS	thermal control system
TV	television
UV	ultraviolet
Vdc	volts direct current
X-REA	X-ray event analyzer
XUV	extreme ultraviolet
ZM	zoom

TECHNICAL MEMORANDUM X-64821

MSFC SKYLAB APOLLO TELESCOPE MOUNT EXPERIMENT SYSTEMS MISSION EVALUATION REPORT

SECTION I. SUMMARY

The ATM experiment instruments consisted of a White Light Coronagraph (S052), an X-Ray Spectrographic Telescope (S054), an Ultraviolet (UV) Scanning Polychromator Spectroheliometer (S055A), an X-Ray Telescope (S056), an Extreme Ultraviolet (XUV) Spectroheliograph (S082A), a Spectrograph and XUV Monitor (S082B), and two Hydrogen-Alpha Telescopes (H-Alpha 1 and H-Alpha 2).

The ATM instruments exhibited outstanding performance throughout the entire Skylab mission. No major hardware problems occurred which significantly impacted the operation of a single instrument. The outstanding performance of the instruments was substantiated by comments from the Principal Investigators (PI) regarding the excellent quality of the scientific data returned. Resolutions approximating one arc-second were attained on much of the solar imagery.

Operation of the instruments was initiated following activation of the control and display (C&D) console by the Skylab 2 crew at 146:18:05 Greenwich Mean Time (GMT) 1973. The instruments obtained scientific data during scheduled operating periods covering a time span of approximately 8.5 months. Final ATM instrument operation terminated by ground command at 039:08:07 (GMT) 1974. All of the instruments were still operational at the conclusion of the Skylab mission although their design life had been exceeded.

The instruments obtained photographs of the solar disk, corona, and solar features of interest in various wavelengths on more than 93 percent of the total film available for the Skylab mission. In addition to solar observations, the instruments collected high-quality data on the mercurian atmosphere, Earth-Moon Lagrangian points, the Earth's atmosphere, and during Skylab 4, on Comet Kohoutek. The number of photographs obtained exceeded premission goals by more than 23,000, because opportunity through the mission allowed extra cameras or magazines to be supplied for all instruments except S082B. More than 2,000 hours of photoelectric data were transmitted real-time or recorded onboard for subsequent transmission. Table 1 is a tabulation of the quantity of scientific data

obtained by the ATM instruments during the Skylab mission.

TABLE 1. QUANTITY OF SKYLAB MISSION ATM SCIENTIFIC DATA

Experiment	Frames Available Per Load (1)	Frames Exposed			
		Skylab 2	Skylab 3 (2)	Skylab 4 (2)	Total
S052	8,025	4,381 (3)	15,735	15,802	35,918
S054	6,970	5,155 (4)	13,325	13,305	31,785
S056	6,000	4,184	11,493	12,098	27,775
S082A	201	220 (5)	402	402	1,024
S082B	1,608	1,608	3,195	1,608	6,411
H-Alpha 1	15,400	12,998	30,787	24,400 (6)	68,185
Total	38,204	28,546	74,937	67,615	171,098
S055A HOURS OF PHOTOELECTRIC DATA		153 hrs	772 hrs	1,368 hrs	2,292 hrs

(1) Except for S082A and S082B, the frames available varied slightly with the amount of film in each load.

(2) For Skylab 3, two film loads were used in each instrument. For Skylab 4, two film loads were used in each instrument except S082B, which used only one film load.

(3) The film transport mechanism in the Skylab 2 film camera jammed. See Section IV.

(4) Data from approximately 1,500 additional frames were lost due to the thermal shield door having failed closed. See Section V.

(5) The second film camera was used after the first malfunctioned. See Section VIII.

(6) The second Skylab 4 film load transport mechanism became intermittent. See Section X.

The video-taped and real-time televised images of the Sun in UV, H-alpha, and whitelight spectra were satisfactory. Based on the results of Skylab 2 improvements were initiated for Skylab 3 and 4. These improvements included the use of a Polaroid camera. During Skylab 3 crew debriefing, the crew pointed out the usefulness of pictures taken with the Polaroid camera. An average of five pictures per day were taken and used in place of sketches for reference in solar observance. During the mission, a program of close coordination between the crew and PIs materialized. This resulted in an ability to conduct instrument operations in a manner to maximize data collection of greater scientific value throughout Skylab 3 and 4. The extensive duration of the Skylab 4 mission

(84 days) allowed the crew to fully exploit the flexibility of the ATM instruments.

The ATM instruments were operated in accordance with Joint Observing Programs (JOPs) defined by the PIs for each mission. The JOPs were scheduled by the PIs on a daily basis during the mission, based on existing solar activity. The four basic objectives used to develop the JOPs were to:

1. Define a set of problems to be solved on ATM as an observatory, as opposed to eight individual instruments.

2. Write the JOPs so that all operating instruments were working on the same scientific objective at the same time.

3. Define the JOPs so that maximum utilization of ground based observatories could be made.

4. Provide maximum capability for the PI to make real-time changes in order to optimize his data return.

This approach was achieved and proved highly efficient and successful during orbital operations. The JOPs, related objectives, and planning guidelines are identified in the Mission Requirements Document (I-MRD-001).

It was concluded from mission experience that the extent of solar observation was unprecedented, instrument design and ATM interface support was adequate, and mission management, problem solving, and crew participation assured mission success.

Recommendations suggest that data delivery capability be increased, methods for easier maintainability be incorporated; and computer, instrument, and control panel modifications be made to increase scientific data return and simplify manned operation.

SECTION II. INTRODUCTION

Report Synopsis

This report contains a detailed evaluation of the Skylab ATM Experiment Systems. It includes a description of the flight hardware and an evaluation of instrument performance, including instrument interfaces, both instrument/spacecraft and man/machine. The quantity and quality of the scientific data obtained by each instrument is described. The description, rationale for development, and effectiveness of the JOPs are presented. Anomalies that occurred during the mission are discussed in depth. The evaluation resulted in a set of conclusions and recommendations which are contained in Section XI. This report does not convey scientific findings or accomplishments. Reports published by each PI address the scientific accomplishments of the ATM solar observing instruments. A listing of the technical memorandums pertaining to the evaluation of the Skylab mission and other individual Skylab systems is included under References.

Mission Profile

The Skylab mission profile is presented in figure 1. The Skylab mission began on 14 May 1973 with the launch of Skylab 1 and ended on 8 February 1974 with the undocking of the Skylab 4 Command and Service Module (CSM). The unmanned Skylab 1 two-stage Saturn V vehicle lifted off from Launch Complex 39 Pad A at the NASA Kennedy Space Center, Cape Kennedy, Florida. The launch configuration consisted of a Saturn-IC first stage, Saturn II second stage and the payload. The payload elements were an Apollo Telescope Mount (ATM), Multiple Docking Adapter (MDA), Airlock Module (AM), Instrument Unit (IU), Orbital Workshop (OWS), and Payload Shroud. The unmanned payload was placed in a nominal 435 kilometer near-circular orbit, inclined 50 degrees to the Equator.

At approximately 63 seconds into the Skylab 1 boost phase, an anomaly occurred which resulted in the loss of the meteoroid shield around the OWS. The meteoroid shield was designed to protect the OWS against micrometeoroid penetration and also served as a thermal insulator. The meteoroid shield loss resulted in the partial deployment of the OWS solar array wings. Wing number 2 subsequently separated from the OWS, apparently when the exhaust plume of the Saturn II stage retrorockets impacted the partially deployed wing. OWS solar array wing number 1 failed to deploy on command because the wing was restrained by debris from the meteoroid

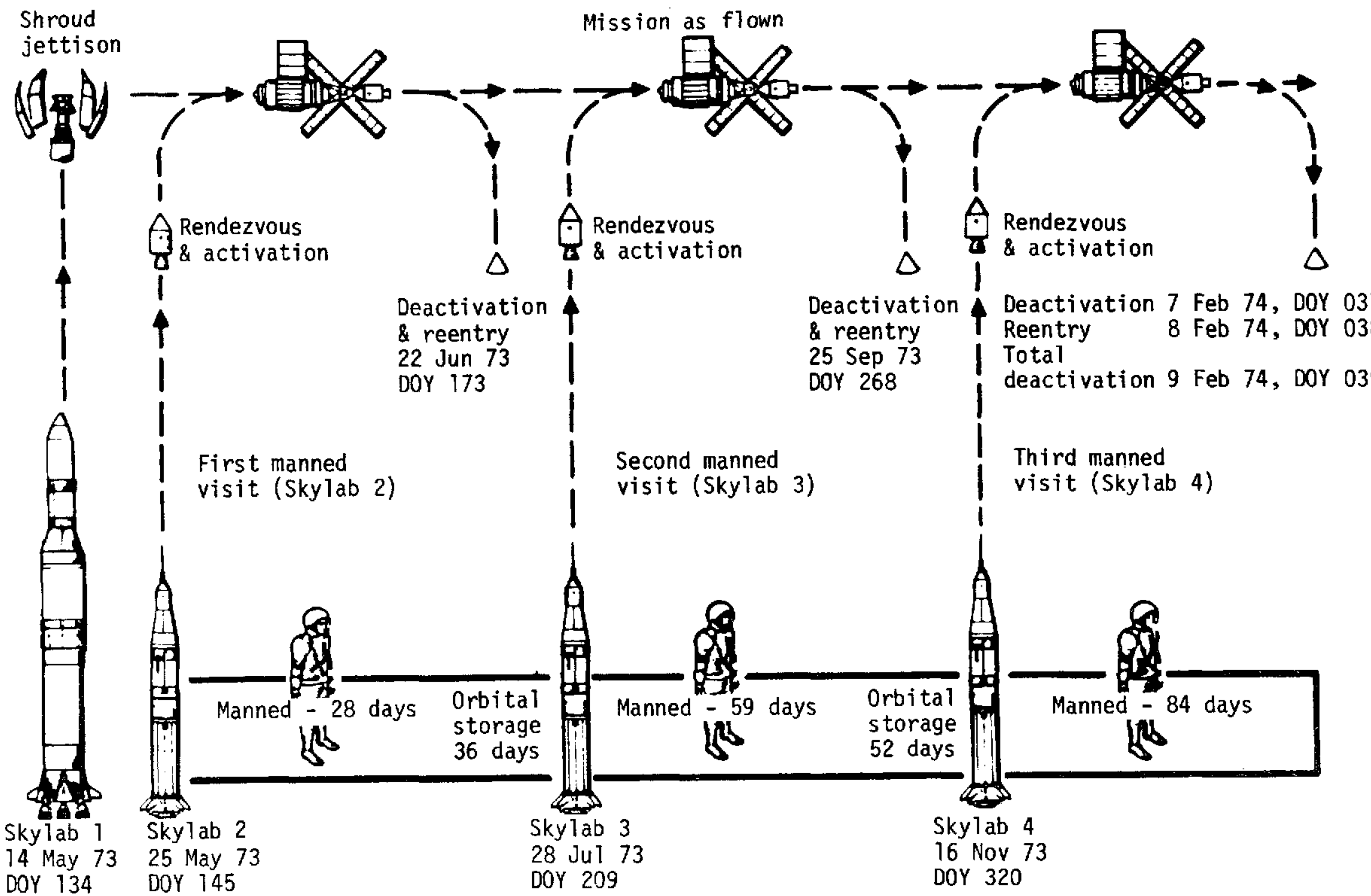


FIGURE 1. SKYLAB MISSION PROFILE

shield and jammed at an approximately 10-percent deployed position.

The ATM and the ATM solar wings deployed normally. The ATM electrical power system provided the only source of electrical power to the OWS because the OWS electrical power supply system was inoperative. Loss of the meteoroid shield resulted in high internal temperatures in the OWS due to direct solar radiation on the workshop wall. Off-normal vehicle attitudes were necessary to maintain safe OWS temperatures. The attitude selected, after initial maneuvering, was a compromise providing partial ATM solar array line-of-sight pointing to the Sun, and acceptable OWS internal temperatures. This attitude was maintained until the Skylab 2 crew deployed a thermal parasol to shade the OWS. The vehicle was then maneuvered to the solar inertial attitude. More power was then available from the ATM electrical power system, and ATM experiment operations began. Later, the partially deployed OWS solar array wing number 1 was fully deployed by the crew during extravehicular activities (EVA). The OWS electrical power system was activated, providing sufficient additional power for all systems to be activated, and assuring continuation of the mission.

The problems that occurred during the launch of Skylab 1 resulted in a delay of the manned Skylab 2 launch from 15 May until 25 May. The Skylab 2 launch vehicle consisted of a Saturn IB stage and a Saturn IVB stage, with the CSM as its payload. A mission day time reference is provided in Table 2.

ATM Module

The ATM module was designed to accommodate eight solar astronomy instruments, provide Saturn Workshop (SWS) or Orbital Assembly (OA) attitude control, and a portion of SWS or OA electrical power. It consisted of a rack, an instrument canister, a solar array, a C&D console, and supporting subsystems. The ATM is illustrated in figure 2.

The ATM structure was designed as a rack and canister. The rack was an octagonal truss-type structure supporting the canister and support equipment. The rack was approximately 3.35 meters across and 3.66 meters high, with a 4.37 meter diameter solar shield at the Sun-end to protect the electronic components from the Sun's direct radiation. The rack was designed to accommodate the instrument canister internally with external attachment points

TABLE 2. SKYLAB MISSION DAY TIME REFERENCE

DAY	DATE (1973)	DOY	MISSION PERIODS
1	5-14	134	(FIRST UNMANNED PERIOD)
2	5-15	135	
3	5-16	136	
4	5-17	137	
5	5-18	138	
6	5-19	139	
7	5-20	140	
8	5-21	141	
9	5-22	142	
10	5-23	143	
11	5-24	144	
12	5-25	145	FIRST MANNED PERIOD MISSION DAYS 1
13	5-26	146	2
14	5-27	147	3
15	5-28	148	4
16	5-29	149	5
17	5-30	150	6
18	5-31	151	7
19	6-1	152	8
20	6-2	153	9
21	6-3	154	10
22	6-4	155	11
23	6-5	156	12
24	6-6	157	13
25	6-7	158	14
26	6-8	159	15
27	6-9	160	16
28	6-10	161	17
29	6-11	162	18
30	6-12	163	19
31	6-13	164	20
32	6-14	165	21
33	6-15	166	22
34	6-16	167	23
35	6-17	168	24
36	6-18	169	25
37	6-19	170	26
38	6-20	171	27
39	6-21	172	28
40	6-22	173	29
41	6-23	174	(SECOND UNMANNED PERIOD)
42	6-24	175	
43	6-25	176	
44	6-26	177	
45	6-27	178	
46	6-28	179	
47	6-29	180	
48	6-30	181	
49	7-1	182	
50	7-2	183	
51	7-3	184	
52	7-4	185	
53	7-5	186	
54	7-6	187	
55	7-7	188	
56	7-8	189	
57	7-9	190	
58	7-10	191	
59	7-11	192	
60	7-12	193	
61	7-13	194	
62	7-14	195	
63	7-15	196	
64	7-16	197	
65	7-17	198	
66	7-18	199	
67	7-19	200	
68	7-20	201	
69	7-21	202	

DAY	DATE (1973)	DOY	MISSION PERIODS
70	7-22	203	
71	7-23	204	
72	7-24	205	
73	7-25	206	
74	7-26	207	
75	7-27	208	
76	7-28	209	SECOND MANNED PERIOD MISSION DAYS 1
77	7-29	210	2
78	7-30	211	3
79	7-31	212	4
80	8-1	213	5
81	8-2	214	6
82	8-3	215	7
83	8-4	216	8
84	8-5	217	9
85	8-6	218	10
86	8-7	219	11
87	8-8	220	12
88	8-9	221	13
89	8-10	222	14
90	8-11	223	15
91	8-12	224	16
92	8-13	225	17
93	8-14	226	18
94	8-15	227	19
95	8-16	228	20
96	8-17	229	21
97	8-18	230	22
98	8-19	231	23
99	8-20	232	24
100	8-21	233	25
101	8-22	234	26
102	8-23	235	27
103	8-24	236	28
104	8-25	237	29
105	8-26	238	30
106	8-27	239	31
107	8-28	240	32
108	8-29	241	33
109	8-30	242	34
110	8-31	243	35
111	9-1	244	36
112	9-2	245	37
113	9-3	246	38
114	9-4	247	39
115	9-5	248	40
116	9-6	249	41
117	9-7	250	42
118	9-8	251	43
119	9-9	252	44
120	9-10	253	45
121	9-11	254	46
122	9-12	255	47
123	9-13	256	48
124	9-14	257	49
125	9-15	258	50
126	9-16	259	51
127	9-17	260	52
128	9-18	261	53
129	9-19	262	54
130	9-20	263	55
131	9-21	264	56
132	9-22	265	57
133	9-23	266	58
134	9-24	267	59
135	9-25	268	60
136	9-26	269	
137	9-27	270	

DAY	DATE (1973)	DOY	MISSION PERIODS
138	9-28	271	(THIRD UNMANNED PERIOD)
139	9-29	272	
140	9-30	273	
141	10-1	274	
142	10-2	275	
143	10-3	276	
144	10-4	277	
145	10-5	278	
146	10-6	279	
147	10-7	280	
148	10-8	281	
149	10-9	282	
150	10-10	283	
151	10-11	284	
152	10-12	285	
153	10-13	286	
154	10-14	287	
155	10-15	288	
156	10-16	289	
157	10-17	290	
158	10-18	291	
159	10-19	292	
160	10-20	293	
161	10-21	294	
162	10-22	295	
163	10-23	296	
164	10-24	297	
165	10-25	298	
166	10-26	299	
167	10-27	300	
168	10-28	301	
169	10-29	302	
170	10-30	303	
171	10-31	304	
172	11-1	305	
173	11-2	306	
174	11-3	307	
175	11-4	308	
176	11-5	309	
177	11-6	310	
178	11-7	311	
179	11-8	312	
180	11-9	313	
181	11-10	314	
182	11-11	315	
183	11-12	316	
184	11-13	317	
185	11-14	318	
186	11-15	319	
187	11-16	320	THIRD MANNED PERIOD MISSION DAYS 1
188	11-17	321	2
189	11-18	322	3
190	11-19	323	4
191	11-20	324	5
192	11-21	325	6
193	11-22	326	7
194	11-23	327	8
195	11-24	328	9
196	11-25	329	10
197	11-26	330	11
198	11-27	331	12
199	11-28	332	13
200	11-29	333	14
201	11-30	334	15
202	12-1	335	16
203	12-2	336	17
204	12-3	337	18
205	12-4	338	19

DAY	DATE (1973-74)	DOY	MISSION PERIODS
206	12-5	339	THIRD MANNED PERIOD MISSION DAYS (CONTINUED) 20
207	12-6	340	21
208	12-7	341	22
209	12-8	342	23
210	12-9	343	24
211	12-10	344	25
212	12-11	345	26
213	12-12	346	27
214	12-13	347	28
215	12-14	348	29
216	12-15	349	30
217	12-16	350	31
218	12-17	351	32
219	12-18	352	33
220	12-19	353	34
221	12-20	354	35
222	12-21	355	36
223	12-22	356	37
224	12-23	357	38
225	12-24	358	39
226	12-25	359	40
227	12-26	360	41
228	12-27	361	42
229	12-28	362	43
230	12-29	363	44
231	12-30	364	45
232	12-31	365	46
233	1-1	1	47
234	1-2	2	48
235	1-3	3	49
236	1-4	4	50
237	1-5	5	51
238	1-6	6	52
239	1-7	7	53
240	1-8	8	54
241	1-9	9	55
242	1-10	10	56
243	1-11	11	57
244	1-12	12	58
245	1-13	13	59
246	1-14	14	60
247	1-15	15	61
248	1-16	16	62
249	1-17	17	63
250	1-18	18	64
251	1-19	19	65
252	1-20	20	66
253	1-21	21	67
254	1-22	22	68
255	1-23	23	69
256	1-24	24	70
257	1-25	25	71
258	1-26	26	72
259	1-27	27	73
260	1-28	28	74
261	1-29	29	75
262	1-30	30	76
263	1-31	31	77
264	2-1	32	78
265	2-2	33	79
266	2-3	34	80
267	2-4	35	81
268	2-5	36	82
269	2-6	37	83
270	2-7	38	84
271	2-8	39	85
TESTS & ORBITAL STORAGE			
272	2-9	40	
273	2-10	41	

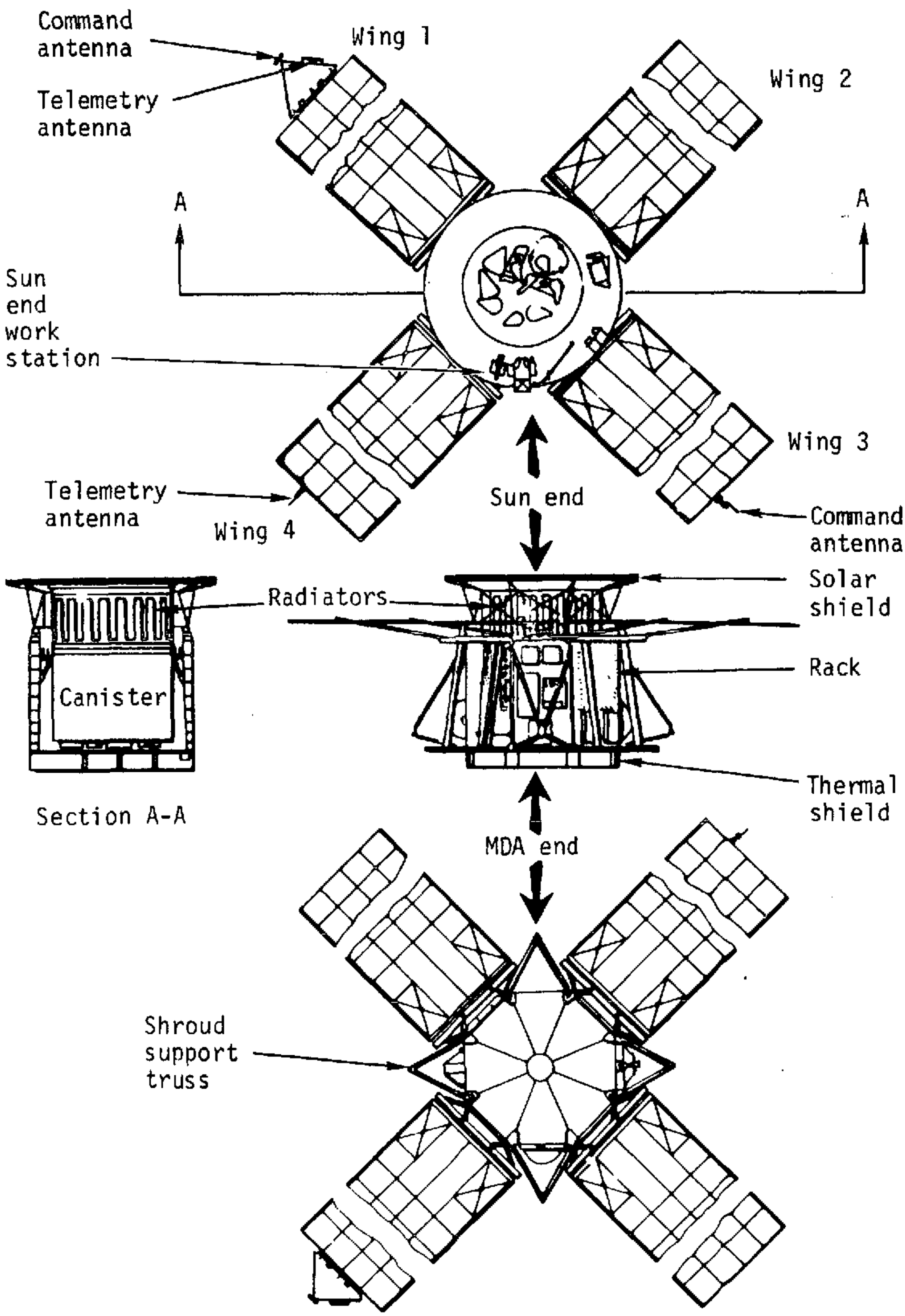


FIGURE 2. ATM GENERAL ARRANGEMENT

for the solar array, deployment assembly, and the ATM subsystem equipment. The instrument canister was a cylinder approximately 2.13 meters in diameter, 3.30 meters long, and closed at both ends except for the solar instrument viewing and film retrieval doors. The canister incorporated an internal cruciform spar to provide mounting points for the eight instruments. The canister was attached to the rack by means of flex-pivot gimbal rings and a roll ring. The roll ring was supported by rollers mounted on the rack, permitting canister rotation. The active thermal control system (TCS) equipment was mounted externally on the lateral wall of the MDA end.

The ATM solar array consisted of four wings covered with solar cells, and the mechanism to deploy them in orbit. The wings were attached to the Sun-end of the rack and spanned approximately 31 meters to provide power to the cluster.

The C&D console was located within the MDA and provided the crew interface with the ATM instruments and subsystems.

ATM Instruments

The ATM instruments consisted of a White Light Coronagraph (S052), an X-Ray Spectrographic Telescope (S054), a UV Scanning Polychromator Spectroheliometer (S055A), an X-Ray Telescope (S056), an XUV Spectroheliograph (S082A), a Spectrograph and XUV Monitor (S082B), and two Hydrogen-Alpha Telescopes (H-Alpha 1 and H-Alpha 2). The instruments were mounted in the ATM canister as shown in figure 3. The instruments were designed to provide high resolution solar data in the spectral range from 2 to 7000 angstroms. A summary of the individual instrument spectral ranges is included in figure 4.

The PIs and their affiliations are Dr. R. MacQueen of the High Altitude Observatory, Boulder, Colorado (S052), Dr. G. S. Vaiana of American Science and Engineering, Cambridge, Massachusetts (S054), Dr. E. Reeves of the Harvard College Observatory, Cambridge, Massachusetts (S055A), Mr. J. Milligan of Marshall Space Flight Center, Huntsville, Alabama (S056), and Dr. R. Tousey of the Naval Research Laboratory, Washington, D. C. (S082A and S082B). The H-alpha 1 and 2 telescopes were supportive instruments. Dr. E. Reeves of the Harvard College Observatory was the scientific interface concerning all matters pertaining to H-alpha instrumentation and utilization.

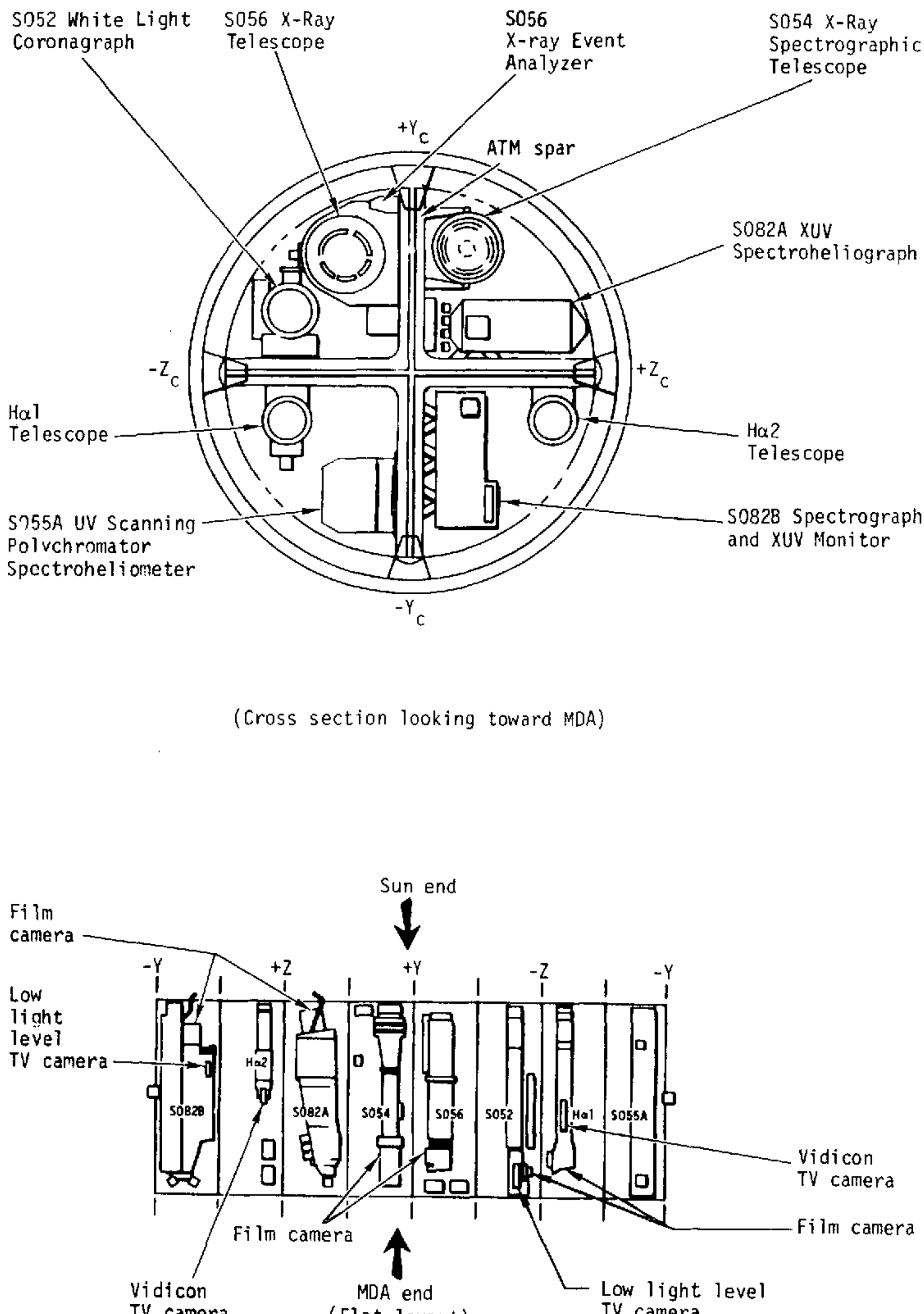
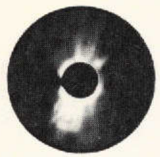
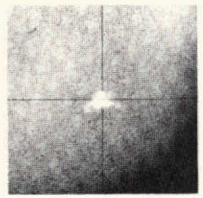
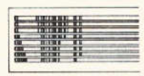
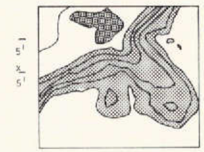
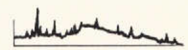
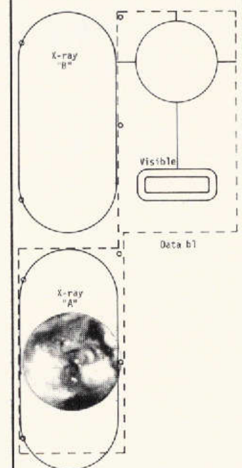
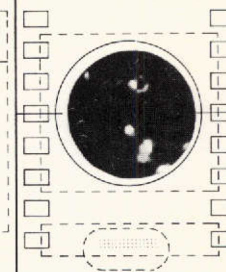


FIGURE 3. ATM INSTRUMENTS ARRANGEMENT

	S052 WLC	Hα1 & 2	S082B XUV slit	S055 Scan spect	S082A XUV spect	S054 X-ray spect	S056 X-ray tele
Primary objective	Observations of solar corona	Provide and record ATM pointing	Record line spectra of chromosphere	Observations of chromosphere and lower corona	XUV images of chromosphere and lower corona	X-ray images and spectra of lower corona	X-ray images of lower corona
Prime scientific data	 Photographic	 Hα 1 only photographic	 Data sample (3 per film strip)  Film format Photographic	 Typical of 7 simultaneous raster spectroheliograms  Line spectra Photoelectric	 Photographic	 Photographic	 Photographic
Available film	8,025 Frames/camera 5 cameras	15,400 Frames/magazine 5 magazines	1,608 Frames/camera 4 cameras	Data recorded on ATM tape recorder and telemetered to ground	201 Frames/camera 6 cameras	6,970 Frames/magazine 5 magazines	6,000 frames/magazine 5 magazines
Field of view	Film 1.5 to 5 D☉ (48 to 192 $\widehat{min}$) TV 1.5 to 4.5 D☉ (48 to 144 $\widehat{min}$)	Hα 1 Film - 35 $\widehat{min}$ TV: Zm (4.5 $\widehat{min}$-16 $\widehat{min}$) Hα 2 Zm (7 $\widehat{min}$-35 $\widehat{min}$)	2 $\widehat{sec}$ by 60 $\widehat{sec}$	5 $\widehat{min}$ by 5.5 $\widehat{min}$ (mirror raster scan) 5 $\widehat{min}$ by 5 $\widehat{sec}$ (mirror line scan) 5 $\widehat{sec}$ by 5 $\widehat{sec}$ (mirror fixed pos) 	56 $\widehat{min}$	48 $\widehat{min}$	40 $\widehat{min}$
Spatial resolution	8 $\widehat{sec}$	1 $\widehat{sec}$ (Film) 1.5 $\widehat{sec}$ (TV zoom in)	≈3 $\widehat{sec}$	5 $\widehat{sec}$	5 $\widehat{sec}$	3 $\widehat{sec}$	2.5 $\widehat{sec}$
Spectral resolution	—	0.7Å	0.06Å - short wavelength 0.12Å - long (design limits)	1.2Å	0.13Å for 10 $\widehat{sec}$ feature	λ/Δλ=30 at 7Å	2.5Å
Additional scientific data	—	—	XUV monitor (TV only)	Intensity data display	—	Hard x-ray TM data (pulse height analyzer)	X-rea data

Wavelength response in angstroms

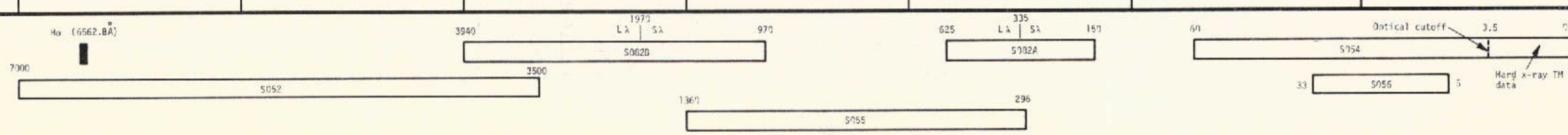


FIGURE 4. ATM INSTRUMENTS INTEGRATED SUMMARY

SECTION III. JOINT OBSERVING PROGRAMS

Development

Initially, each of the ATM instruments had a unique set of scientific objectives, individually determined by each respective PI. The ATM instruments were designed to operate independently to achieve these objectives. When the Skylab program reached the preliminary flight planning stage, it was determined that there was not enough crew time available to satisfy the individual scientific objectives for each of the ATM instruments. Also, the concept of individual instrument operations presented a monumental crew-training task. It became obvious that the common interfaces including power, pointing, contamination management, and target selection required a more efficient technique of utilizing ATM viewing time. Therefore, the Joint Observing Program (JOP) was developed. A JOP was a program which allowed the ATM instruments to jointly observe selected phenomena and defined the related objectives, expected scientific achievements, pointing, and instrument participation. Major scientific investigations for the ATM, as an integral solar observatory, were defined and a JOP was developed for each major scientific investigation. The JOP included a set of scientific objectives, an overall scheme as to how the data was to be obtained, the selection of the instruments to be used, the ATM pointing required, and the operational modes of the instruments. The individual instrument operations were integrated into a single observing program. The JOPs developed for the Skylab mission are listed in Table 3. JOPs 1 through 14 were developed for the Skylab 2 mission. Skylab 2 data analysis and crew comments resulted in the generation of JOPs 15 through 17 for the Skylab 3 mission. Similarly, Skylab 3 data, crew comments, and the arrival of Comet Kohoutek resulted in JOPs 18 through 27 being added for the Skylab 4 mission.

Implementation

The individual instrument operations to be performed in accomplishing the JOPs were defined and identified as building blocks. The JOPs listed consisted of various combinations and multiples of the related building blocks. The approach allowed a great deal of flexibility in selecting the data acquisition method for a particular investigation. The three building blocks that were used to perform JOP 15C, Evolution of a Coronal Hole, are shown in figure 5. To perform the JOP, two of the three building blocks were used. A JOP/building block matrix is included in Table 4. The instruments

TABLE 3. JOINT OBSERVING PROGRAMS (1)

JOP NO.	TITLE
1	CHROMOSPHERIC NETWORK AND ITS CORONAL EXTENSION
2	ACTIVE REGIONS
3	FLARES
4	PROMINENCES AND FILAMENTS
5	LIMB PROFILE STUDIES
6	SYNOPTIC OBSERVATIONS OF THE SUN
7	ATMOSPHERIC EXTINCTION
8	CORONAL TRANSIENTS AND DISK TRANSIENTS
9	SOLAR WIND
10	LUNAR LIBRATION CLOUDS
11	CHROMOSPHERIC OSCILLATIONS AND HEATING
12	PROGRAM CALIBRATION
13	OBSERVATIONS OF NIGHT SKY OBJECTS
14	SOLAR ECLIPSE
15	CORONAL HOLES
16	DISK TRANSIENTS
17	CORONAL BRIGHT SPOTS
18	COMET KOHOUTEK
19	ALFVEN WAVES IN THE CORONA
20	RAPIDLY CHANGING CORONAL STRUCTURES
21	TIME VARIATIONS IN CORONAL STRUCTURES

(1) The purpose, background, scientific objectives and scheduling guidelines for each of the JOPs are identified in the Mission Requirements Document (I-MRD-001).

TABLE 3. JOINT OBSERVING PROGRAMS (Continued)

JOP NO.	TITLE
22	RADIO OCCULTATION
23	MERCURY TRANSIT
24	LATITUDE VARIATION OF CHROMOSPHERIC STRUCTURE
25	S055A MAXI RASTER AND SUPER RASTER
26	CORONAL STRUCTURES
27	VELOCITIES

TABLE 4. ATM BUILDING BLOCK USAGE SUMMARY

ATM JOP NO.	BUILDING BLOCKS																																						
	1		3		5		7		9		11		13		15		17		19		21		23		25		27		29		31		33		35		37		39
1							X			X	X							X	X								X	X					X				X		
2				X	X		X			X	X		X	X									X					X								X	X	X	
3								X	X															X															
4		X									X			X														X					X			X	X		
5						X							X										X						X										X
6	X	X																										X				X							
7															X																								
8		X								X							X								X							X							
9		X	X																									X											
10			X																																				
11		X								X		X						X																					
12		X				X				X						X					X	X				X		X											
13																				X																			
14		X																													X								
15		X	X							X	X		X										X					X					X			X	X		
16																																							
17										X	X																						X			X	Y		
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27										X									X																				

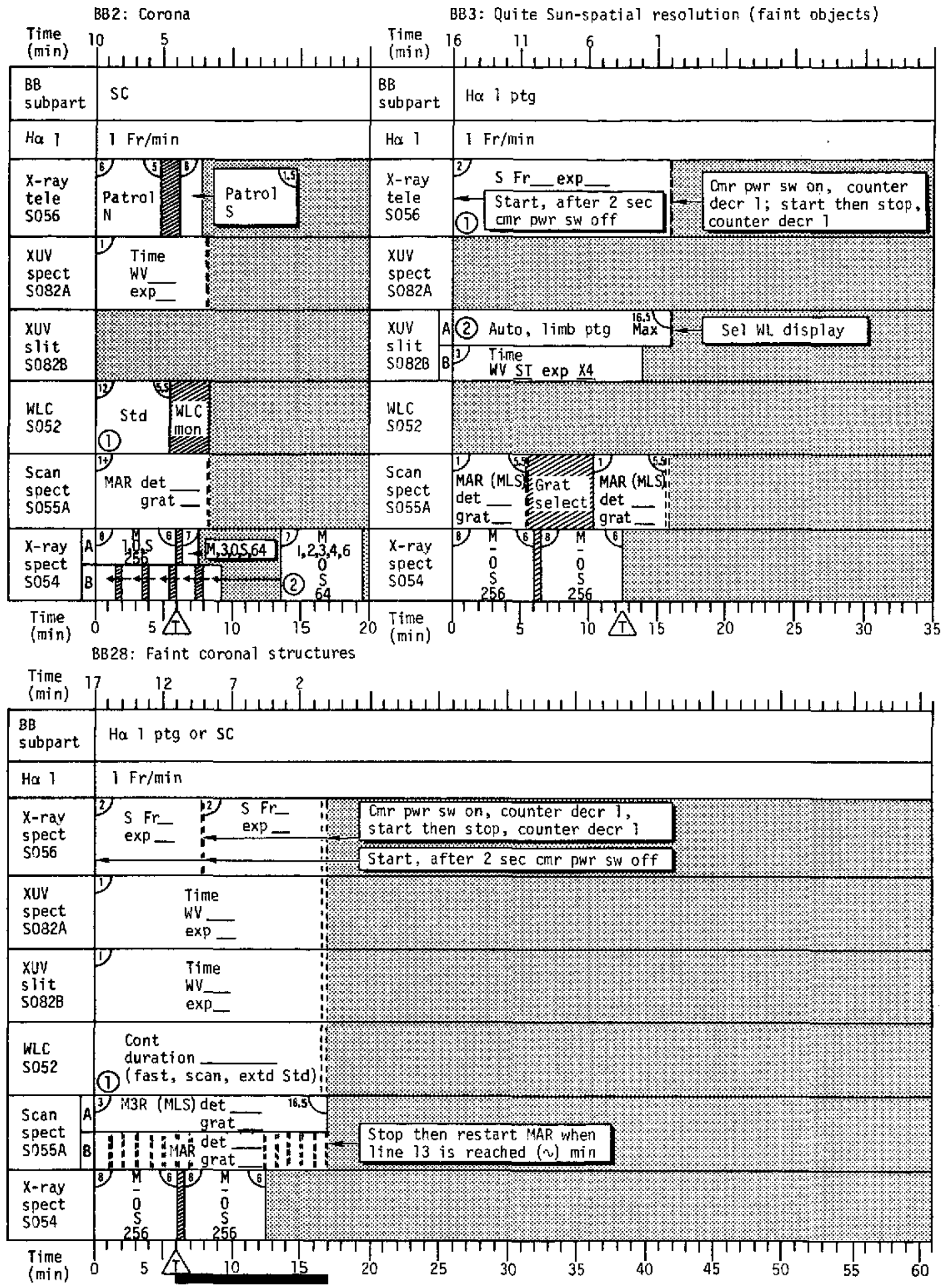


FIGURE 5. BUILDING BLOCK (BB) EXAMPLE

were listed in the left most column. The remaining abbreviated nomenclature described for the crew the exact manner in which the individual instruments were to be operated. In most cases, the building blocks contained some blank instructions. The blanks were filled in when an ATM schedule message was uplinked to the crew via the teleprinter. An example of a typical ATM schedule message for two orbits of operations is presented in figure 6. The message contained a starting time in GMT, the JOP to be performed plus the specific scientific objective in parentheses, and the sequence of building blocks to execute. The

ATM SCHEDULE

STRT	JOP	BB	TGT	COMMENTS
1148	2A (1)	4A	09	OMIT 82A, 54 55 MAR DET ALL GRAT 0766
		4B	09	OMIT 56, 82B, 54
		4C	09	OMIT 56, 82B, 54
		4D	09	OMIT 82B, 54
		4D	09	OMIT 82B, 54
1313	6 (1)	1A	SC	82A EXP 2:40 EXP 0:10 55A MAR DET 123465 GRAT 2436
		18	SC	RL + 5400 OMIT 82A
12	2. (7)	10	09	OMIT 56, 82A, 54 82B EXP 0:10 EXP 0:40 55 MAR DET ALL GRAT 0000

FIGURE 6. ATM SCHEDULE MESSAGE FORMAT EXAMPLE

comments column completed the building block instrument operational instructions and contained all other appropriate comments. The pointing coordinates for the various targets were uplinked to the crew in a separate message entitled solar activity pad. The ATM schedule message and solar activity pad were developed by the ATM planning group. The group consisted of representatives from each PI organization, National Oceanic and Atmospheric Agency (NOAA), and Flight Operations. The message contents were based upon ATM viewing time scheduled, the NOAA solar forecasts, downlinked television (TV) transmission, and crew comments on their observations. Deviations from the planned schedule were implemented, with coordination between the crew and ground support personnel, for reacting to unexpected solar activities.

The uplinked messages combined with the ATM JOP Summary Sheets and the ATM Experiment Reference Book, which were a part of the onboard Flight Data File documentation, provided the crew with the objectives and detailed procedures for operating each of the ATM instruments. The extensive premission crew training, which applied this approach, resulted in a highly efficient utilization of the manned ATM viewing time. There were additional building blocks used during unmanned and unattended mission phases.

Accomplishments

Skylab 2. Scientific data were obtained on 11 of the 12 JOPs planned for Skylab 2. The following four JOPs were completely accomplished.

1. JOP 6 - Synoptic Observations

2. JOP 9 - Solar Wind

3. JOP 10 - Lunar Libration Clouds

4. JOP 11 - Chromospheric Oscillations

The remaining JOPs, except JOP 13, were not fully completed due to the limited number of solar phenomena occurrences, insufficient total observing time, the large number of partial cycles (29), and the lack of proper cycle sequences. A full cycle is defined as the portion of an orbit that the spacecraft line-of-sight (Sun vector) to the Sun is 400 km above the Earth's horizon for a minimum of 49 minutes. A viewing cycle is illustrated in figure 7.

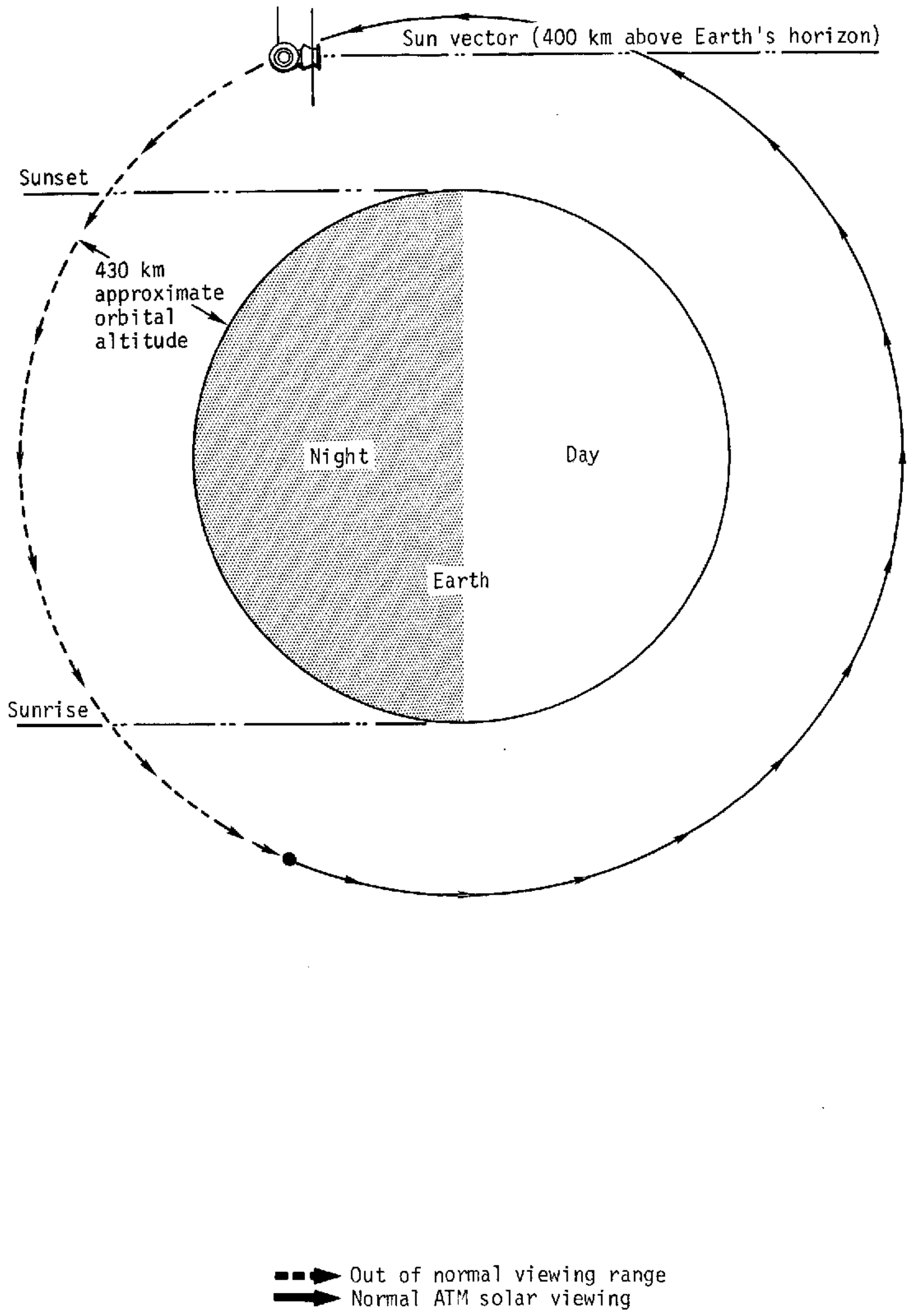


FIGURE 7. ATM SOLAR VIEWING CYCLE

Skylab 3. Of the 15 JOPs and related objectives planned for Skylab 3, all but two were completed.

1. JOP 5 - Limb Profile Studies - This JOP was not completed because the necessity to manually operate S082B created an inconvenience that impacted concurrent operation of other instruments. JOP 5 was not scheduled again and the absence of this data was not considered significant since more useful data were obtained from other JOPs.

2. JOP 13 - Night Sky Objects - This JOP was not completed because of spacecraft maneuvering restrictions. Prior to aborting JOP 13, an X-ray star, SCO X-1, was observed (DOY 262). No UV star observations were made.

Skylab 4. During Skylab 4 a total of 223 full and 141 partial cycles were scheduled for manned solar observations. The high percentage of partial cycles and lack of available orbital sequences precluded scheduling as many JOPs as originally planned. Of the eight new JOPs added specifically for Skylab 4, the following were completed:

1. JOP 18 - Comet Kohoutek
2. JOP 19 - Alfven Waves
3. JOP 21 - Time Variations in Coronal Structure
4. JOP 25 - Maxi and Super Rasters

The JOP approach was proven through highly efficient and successful orbital operations. The total ATM observing time is summarized in Table 5.

TABLE 5. ATM INSTRUMENTS OBSERVING TIME

Mission Phase	Hours of Operation	
	Planned	Actual
Skylab 2		
Attended	101.5	81.7
Unattended	As Available	154.0
Skylab 3		
Unmanned	As Available	191.0
Attended	205.0	305.1
Unattended	As Available	276.0
Skylab 4		
Unmanned	As Available	556.3
Attended	350.0	338.0 (1)
Unattended	As Available	473.0 (2)
Total	656.5	2,375.1

(1) Includes 30 hours devoted to Comet Kohoutek observations.
(2) Includes 8 hours devoted to Comet Kohoutek observations.

SECTION IV. WHITE LIGHT CORONAGRAPH (S052)

Description

General. The White Light Coronagraph, shown in figure 8, was an externally occulted coronagraph, designed to photograph the solar corona in the visible region of the electromagnetic spectrum. The field of view was from 1.5 to 6.0 solar diameters. The instrument weighed approximately 153 kilograms, and was 315 by 56 by 53 centimeters in length, width, and height, respectively.

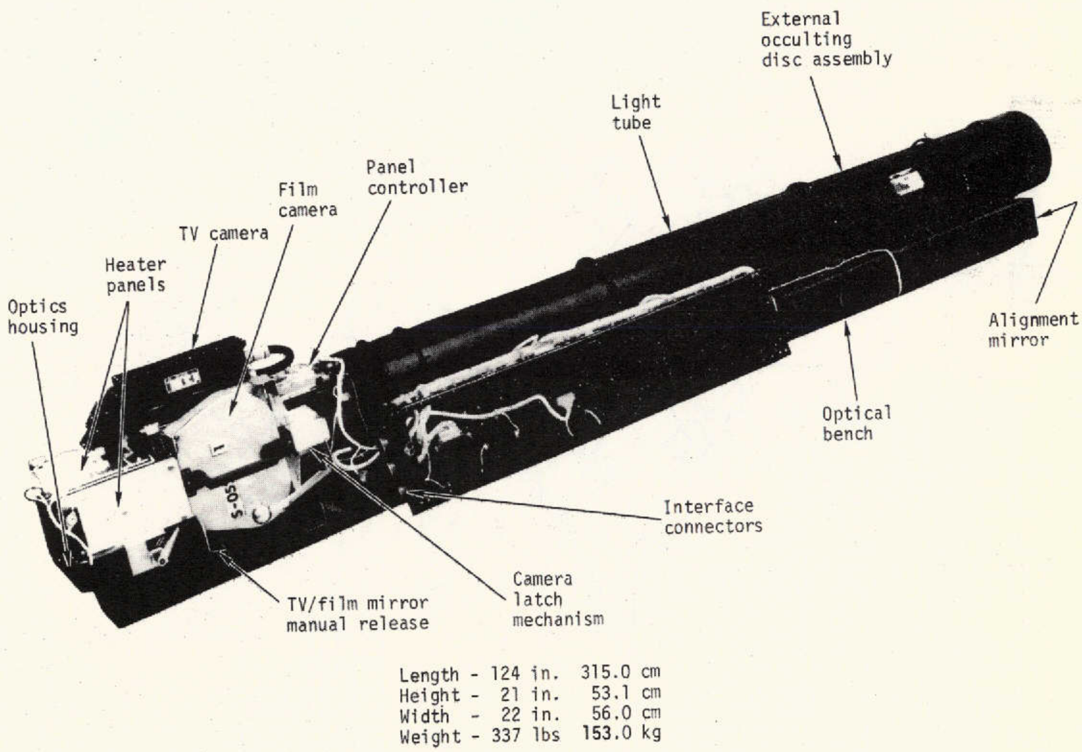


FIGURE 8. S052 WHITE LIGHT CORONAGRAPH

Optics. The instrument was an f/13.7 system with an effective focal length of 43.7 centimeters. An external occulting disk assembly was located on the forward end and an optics housing on the aft end of a dimensionally stable optical bench. The S052 optical schematic is illustrated in figure 9. Three external occulting disks blocked direct sunlight from the 3.2-centimeter

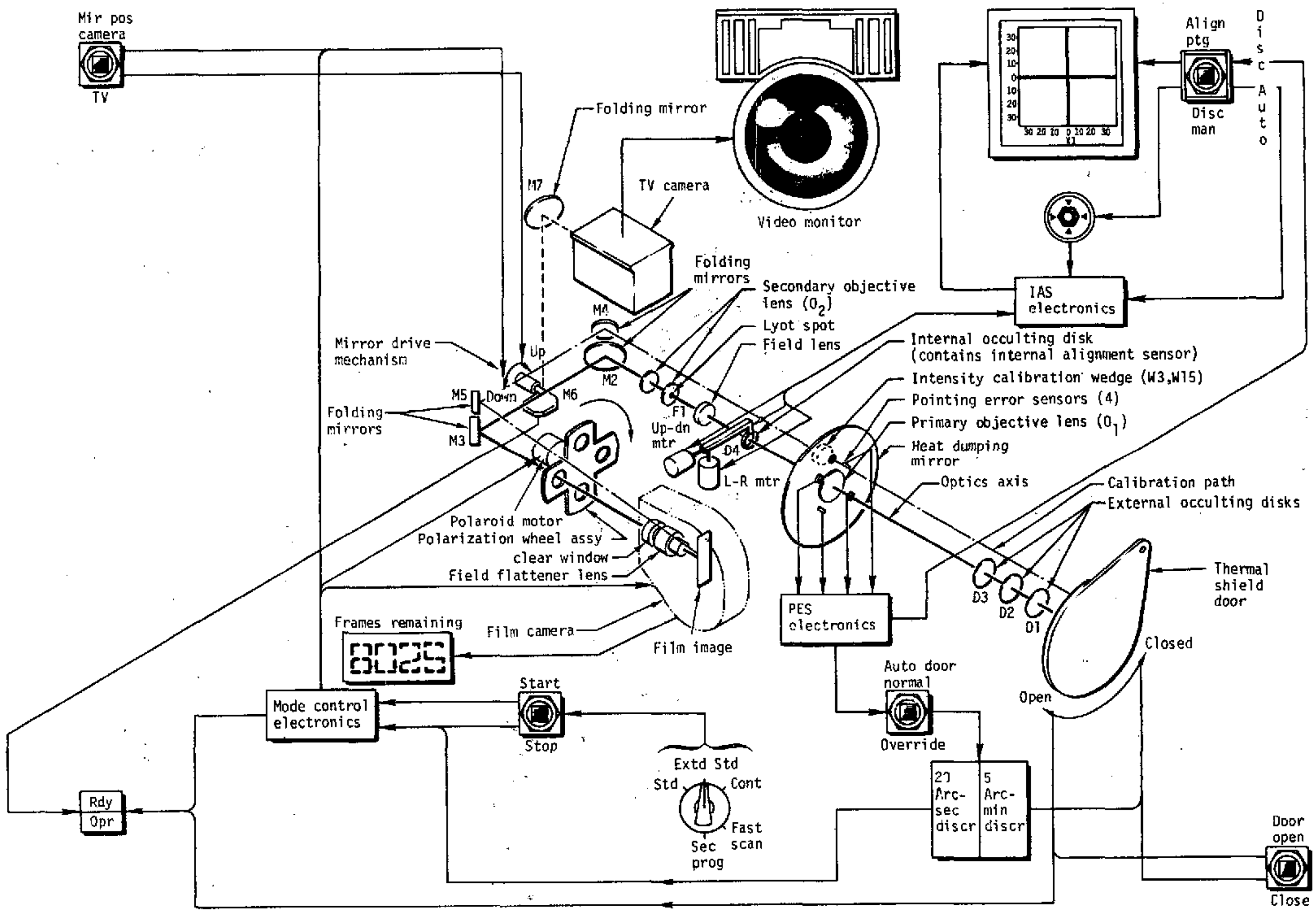


FIGURE 9. S052 OPTICS LAYOUT AND CONTROLS AND DISPLAYS CONCEPTIVE REPRESENTATION

diameter primary objective lens and reduced diffracted light to an acceptable level. Lenses and folding mirrors imaged the solar corona at either the film camera or the TV camera focal plane, depending on the position of the TV folding mirror (M6). The Lyot spot on the secondary objective lens occulted internally reflected images from the primary objective lens. The internal occulting disk, which was servo-controlled to maintain internal optical alignment, blocked residual diffracted light from the external occulting disks. Final traces of stray light were intercepted by light baffles. The instrument optical elements performed the function of variable vignetting, which provided a damping of brightness variation with radius. For a given exposure, this enhanced faint outer corona detail and suppressed blooming in the bright inner corona. Three polaroid filters, oriented 60 degrees from each other, and one clear window were positioned sequentially into the optical path by the polaroid wheel mechanism. A mirror on the forward end of the optics housing rejected excess heat to space. A light baffle tube was integrated between the optics housing and the ATM canister.

A separate calibration path imaged direct sunlight through an 18 step wedge filter upon the central (occulted) portion of each film frame, providing a precise calibration of brightness from 3×10^{-8} to 1×10^{-10} radiance of the mean solar disk.

An ATM thermal shield door and a flexible boot between the S052 entrance aperture and the canister Sun-end were provided to protect the instrument from contamination, micrometeoroid impact, and direct sunlight when not in use. The instrument provided automatic thermal shield door closure when the ATM was not pointing to within 5 arc-minutes of Sun-center.

Film Camera. Five film loads (film cameras) were provided for the S052 instrument. Film load 1 was installed on the instrument prior to Skylab 1 launch, and three were stowed in the MDA film vaults; the fifth film load was supplied on Skylab 4. One film load was used on Skylab 2, and two each on Skylab 3 and 4. Each film load consisted of a film camera, containing 228 meters (8,025 frames) of 35mm Kodak Special 026-02 thin base film. Each camera contained its own film transport system, shutter mechanism, frame count pulse generator, fiducial marking system, and diode matrix which imprinted pertinent data on each film frame. Since the S052 optics formed an image at the camera film plane, the only optical element in each camera was a field flattener lens, which also served as the entrance window. Each camera was pressurized to 5 psia with 45-percent relative-humidity gaseous nitrogen. The film camera was mounted on the side of the optics housing and was held in place with the camera latch mechanism. Changing of film loads on the instrument was accomplished by EVA.

Television Camera. A low-light-level TV camera was mounted on top of the optics housing. The TV image was available for viewing by the crew on either of two TV monitors on the C&D console, or was transmitted to ground when Skylab was in communication with a ground station. The field of view on the TV monitors was 1.5 to 4.5 solar diameters; the specified resolution was 30 arc-seconds. The camera control unit was mounted separately in the ATM. The only electrical interface between the TV camera and the rest of the instrument was grounding.

Pointing Reference System. The pointing reference system (PRS) consisted of a pointing error system (PES) and an internal alignment system (IAS). The PES consisted of four photovoltaic detectors mounted around the primary objective lens in the penumbra of the occulting disk assembly shadow; together with associated electronics, these provided pointing error measurements. The IAS consisted of one photovoltaic chip, divided into four quadrants, mounted on the internal occulting disk. Infrared sunlight from an aperture in the external occulting disk assembly energized the four quadrants to provide signals proportional to the misalignment of the internal and external occulting disks. These signals activated the servomechanism which aligned the internal occulting disk.

The PES incorporated two discriminator circuits: 1) offset pointing of the ATM in excess of approximately 20 arc-seconds automatically terminated instrument operation to prevent waste of film; 2) offset pointing in excess of approximately 5 arc-minutes automatically closed the thermal shield door to prevent damage to the vidicon, film camera shutter, and polaroid filters. A manual override of these discriminators was provided.

Electronics. The instrument electronics were contained in a separate bracket assembly which mounted directly to the ATM spar. The electronics provided automatic programming of operation in the various modes, film camera diode matrix drive logic, and PRS logic. Logic was also provided for a redundant programmer mode. Drive signals were provided for the polaroid wheel and internal occulting disk mechanisms, and automatic thermal shield door close. The electronics provided TV folding mirror drive signals and status indication signals. Instrument power was provided by a dc-to-dc converter having five output voltages. A secondary power supply offered complete redundancy. The electronics bracket assembly also contained a TCS power supply, various junction boxes, filter boxes, and connectors.

Instrument Thermal Control System. The instrument TCS provided semi-passive thermal control, consisting of insulation, thermal coatings, and active heater panels. It maintained instrument temperature level and minimized thermal gradients.

Operation. The crew performed experiment pointing, operating mode selection, and activation and deactivation control from the C&D console, as shown schematically in figure 9. Similar operation, in limited operating modes, was possible by ground command. Activation of any of four primary operating modes resulted in the primary programmer automatically sequencing the instrument through a series of exposures with various combinations of exposure time and polaroid wheel position. Should the primary programmer fail, a one-mode, secondary programmer was available to the operator as a backup. These modes are summarized in Table 6.

TABLE 6. S052 OPERATING MODES

Mode	Min	Frames	Exposure Time (Sec)	Polaroid[1] Positions	Stop
Standard Patrol	5.5	12	9,27,3	1,2,3,4	Automatic
Extended Standard Patrol	16.2	36	9,27,3	1,2,3,4	Automatic
Continuous Patrol	Continuous	3/82.5 sec	9,27,3	1	Start/Stop Switch
Fast Scan	16.2	72	27,3,9	1	Automatic
Secondary Programmer o Backup for Primary Programmer Failure	Continuous	3/64 sec	6,18,2	1	Mode Select Switch

(1) Position 1 contained the clear window.

Sun-center pointing was accomplished utilizing the PES measurements displayed by crosspointers on the C&D console. In addition to automatic alignment of the internal occulting disk, provision was made for manual internal alignment via either the C&D console or ground command. The crew could manually retract the TV folding mirror during EVA to allow film camera operation in case of TV mirror mechanical failure.

Mission Performance

General. The White Light Coronagraph demonstrated excellent performance throughout the Skylab mission. The crew, making real-time adjustments to observing programs and taking corrective actions in orbit, greatly enhanced the quality of the data and minimized the impact of anomalies. The instrument significantly exceeded its design specifications in at least two important areas; the orbital life of the instrument, and the spatial resolution. More observation time of the Sun's corona was obtained during the first few days of the Skylab mission than had been accumulated in all previous history. The design of the S052 picture taking modes and the extensive period of observation permitted observing for the first time coronal dynamics with time constants ranging from one-half the period of rotation of the Sun (roughly two weeks) down to minutes or seconds.

Instrument Performance. The primary objective of the S052 instrument, to provide high-resolution photographs of the solar corona in the visible region of the electromagnetic spectrum, was completely accomplished. The scattered-light level in the instrument was 1 to 2 x 10^{-10} times the brightness of the Sun, the lowest of any previous coronagraph. The design specification requirement for orbital operating life was 56 days. During the 270 days of the Skylab mission, this design requirement was considerably exceeded, as the instrument was still operational at the conclusion of the Skylab mission.

Five film-camera loads were used during the Skylab mission. The film-transport failure in camera load 1 on DOY 161 is discussed in detail on page 37. The quantity of unexposed film resulting from this anomaly was less than 10 percent of the total film available in the five loads. TV recording of synoptic observations, during the film-transport-failure period, reduced the loss of scientific data. Proper film-camera operation resumed on DOY 170 when the crew replaced film load 1 with film load 2. Other film-camera anomalies which occurred during the mission are discussed in detail in the Anomalies Section.

The instrument TV system performed as designed throughout the mission. Premission requirements were for 3 to 5 minutes of TV observation or downlink once per day. This was changed to twice per day during the mission. On DOY 337 the crew observed a bright spot on the S052 TV monitor. On DOY 031 a second bright spot occurred. These anomalies are discussed in detail on page 46.

The S052 electronics system performed as designed. A significant, constant pointing error was introduced into the system during Skylab 2: when the S052 instrument was boresighted on Sun-center using the TV monitor, the S052 PES read a mean value of 14 arc-seconds up and 62 arc-seconds right. This anomaly is discussed in detail on page 37. The primary programmer continued to command the four programmed modes, providing, in proper sequence, the various combinations of three exposure times and four polaroid wheel settings, and terminating each automatic mode with the proper number of frames having been exposed. The internal alignment sensor and drive circuits operated correctly throughout the mission. Proper operation of the 20-arc-second discriminator was verified on several occasions by terminating mode operations when the pointing error was excessive. The operation of the 5-arc-minute discriminator circuit was verified on DOY 197, when ATM pointing problems inadvertently caused mispointing the ATM while the S052 thermal shield door was open.

The polaroid wheel mechanism, the TV folding mirror mechanism, and the internal occulting disk mechanism operated correctly.

The instrument TCS performed within design limits throughout the mission. Locations of S052 temperature sensors are shown in figure 10. Figure 11 shows typical mission temperatures with predicted temperatures and limits. The effectiveness of the thermal analysis was evident in the correlation between predicted and actual temperatures.

The five outputs of the S052 instrument primary power supply remained within operating limits throughout the mission. Figure 12 presents typical voltage levels of the various outputs. The secondary power supply, identical in characteristics to the primary supply, was verified to operate correctly.

ATM Interface. The ATM provided satisfactory support to the S052 instrument. Initially, caution was exercised in managing the limited electrical power caused by loss of OWS solar wing number 1 (reference page 4). The resultant delay in the ATM canister thermal system power-up had no detrimental effects on subsequent instrument operation. The film vault temperature shown in figure 13 verified that during this anomalous period the upper temperature limit of the film was not exceeded. Figure 14 shows comparable data for the film camera on the instrument.

The S052 thermal shield door was required to remain open for over 100 hours due to an S054 thermal shield door anomaly on DOY 153 (reference Section V). Until the S054 door was latched open on DOY 158, it was necessary to place the S052 instrument in a safe configuration when the ATM was pointed off Sun-center. The safe Configuration consisted of having the TV folding mirror in the TV position with the TV power off.

On DOY 216 the crew reported random blinking of the S052 ready light. The ready light operation continued to degrade until it was non-operational. Although the crew was inconvenienced, loss of the ready light did not significantly degrade the operation of the instrument.

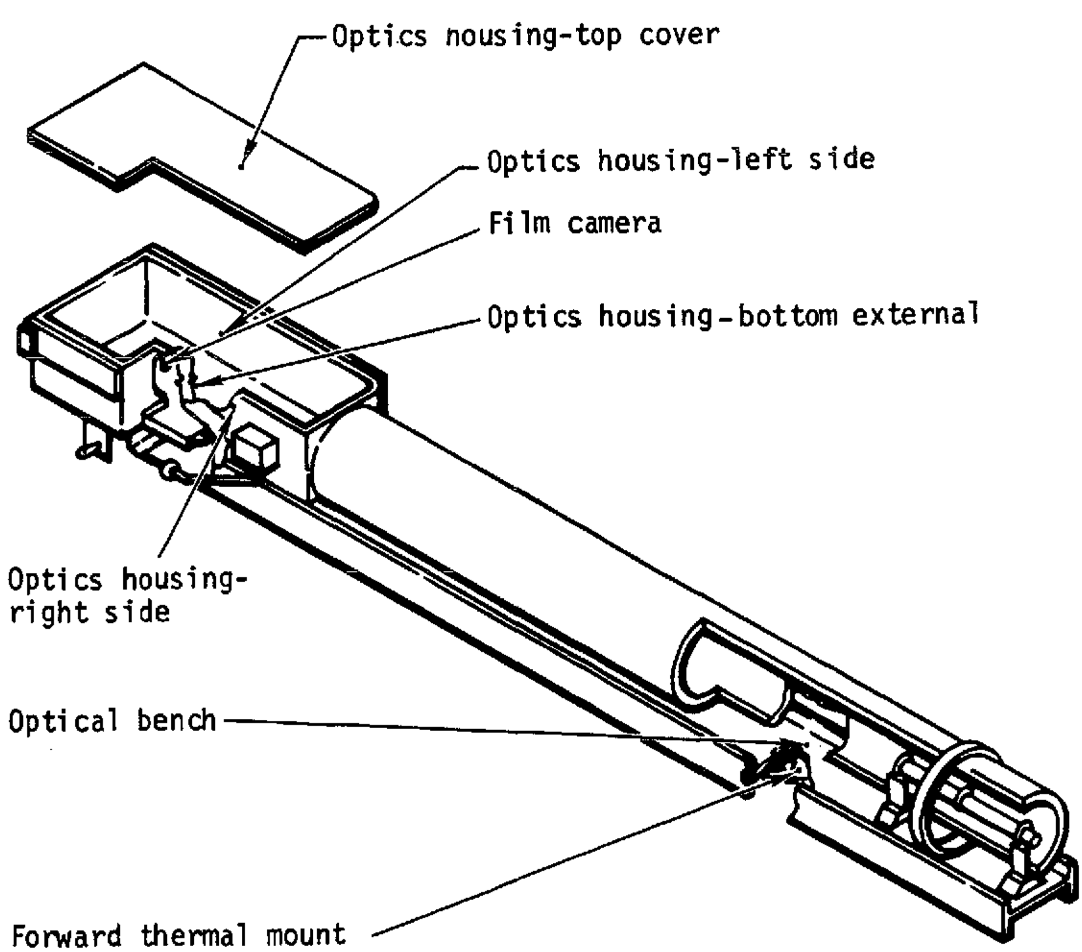


FIGURE 10. S052 TEMPERATURE SENSOR LOCATIONS

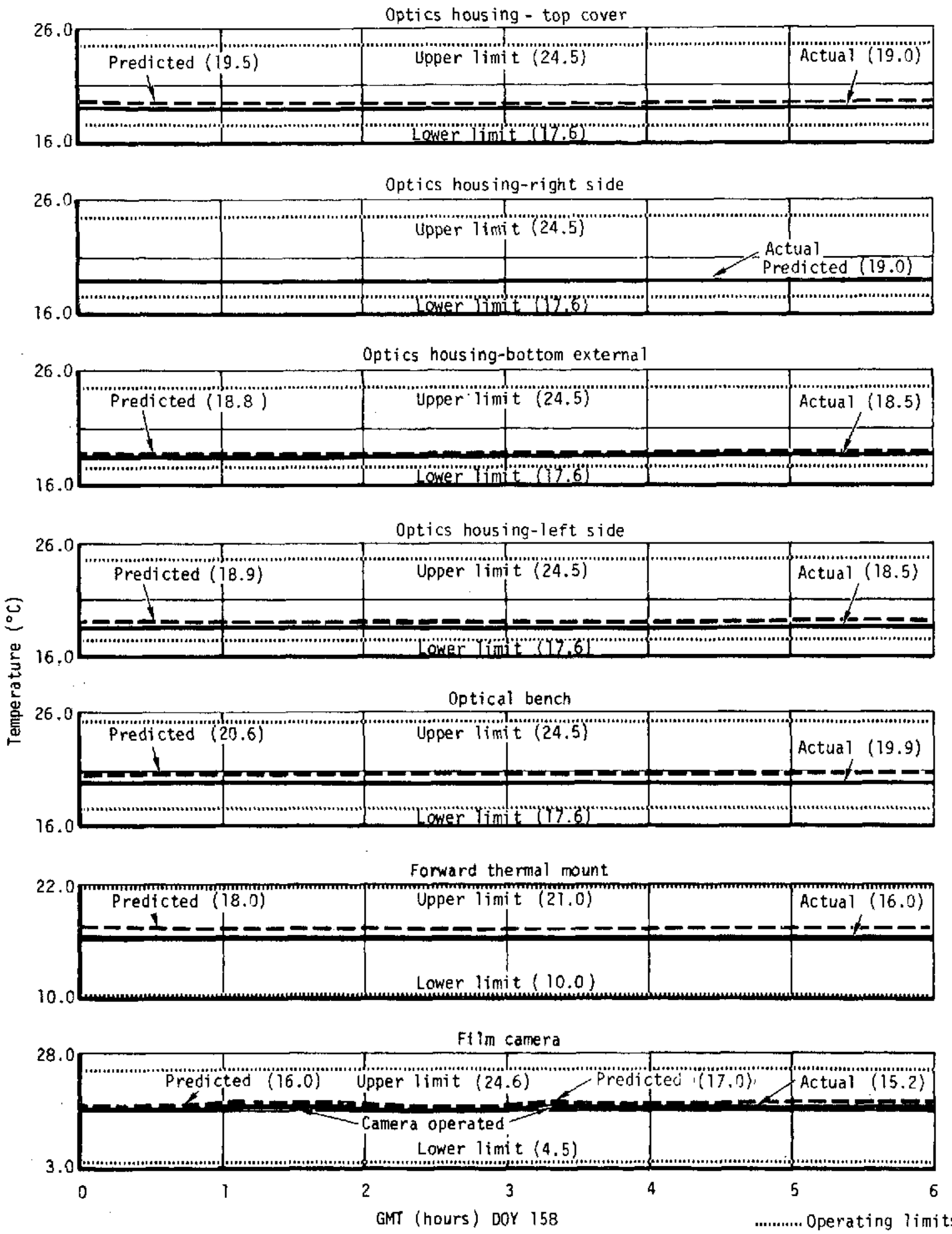


FIGURE 11. S052 TYPICAL MISSION TEMPERATURES

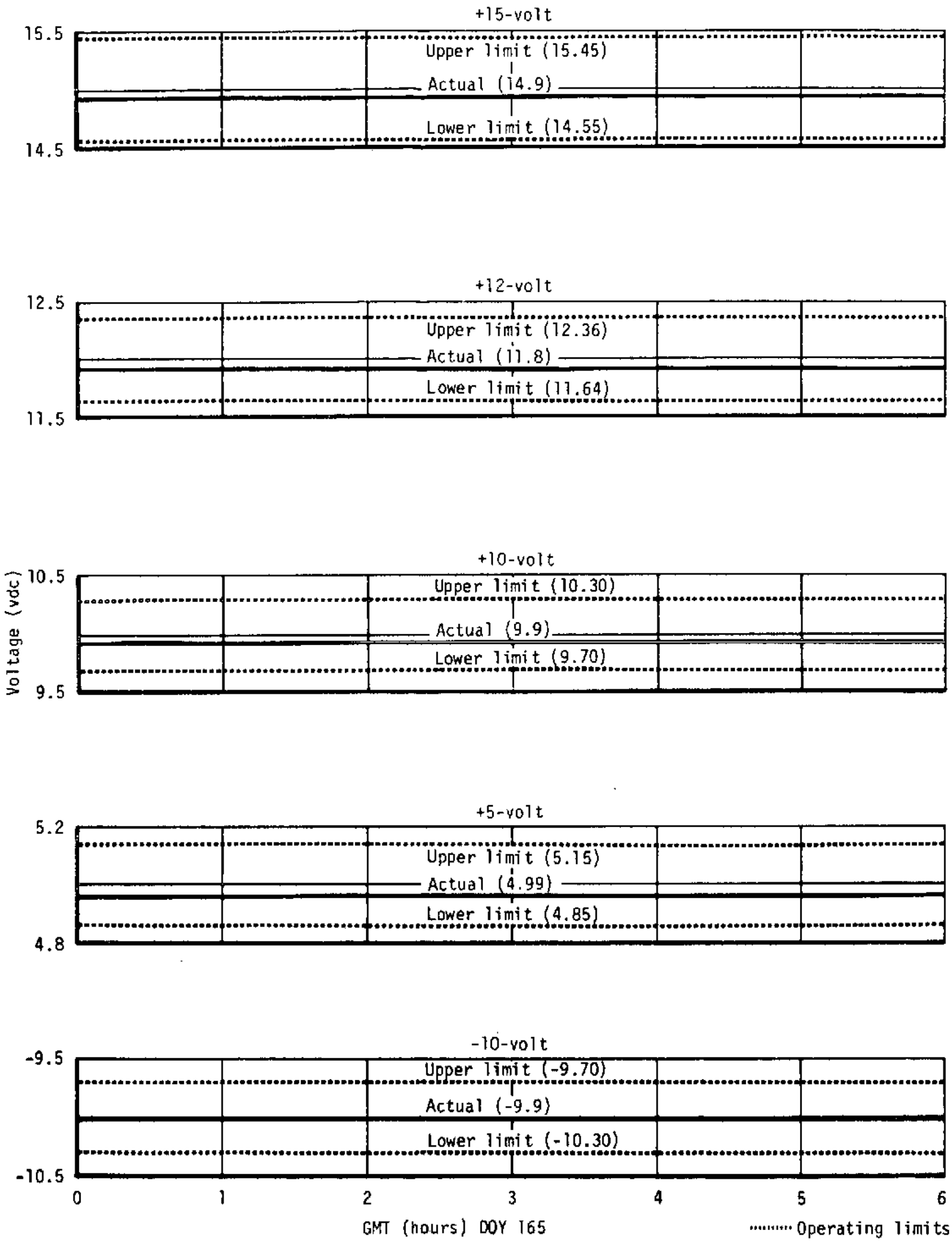


FIGURE 12. S052 TYPICAL POWER SUPPLY OUTPUTS

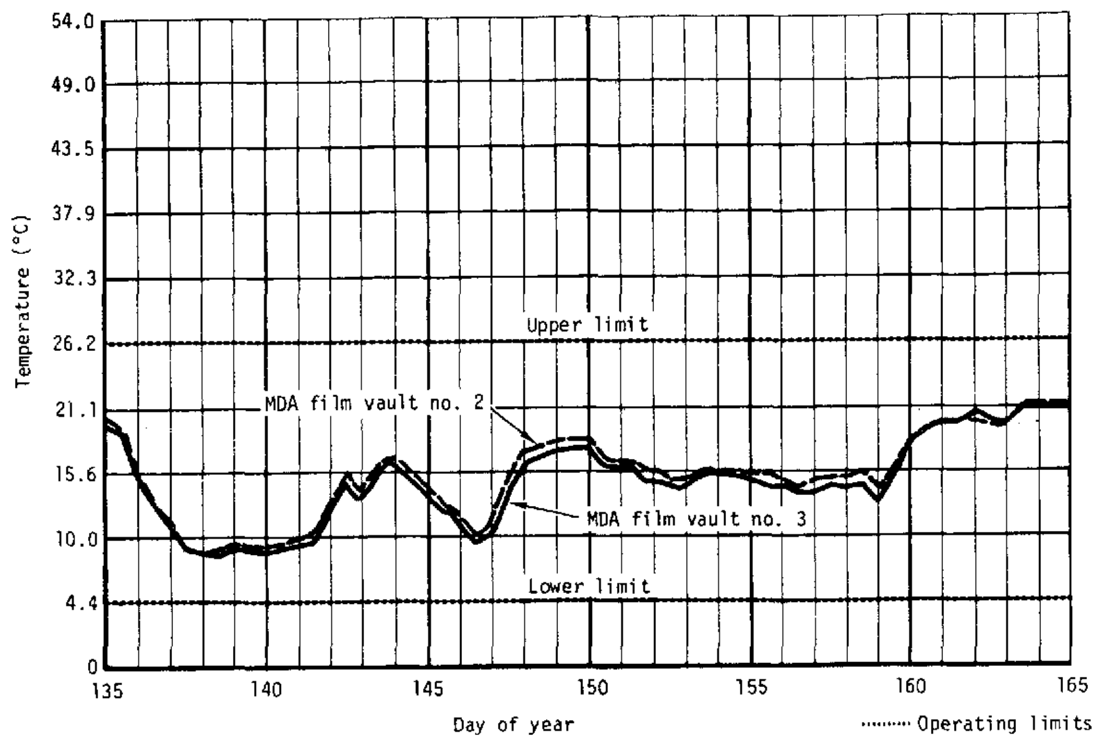


FIGURE 13. FILM VAULT TEMPERATURE

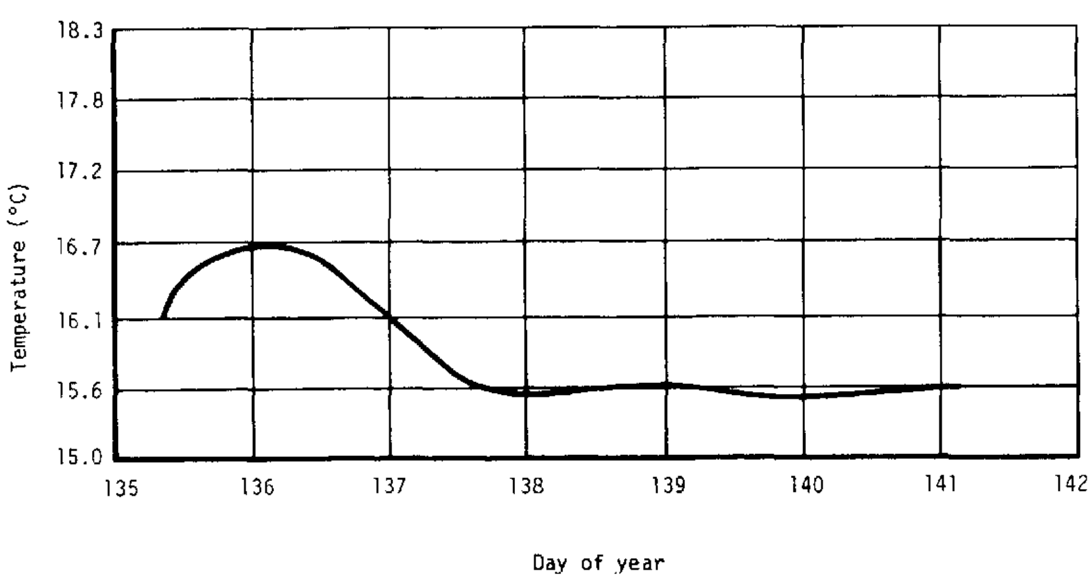


FIGURE 14. S052 FILM CAMERA TEMPERATURE DURING HIGH STRESS PERIOD

Difficulties with the ATM experiment pointing control system created some minor problems, such as a break in S052 synoptic observations on DOY 197 until DOY 210. Erroneous thermal shield door indications occurred on DOY 216 and DOY 236, interrupting the instrument operating plan. A navigational anomaly on DOY 179 interrupted a synoptic observing program.

Real-time planning was affected by limited ground-data-processing capabilities. Retrieval of engineering data was delayed, which hindered real-time engineering analysis.

Man/Machine Interface. The operation of the S052 instrument by the crew was commendable. The few human errors observed were generally attributable to the extensive mission duration, the multiplicity of operations, and the proximity of control locations.

On two occasions, the crew removed contamination from the front occulting disk without damage to the instrument. The contamination caused a significant area of scattered light within the field of view.

Several inadvertant switch operations, primarily with the S052 TCS, were noted. Real-time analyses, and crew comments during debriefing, suggest a possibility of more emphasis on human-factors engineering design.

Scientific Data Quantity and Quality. During the Skylab mission, a total of 35,918 frames were exposed. Table 7 shows the usage of the five film loads. Approximately 1,600 frames were of Comet Kohoutek. Also, some 150 frames were taken in an attempt to observe lunar libration points. Evaluation of the developed film indicated that exceptionally high quality photographic data were obtained, with considerable coronal detail visible on the film. Except for brief periods of perturbation due to crew motions, a spatial resolution of 8 arc-seconds was achieved, exceeding the instrument design specification of 15 arc-seconds, and equaling the limiting resolution of the film.

The high-quality, high-resolution photographs brought out a wealth of detail on the structure of the corona. The vignetting feature, together with the three lengths of exposure (3, 9, and 27 seconds), served to extend the effective photographic dynamic range of the instrument. This permitted detailed observation of the very faint outer-corona on long exposures and of the inner-corona, without blooming, on short exposures. As an example, figure 15, a photograph in unpolarized light, is one of a sequence of 144 frames taken of an eruptive prominence, moving outward from

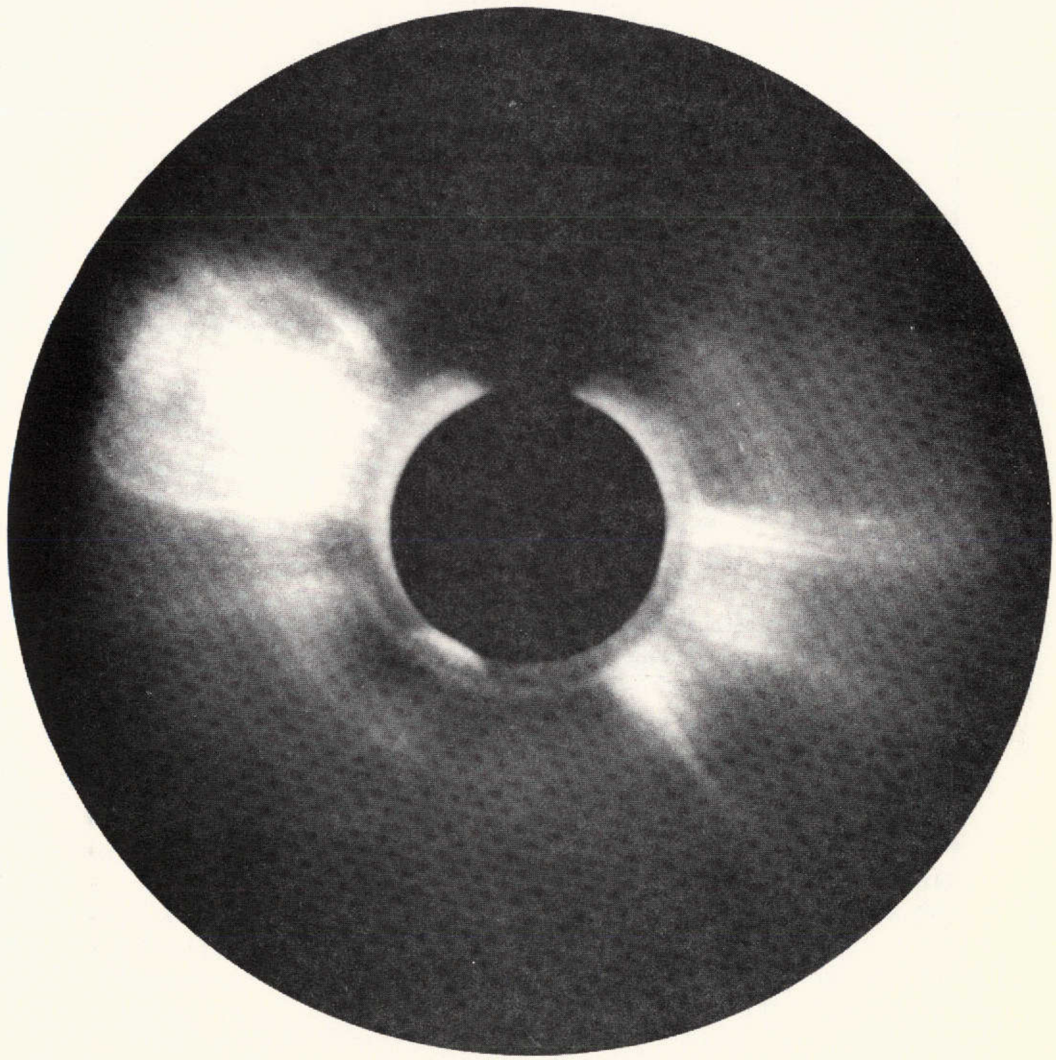


FIGURE 15. S052 FILMED CORONA DETAIL PHOTOGRAPHED IN UNPOLARIZED LIGHT

TABLE 7. S052 FILM LOAD USAGE

Film Load	Skylab Mission	Frames(1) Available	Frames Exposed		Installed (DOY)	Removed (DOY)
			Unmanned	Manned		
1	2	8025	--	4381	Prior to Skylab 1 Launch	170
2	3	8025	1230	6747	170	236
3	3	8025	--	7758	236	265
4	4	8025	1630	6227	265	359
5	4	8025	--	7945	359	034

(1) The frames available varied slightly with the amount of film in each load.

the solar limb into the corona. The loop structures are material, moving outward, with a velocity of approximately 450 km/sec. This rare event was observed for approximately one-half hour.

Figure 16 shows Comet Kohoutek when it was 14.6 million miles from the Sun and 106 million miles from Earth. At this time the Comet was behind the Sun moving toward the left (ahead of the tail) and was approximately 28 hours from its nearest approach to the Sun (13 million miles).

Figure 17 presents a typical TV monitor display, as recorded from TV downlink. The occulting disk supporting leg (pylon) was at the left of the picture, so that the orientation of the S052 pictures on the TV monitor was consistent with the other instruments. The TV display proved useful to the crew and to the scientists on the ground: coronal features were visible, enhancing the definition of the observing program; the TV was used to calibrate S052 Sun-center pointing with respect to the PES; contamination on the front occulting disk was twice observed on the TV which permitted early corrective action by a crewman during EVA.

The duration of the mission permitted observation of the corona during several rotations of the Sun (approximately four weeks per rotation). The dynamics of some coronal features were shown to have time scales on the order of one-half the period of rotation of the Sun. Some coronal features were observed to have time scales on the order of days. With observing periods of approximately one hour out of every hour and one-half (period of Skylab orbit), other coronal features were observed with time

FIGURE 16. S052 FILM CAMERA PHOTOGRAPH OF COMET KOHOUTEK

FIGURE 17. S052 TV MONITOR DISPLAY RECORDED FROM TV DOWNLINK

scales on the order of hours. The fast-scan mode permitted observation of coronal dynamics with time scales on the order of minutes. Some changes were observed between frames taken 40 seconds apart. Opportunity for extensive observation of solar corona dynamcs on these time scales had never before been afforded. The scattered-light level was more than an order of magnitude better than experienced with ground-based observations during an eclipse.

The JOPs provided data on coronal and surface features, which should permit correlation of the coronal features and their dynamics with activity on the Sun's surface.

Anomalies

General. Although the S052 instrument experienced several anomalies throughout the Skylab mission, only two had a potential impact on continuing instrument operation. In both cases, corrective action precluded compromising mission objectives. The first, a PES bias that became apparent during initial S052 operations, was corrected by repointing the instrument to partially eliminate the offset. The second potentially major problem occurred when the film camera jammed during Skylab 2. Replacement of the camera by the crew during EVA allowed S052 film camera operation to continue with minimal data loss. Other minor anomalies occurred, but had no significant impact on instrument operation. Details of these anomalies are discussed below.

Pointing Error System Bias. When the Skylab 2 crew began operations with the S052 instrument, a discrepancy existed between Sun-center pointing as observed on the C&D console TV monitor versus the PES readouts. With the S052 instrument boresighted on Sun-center using the TV monitor, the PES readings averaged 14 arc-seconds up and 62 arc-seconds right. This bias was relatively constant throughout the Skylab mission. In order to reduce diffracted light, it was necessary to point the S052 instrument, as accurately as possible, to Sun-center. However, as shown in figure 18, an offset of 14 arc-seconds up and 62 arc-seconds right would trigger the 20-arc-second discriminator in the PES, thus automatically preventing operation of the instrument in any mode. It was possible to override the 20-arc-second discriminator to permit instrument operation, but this would also override the 5-arc-minute discriminator, thus eliminating protection against instrument damage from excessive mispointing with the S052 thermal shield door open. Therefore, a compromise was effected by pointing the instrument to 8 arc-seconds up and 16 arc-seconds right, as indicated by the C&D console PES crosspointer display. This provided instrument pointing as near as possible to Sun-center without triggering the 20-arc-second discriminator. Since diffracted light was not minimized, due to the off Sun-center pointing of 6 arc-seconds down and 46 arc-seconds left, the quality of the data was slightly degraded. Possible causes of this anomaly were analyzed; however, available data were insufficient to determine the cause.

S052 Camera Jam and Torn Film. On DOY 161 an unusual rate of temperature rise inside the film camera was observed. The rate of rise was comparable to that derived by computer simulation for a stalled film-transport motor, as shown in figure 19. The crew performed the applicable malfunction procedure. Results

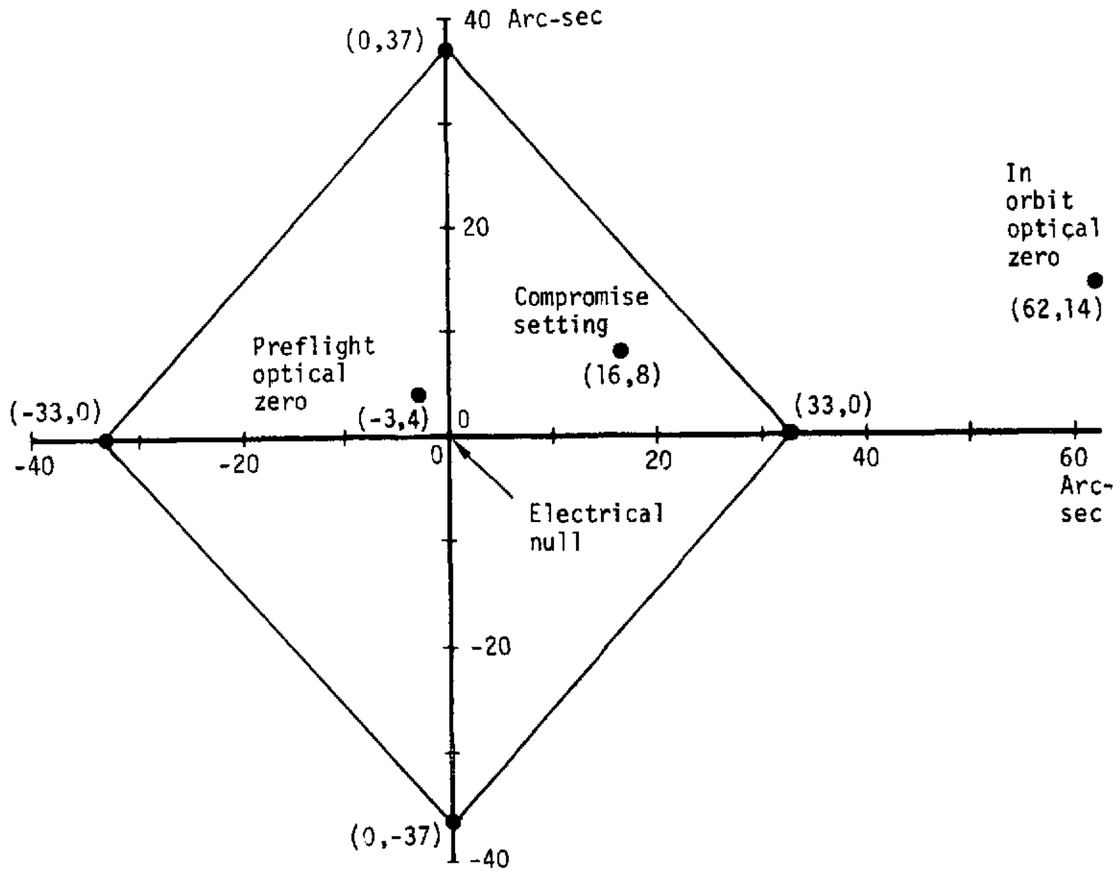


FIGURE 18. S052 20-ARC-SECOND DISCRIMINATOR SET POINTS

indicated a possible film-camera or primary-programmer failure. At the next scheduled operation of the instrument, the crew reported that the operate light would not illuminate and the frames remaining counter (FRC) was not decrementing; and the anomalous temperature conditions repeated. These conditions confirmed that the film-transport motor was stalled, and no further film-camera operation was possible until the camera was replaced by EVA on DOY 170. Coronal observations were performed using TV downlink minimizing the loss of film data. Operation of the second film camera was verified before the departure of the Skylab 2 crew.

After return of the Skylab 2 film camera to Earth, the exposed and unexposed film reels were carefully removed without disturbing the jammed portion of the film shown in figure 20. The film appeared to have caught on a film-sprocket hole near the trailing edge of the second pressure-plate in the aperture area, as shown in figure 21. The film was torn completely out of the transport mechanism, and was wound onto the takeup reel. The

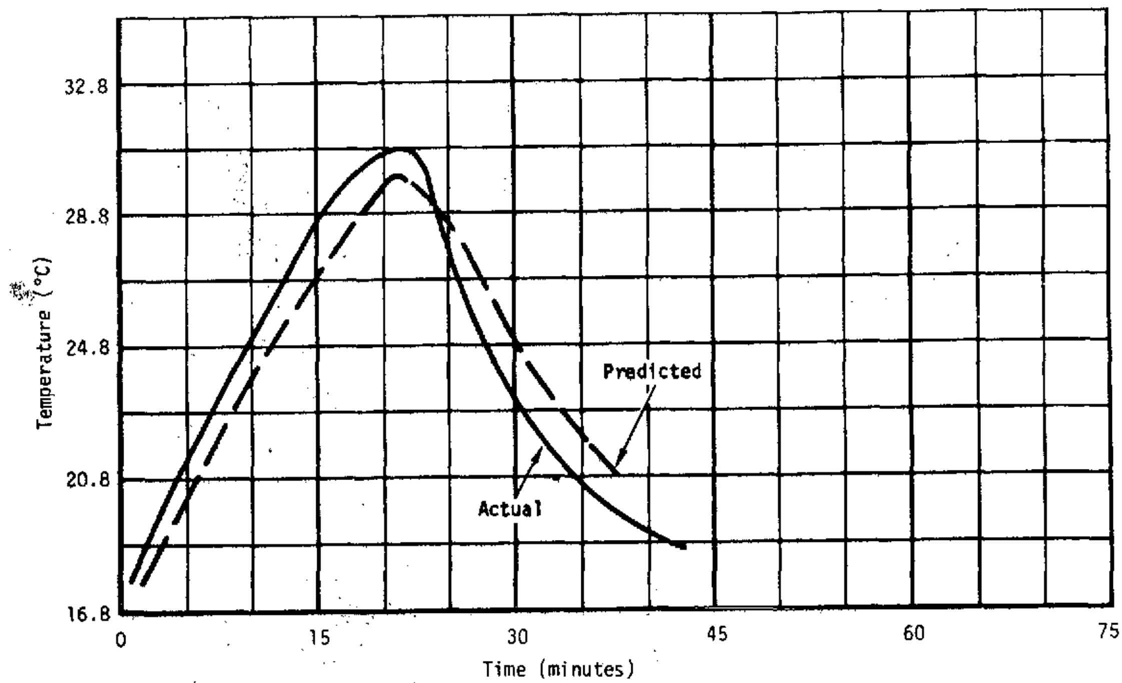


FIGURE 19. S052 CAMERA TEMPERATURE DURING STALL ON SKYLAB 2

supply drive-sprocket had continued to feed film, but with no film takeup. After the film was torn, this film piled up around the supply drive-sprocket until it jammed and stalled the transport motor. Figure 22 shows the amount of film jammed into the supply drive-sprocket after the film gate had been released. Although other failure modes were experienced and corrected during development and testing of these cameras, this was the first and only occasion of this failure mode.

Failure analysis showed that a particle of silicon and calcium composition, shown in figure 23, became lodged in the aperture plate area. The particle was originally small enough to be carried into the clearance space between the film and the backup-plate. The particle became lodged in the separation between the pressure-plate and the backup-plate, as shown in figure 21. As film continued to feed through the camera, this resulted in a long, axial gouge in the perforation area of the film. Film material built up on the particle and was hardened by the friction and, eventually, the particle became large enough to bind the film. The particle finally notched the edge of a perforation, causing the film to be torn by continued film-transport action. The

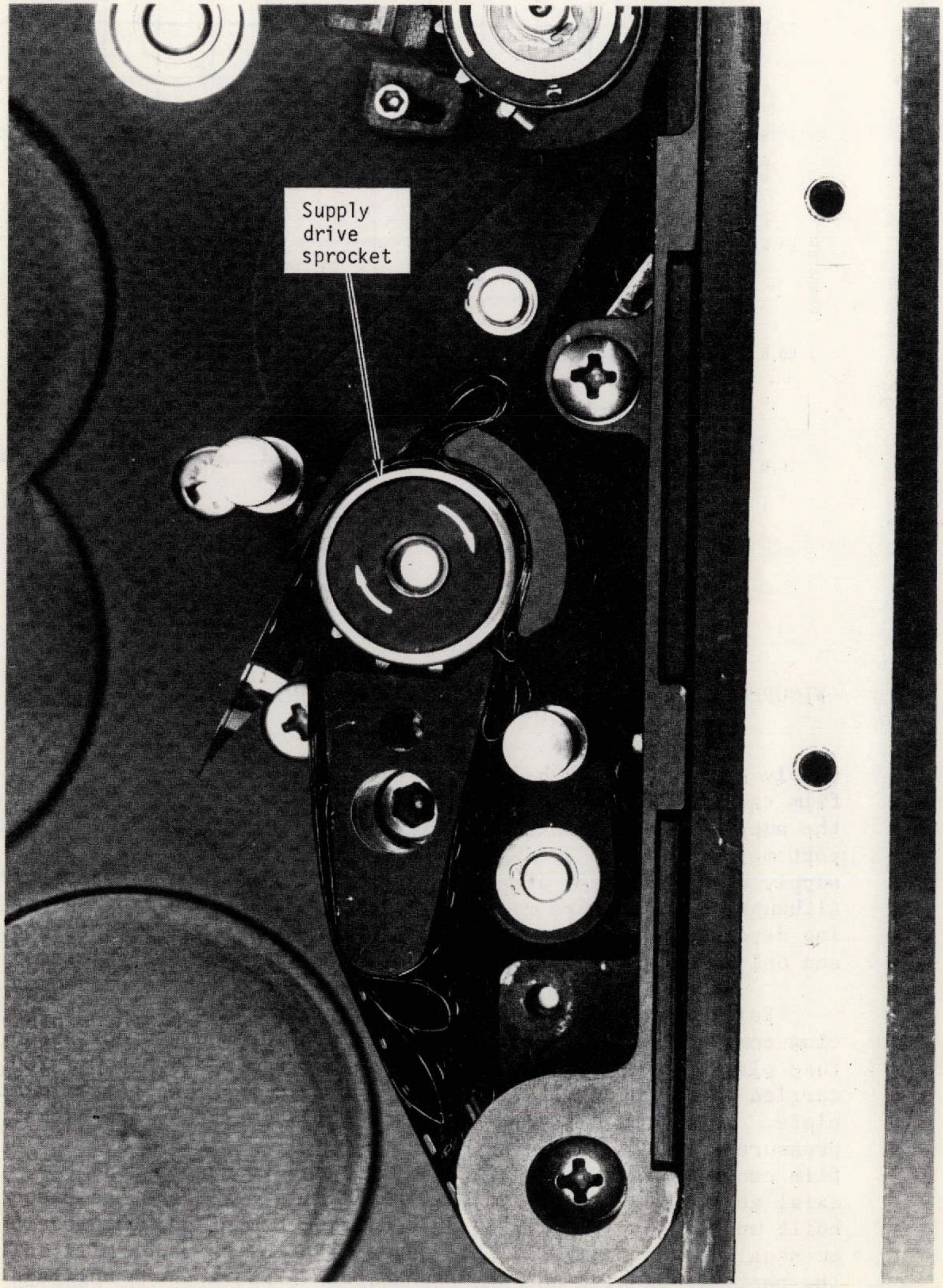


FIGURE 20. S052 CAMERA, JAMMED FILM

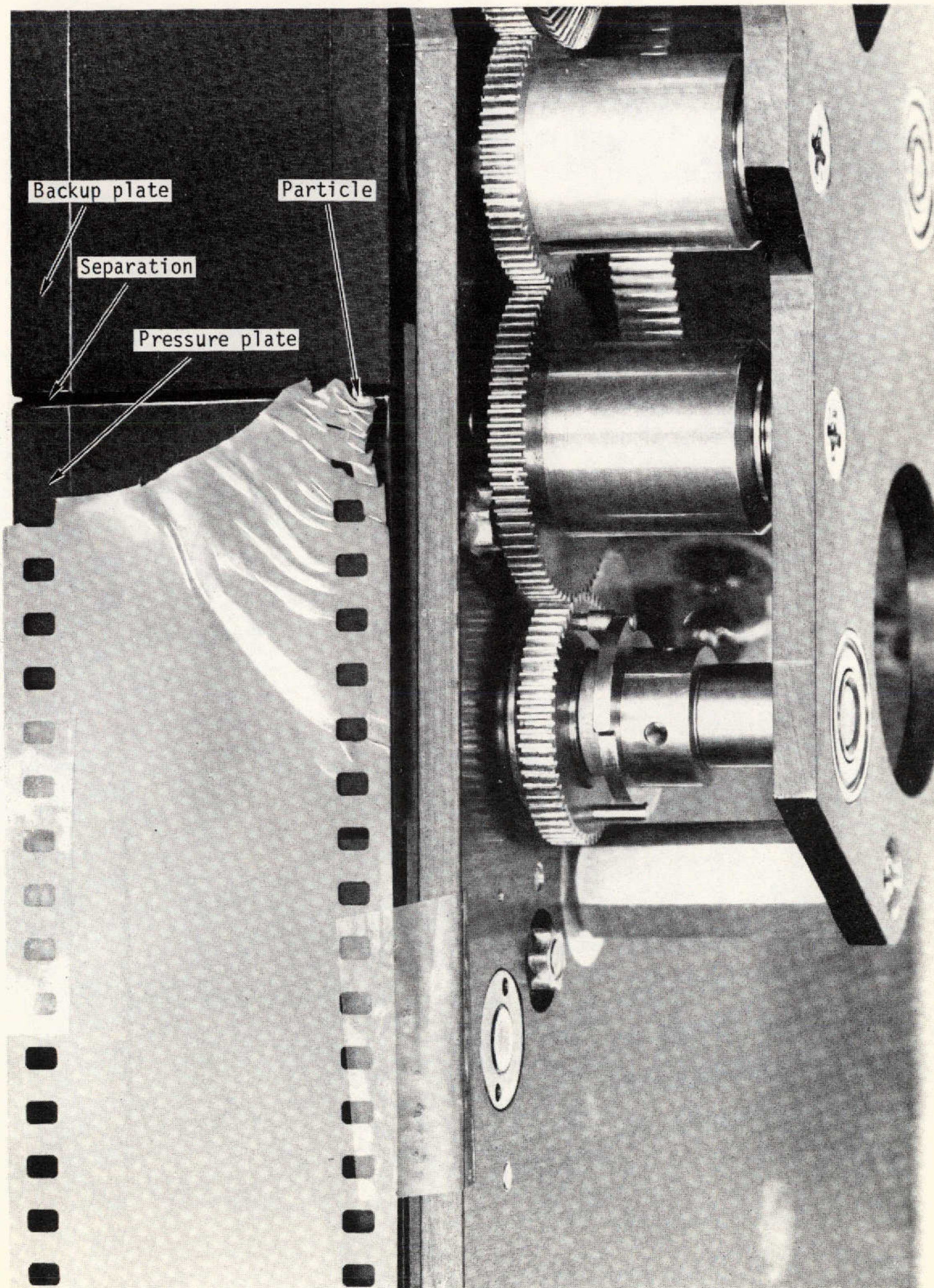


FIGURE 21. S052 CAMERA, TORN FILM

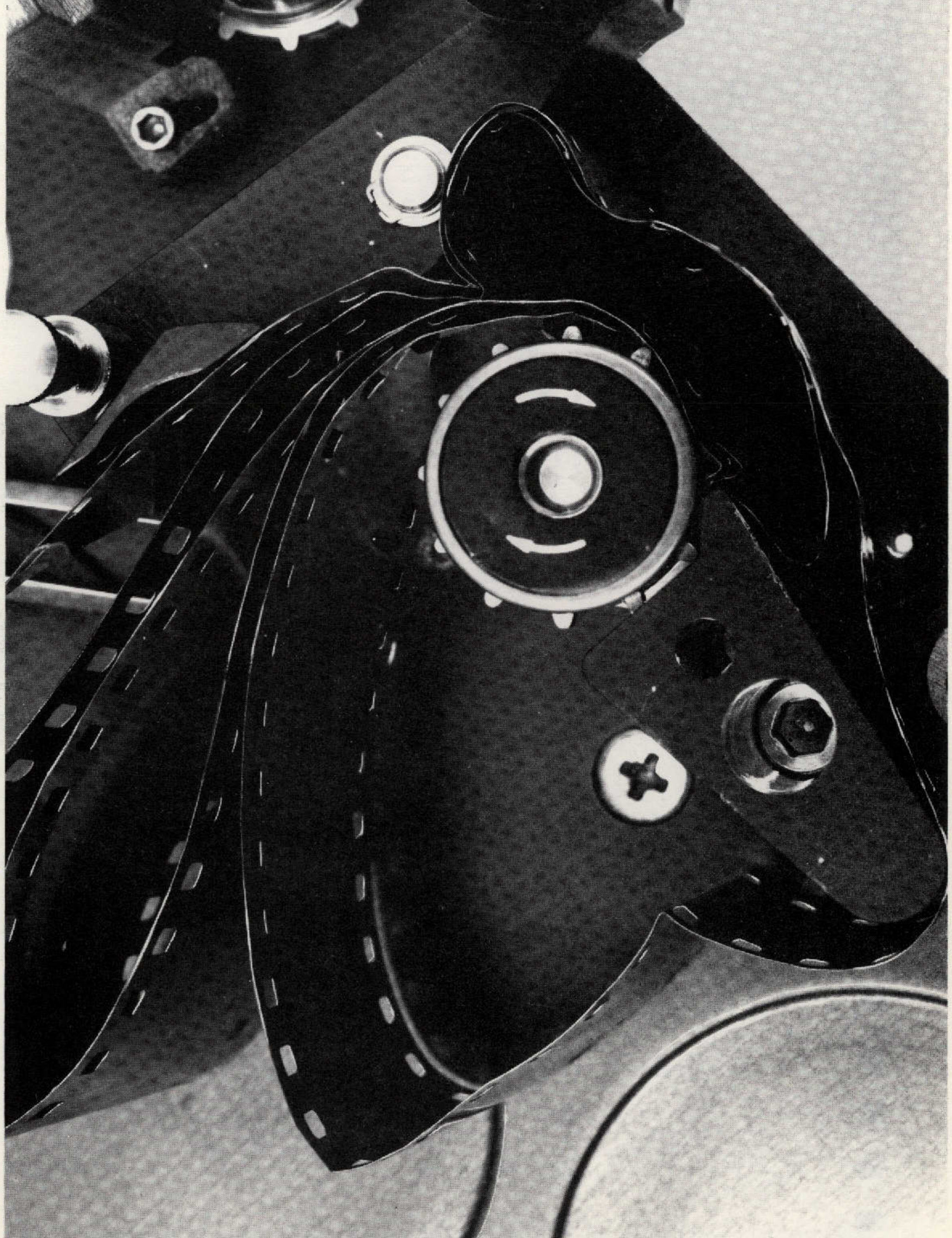


FIGURE 22. S052 CAMERA, FILM PILE-UP

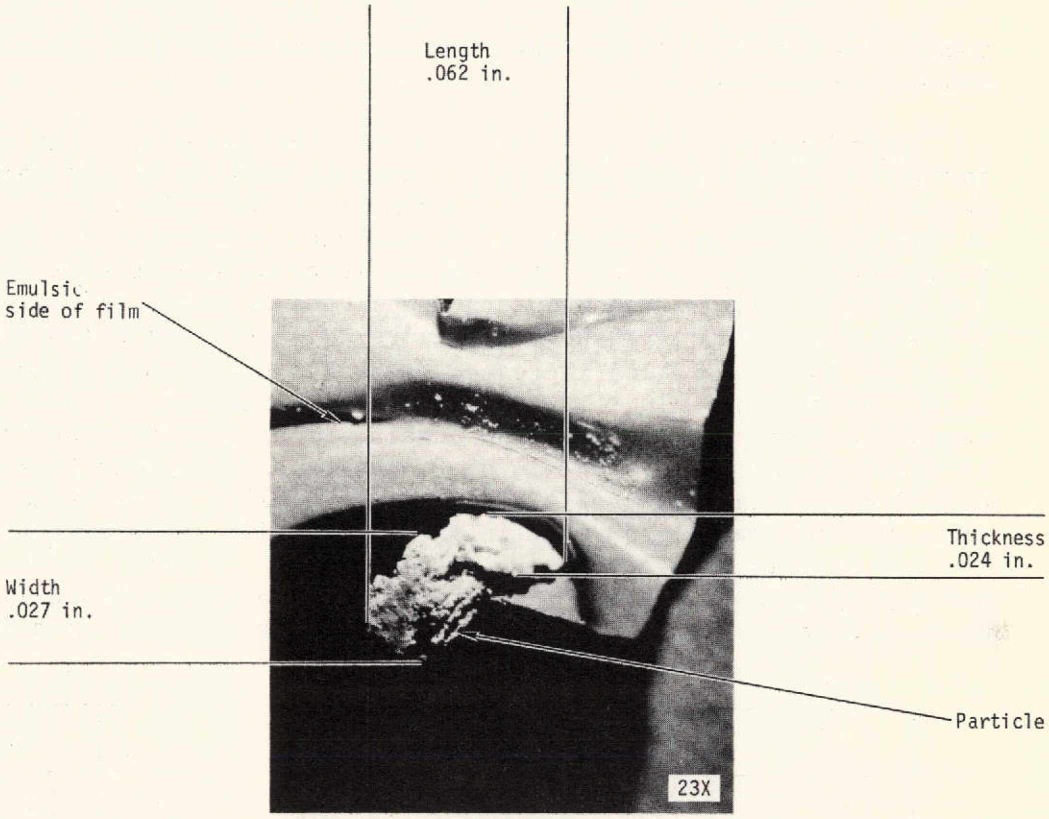


FIGURE 23. S052 CAMERA, SILICON AND CALCIUM PARTICLE

particle was still firmly affixed to the film when failure analysis began. Examination of the film also showed irregularly curved indentations or marks at various places, which were assumed to have been made by a particle, or particles, rolling with the film through the aperture-plate area. The source of the particles is unknown. The camera was carefully cleaned and extensively inspected prior to supplier delivery, and again before loading with flight film. Comparable contamination was not noted in the other cameras or in other rolls of film.

Partial Frame Advances. Approximately 100 partial frame advances were observed near the beginning of the developed film for each of the first two film loads. This resulted in the overlapping of approximately 0.5 percent of the frames exposed.

During postflight analysis, a thorough examination was made of camera load 1, including measurement of clutch torques. All conditions were within specification. The cause of this anomaly was not determined.

Film Transport Stalled. On DOY 264, the day before the EVA for changing film loads, the film transport stalled in the second Skylab 3 camera (film load 3). This anomaly was evidenced by failure of the frames-remaining indicator to down count during an operating mode, and the film camera internal temperature showing an increase comparable to that predicted by computer analysis for a stalled camera as shown in figure 24. When the drive motor stalled, the temperature increased at a rate of approximately 0.56°C (1.0°F) per minute. The temperature increase was also comparable to that exhibited by the camera which stalled on Skylab 2, as shown in figure 19. The 7,758 frames exposed at this time were considered to have denoted successful performance of the film camera. Of the nominal 750 feet in the camera film load, less than 10 feet of film remained on the supply spool. The film on the take-up spool completely filled the take-up cavity. The full take-up reel rubbed on the frame-advance switch bracket, as shown in

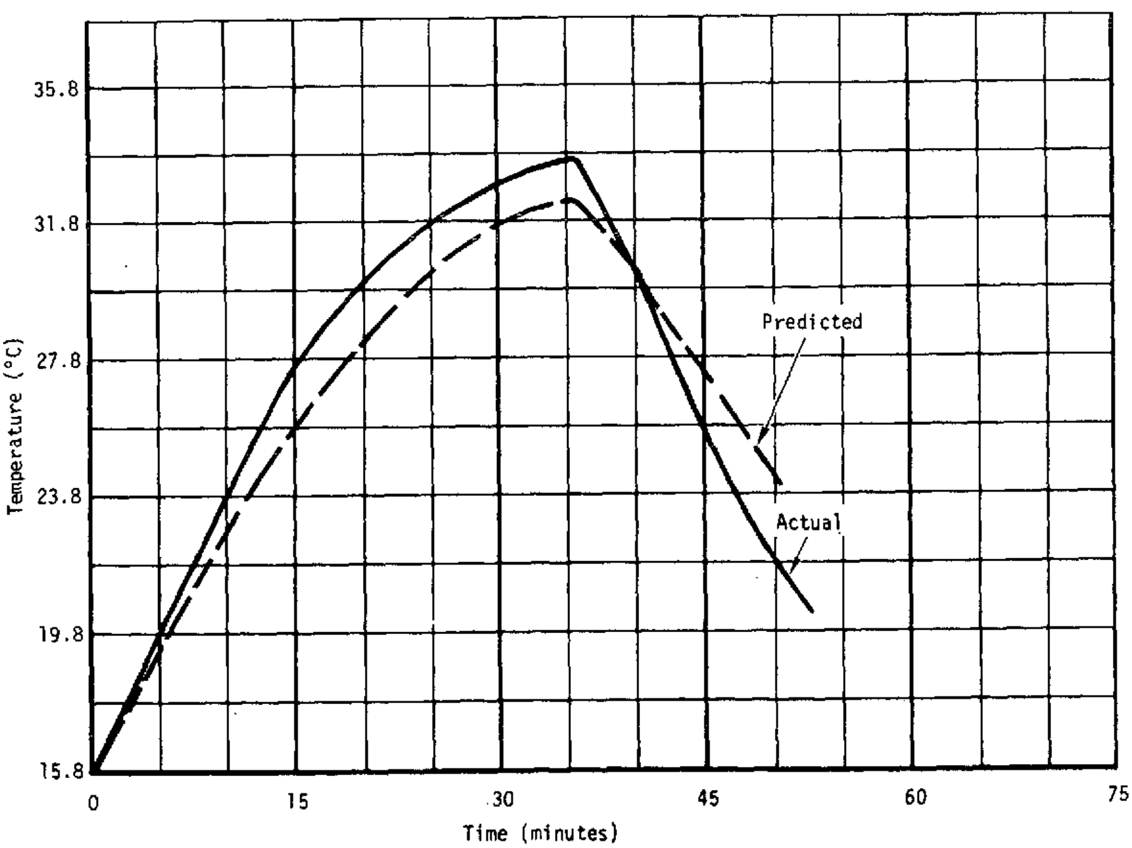


FIGURE 24. S052 CAMERA TEMPERATURE DURING STALL ON SKYLAB 3

figure 25, braking the take-up reel until it stopped. As film continued to feed through the camera, the exposed film threaded randomly into the remaining cavity. A loop became threaded in the supply drive-sprocket, causing a jam at that point. When the supply drive-sprocket stopped, the film-transport operation was stopped through the drive gear train.

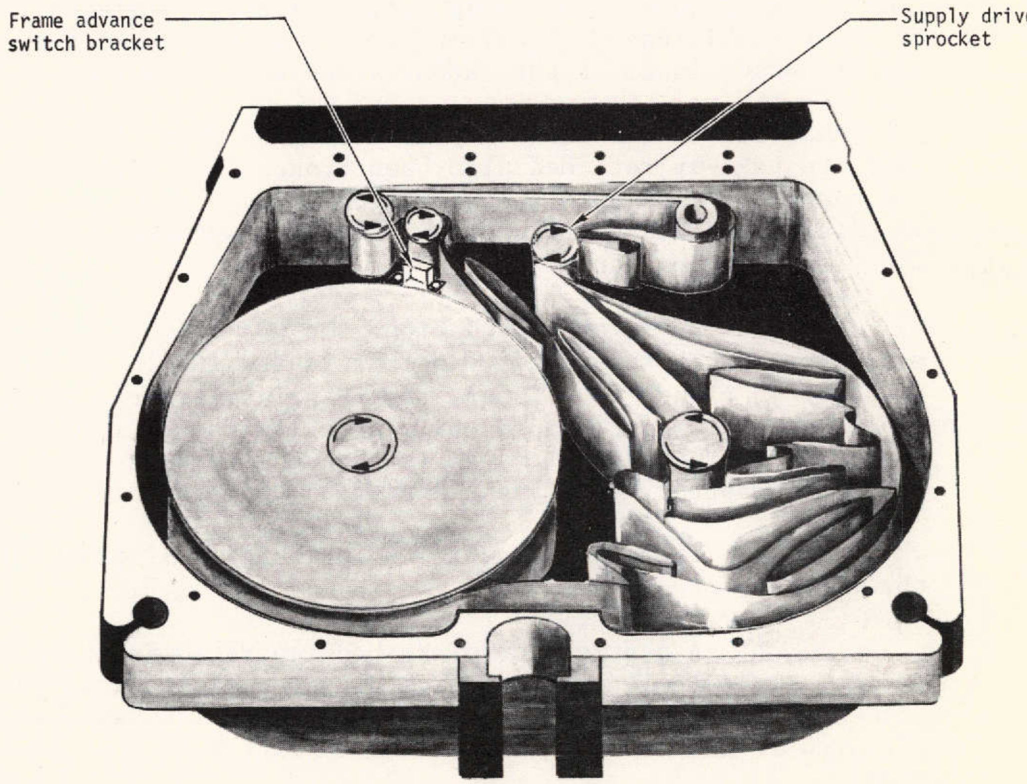


FIGURE 25. S052 REPRESENTATION OF FILM CAMERA STALLING DUE TO FULL TAKE-UP REEL

Although the second Skylab 3 camera was considered to have operated satisfactorily, possible causes for the condition were investigated. Improper placement of the frame-advance switch bracket could reduce the quantity of film required to cause the braking action. However, each film-camera was checked out with a full roll of film a minimum of two times prior to acceptance. It was possible that the film took a more rigid permanent set than was previously experienced. Since the film was wound on the take-up spool in a direction opposite to that on the supply spool, such a set in the film may have caused the average layer thickness to increase. An increase of 0.00051 cm (0.0002 inch) in average layer thickness would have resulted in an increase in radius of the take-up film roll of more than 0.254 cm (0.1 inch). The average thickness of each layer of film on the take-up roll may have been increased if the film drive sprockets had deformed the sprocket holes in the film, raising the edges of the holes. If the take-up slip-clutch torque had been out of limits, the tightness of the take-up roll would have been affected, which could have allowed the take-up roll to increase in size. None of these conditions were evident from examination of the film, and the exact cause of this anomaly was not determined.

Analysis of the first Skylab 3 camera (film load 2) showed that its take-up reel had also been braked to a stop and film had randomly piled into the remaining cavity. However, the film in this camera had not caught in the drive sprocket, or jammed the film-transport drive.

Television System Degradation. On DOY 337 the crew observed a bright spot on the S052 TV monitor in the 10 o'clock position as shown in figure 26. Later, the TV grid discharge switch was depressed and then released while watching the TV image. This test indicated the problem was in the S052 TV camera, as the spot did not disappear. Analyses identified two possible causes:

a. There was a particle on the grid discharge line of the vidicon; or

b. A particle or flake had separated from the vidicon target. This could create a high signal current sufficient to saturate limiting circuits in the TV electronics, and cause the affected TV rasters to go black due to the absence of beam current.

The degradation was considered permanent, and normal S052 operations continued with the degraded TV until the end of the mission. The exact cause of the anomaly was not determined.

On DOY 340 the crew reported the presence of a black bar extending across the screen through the white spot. The crew noticed that the bar remained, even when the TV mirror was in the film-camera position, and the grid discharge did not change the polarity of the spot or bar. The condition of the TV vidicon remained static from DOY 340 to DOY 031, at which time a second bright spot

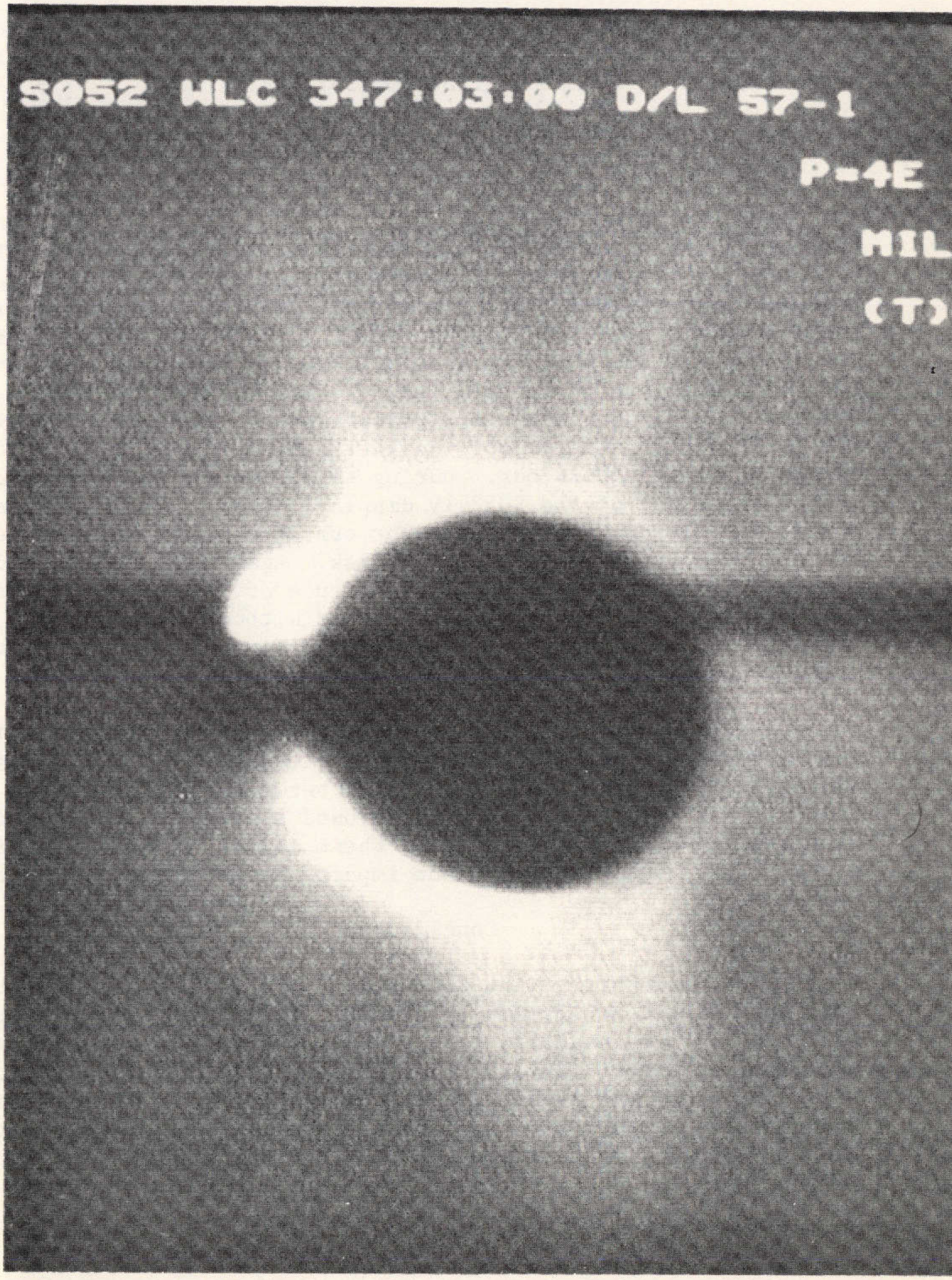


FIGURE 26. S052 TV MONITOR DISPLAY SHOWING BRIGHT SPOT AND BAR

and corresponding black streak were noticed on the S052 monitor. The condition of the TV camera remained unchanged from DOY 031 until the end of S052 operations on DOY 034.

The S052 TV degradation had no significant impact on the experiment mission objectives.

Occulting Disk Contamination. On DOY 164 and DOY 238, contamination was noted on the S052 instrument occulting disk. This was observed by the crew and verified by downlink TV. The effect of this contamination is seen in figure 15 as a crescent of light, tangent to the occulted area, at the 7 o'clock position. During EVA on DOY 170 and 265, the crew brushed the occulting disk area, and the contamination was removed. However, while the EVA on DOY 265 was in progress, additional floating particles were observed. The S052 thermal shield door was left open in hopes that the contamination would drift out. During this same EVA, the crew reported streaking of the S052 TV display, closing of the thermal shield door twice by automatic door operation, and reappearance of contamination on the occulting disk. Again the occulting disk area was brushed, and no further evidence of contamination was seen. These measures were accomplished without damage to the occulting disk knife edges, and eliminated significant sources of scattered light.

Operate Light Went Off. On DOY 151 the crew reported that the S052 operate light went off for periods of 5 to 10 seconds. Additionally, a discrepancy was noted between the onboard FRC indication (7,641 frames) and the ground estimate (7,159 based on telemetry data). The cause of these anomalies was not determined. There was no significant impact on instrument operation.

Conclusions

The manned White Light Coronagraph operated within the stringent specifications imposed by Skylab. The result was the accumulation of a large quantity of the highest quality data in history of coronal science. Because of the previous limitations on coronal observing time, the Skylab mission has afforded a veritable breakthrough in solar-corona observations. The Skylab mission is certain to become a major milestone in the development of solar-corona physics.

SECTION V. X-RAY SPECTROGRAPHIC TELESCOPE (S054)

Description

General. The X-Ray Spectrographic Telescope was designed to study solar emissions in the soft X-ray spectrum (from 3 to 60 angstroms). The instrument photographed solar flares within this spectrum during active periods and obtained broadband X-ray photographs of the Sun in selected regions of the X-ray spectrum during non-flare periods. The telescope provided a field of view of 48 arc-minutes covering the entire solar disk. The S054 system contained a telescope assembly and seven electronic assemblies. The dimensions and weights of the assemblies are presented in Table 8 and their locations are shown in figure 27. The S054 telescope is presented in figure 28.

TABLE 8. S054 ASSEMBLIES DIMENSIONS AND WEIGHTS

Assembly	Weight (Kilograms)	Dimensions (Centimeters)
Telescope Assy	133.6	291.6 by 54.6 by 49.3
Main Electronics Assy	27.3	54.6 by 47.8 by 20.6
Temperature Control Assy	7.7	17.8 by 20.8 by 30.0
*Intensity Display Counter	2.3	23.9 by 13.5 by 9.9
*Exposure Display Counter	2.3	23.9 by 13.5 by 9.9
*Intensity Modulation Assy	2.3	27.7 by 6.1 by 15.2
*CRT Display Assy	4.6	25.4 by 19.8 by 9.9
*Low Voltage Power Supply	3.2	22.4 by 12.7 by 7.1

*Mounted in C&D Console

Optical Systems. The telescope contained 3 distinct optical systems which are shown in figure 29. The primary imaging system consisted of prefilters, grazing-incidence X-ray telescope mirrors, transmission grating, filters, and a film camera. The coaxially-mounted, grazing-incidence X-ray mirrors provided a total collecting area of approximately 42 square centimeters at 8.3 angstroms. The mirror inside diameters were 22.8 centimeters and 30.5 centimeters and the focal length was 213 centimeters. The transmission grating was positioned in or out of the X-ray radiation path by C&D console command. The grating intercepted a portion of the incident energy and produced a dispersed image over a range of 3 to 60 angstroms. Five broadband X-ray filters were mounted on a rotating filter wheel located in front of the camera. The wheel

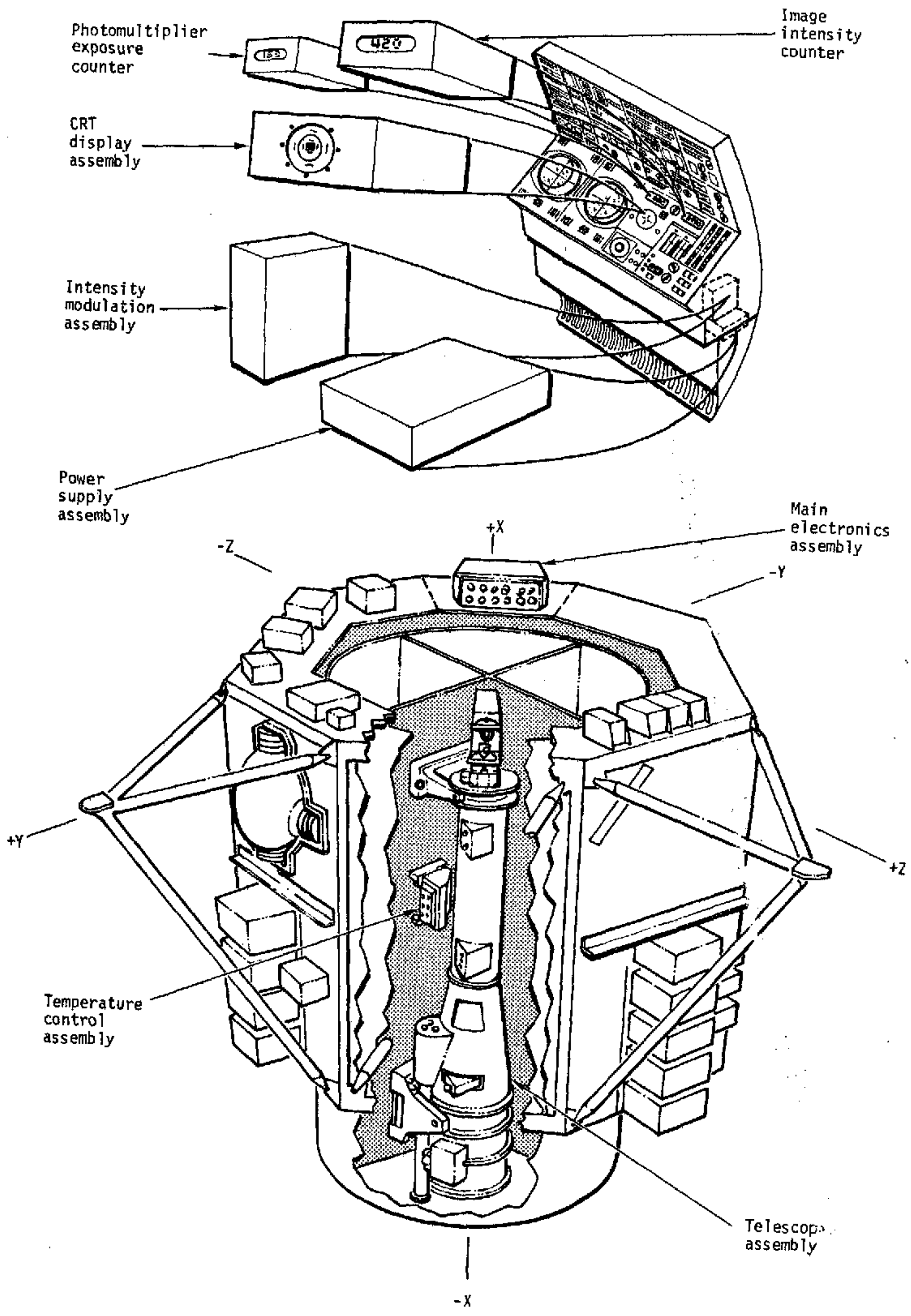
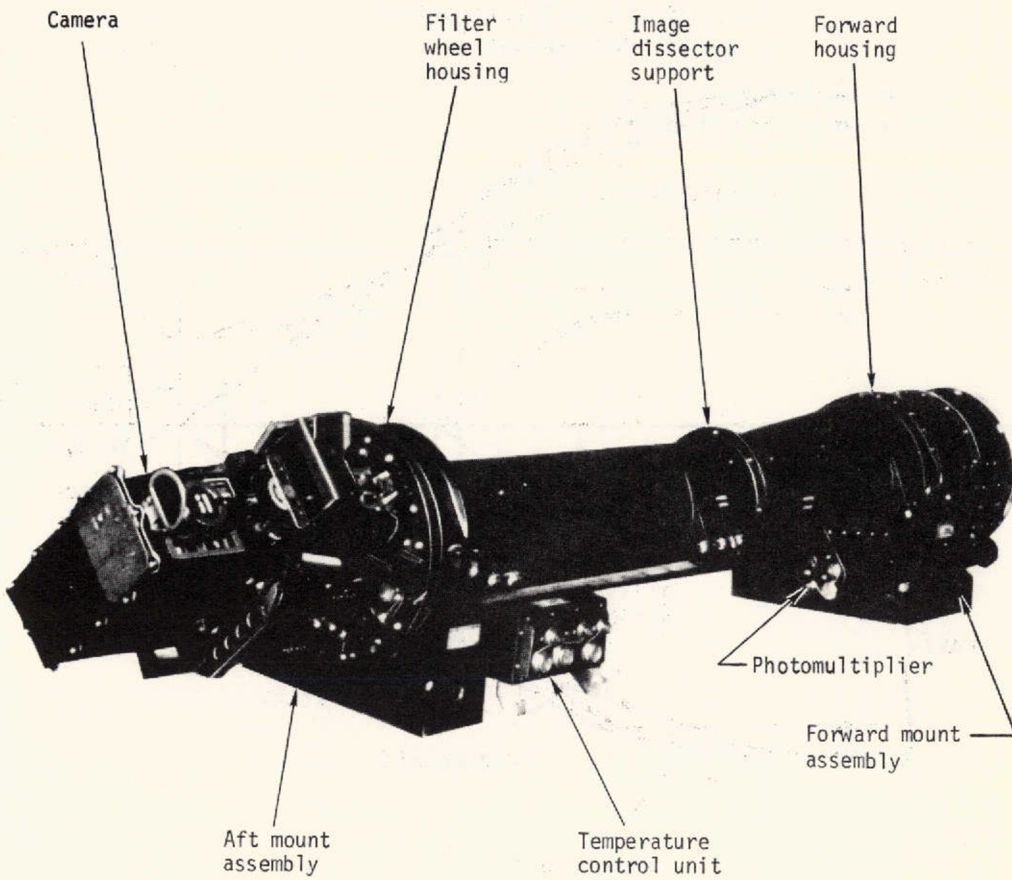


FIGURE 27. S054 ASSEMBLY LOCATION



Length - 114.8 in. 291.6 cm
Height - 19.4 in. 49.3 cm
Width - 21.5 in. 54.6 cm
Weight - 311.0 lbs 141.3 kg

FIGURE 28. S054 X-RAY SPECTROGRAPHIC TELESCOPE

also contained an open aperture position. Any one of the six filter wheel positions could be selected from the C&D console. Any one of three positions could be commanded from the ground. In addition to the five wheel-mounted filters, a prefilter and a camera magazine window were mounted in the radiation path. The prefilter was located in front of the telescope mirrors, and reduced the heat transmitted to the X-ray filters and film. The camera magazine window prevented exposure to visible and ultraviolet light.

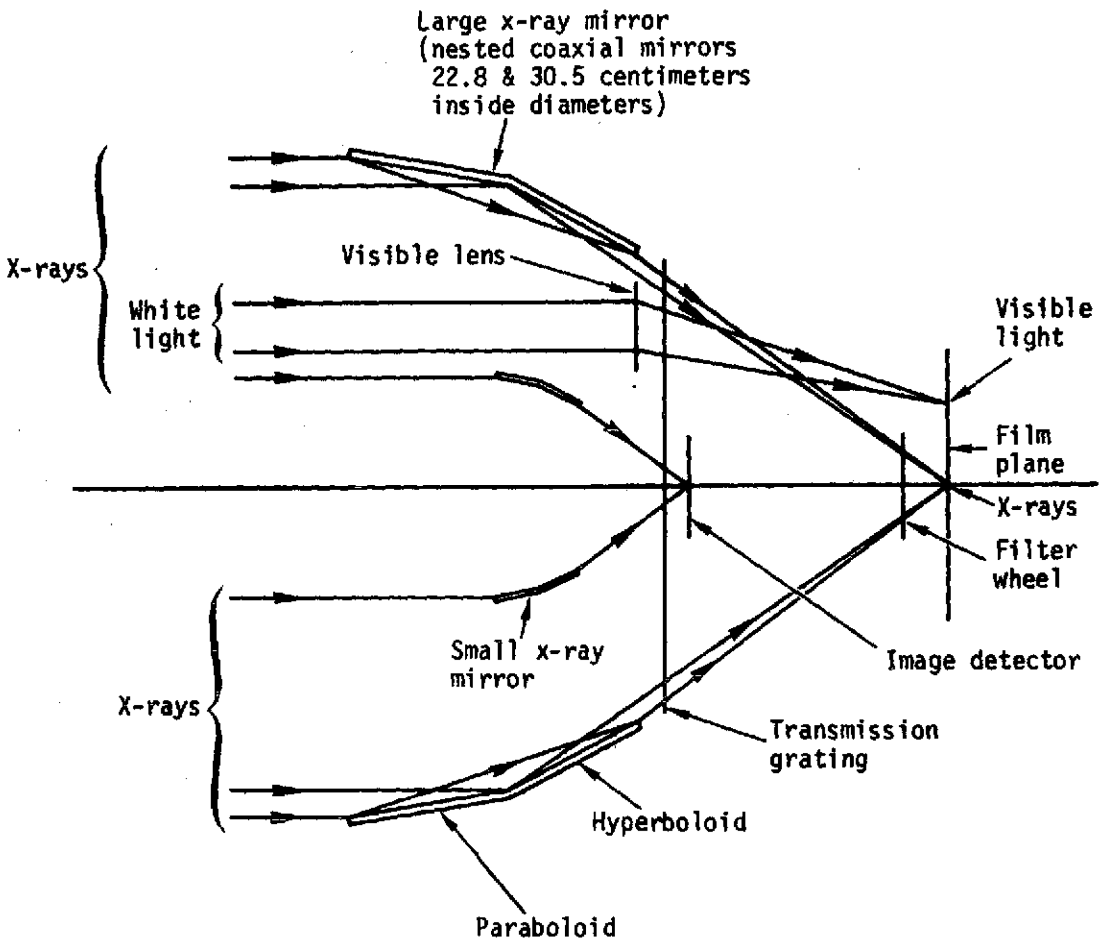


FIGURE 29. S054 OPTICAL SCHEMATIC

The second optical system consisted of a visible light lens which recorded a solar image on each film frame. The lens was an achromatic doublet with 2 neutral density filters and was 4.45 centimeters in diameter.

The third optical system contained a 7.6 centimeter X-ray mirror which provided a solar image to the C&D console for X-ray pointing.

Film Camera. The film camera consisted of a shutter assembly, a removable magazine assembly, a support structure, and electronics. The shutter assembly contained a visible light shutter and X-ray shutters. The visible light exposure time was fixed at 1/100 second. The X-ray shutter consisted of two blades which moved across the X-ray aperture. X-ray exposure duration was controlled by moving the first blade clear of the aperture and then moving the second blade to cover the aperture. X-ray exposure time ranged from 1/64 to 256 seconds. Each frame recorded X-ray and visible light images, spececraft time, exposure duration, grating position, and filter position.

The magazine contained a nominal 6,970 frames of 70-millimeter SO-212 film, the film transport mechanism, and the takeup and supply cassette. Magazines (film loads) were replaced by the crew during EVA. Five film loads were used during Skylab. Four magazines were launched aboard Skylab 1. One magazine was mounted on the camera and three magazines were stored in the MDA film vaults. The fifth film load was made available by supplying a film cassette on Skylab 4 which the crew loaded into a spent magazine.

Pointing System. The pointing system provided position information and an image intensity count of active solar regions. X-ray energy was collected by the 7.6-centimeter mirror and was imaged on the image dissector. The output of the image dissector was displayed on the X-ray image monitor on the C&D console. During flares the location of the emitting region was detected by the brightening of a portion of the X-ray image monitor and the crew could point the ATM canister to center the flare on the display. The adjacent digital image intensity counter indicated the overall relative solar X-ray intensity.

Photomultiplier System. The photomultiplier system monitored X-ray activity within a 6-degree field-of-view. The output of the photomultiplier was used for automatic flare detection, automatic control of camera and exposure times, and telemetry data on solar activity for scientific analysis. Photomultiplier activity counts were also displayed on the C&D console. Flare alarm intensity threshold levels were set by the crew at the C&D console according to mission philosophy. When the photomultiplier exposure counter readout exceeded the flare threshold setting, outputs were provided to the flare alert system which triggered a visual and audible alarm.

Thermal Control System. The TCS consisted of primary and secondary control loops which provided a fully redundant thermal control capability. Four primary temperature sensors were located within the telescope assembly and regulated proportional controllers which supplied power to the primary elements of heater blankets located within the telescope assembly. The primary thermal control loop maintained an average temperature of 21.1 $\pm$ 1.1°C (70 $\pm$ 2°F) when the telescope was in the 10°C (50°F) environment of the ATM canister. The secondary temperature control loop was controlled by four mercury thermostat temperature controllers located on the telescope assembly. Selected temperature data were telemetered to ground.

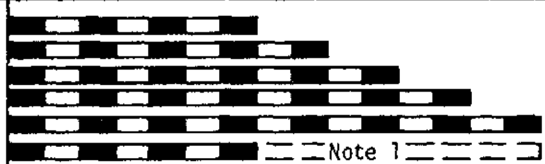
Operation. The most frequently made solar observations were daily synoptic observations. The minimum synoptic observation consisted of a sequence of 8 frames taken with filter 1 or 3. During attended operations additional sequences using filters 2 and 6 followed.

During manned operations the instrument was configured as specified in the uplinked flight plan, in accordance with JOPs. In general, shorter exposure ranges were selected during periods of high activity. A faster picture rate was used during flare rise observations, and the X-ray diffraction grating was placed in the optical path during some flare observations. Filters were selected as required to vary the spectral transmission characteristics of the instrument. The automatic picture sequences controlled by the photomultiplier system were not used during the mission. Figure 30 illustrates camera modes and figure 31 is a schematic showing instrument functions.

Mission Performance

General. The X-ray Spectrographic Telescope successfully accomplished mission objectives by obtaining data of the solar corona in the 3- to 60-angstrom range of the soft X-ray spectrum. High-resolution photographic and photoelectric data verified successful instrument performance. Although the instrument was designed to an orbital life requirement of 42 days, it operated within design specifications through the 270 days of the mission.

Instrument Performance. The S054 instrument obtained more than 31,000 photographs. Four film magazines and one reload operated as designed with no failures. Additional X-ray data were obtained by the photomultiplier and image dissector systems which provided intensity and pulse height information on solar activity. The photographic data system performed as designed until DOY 331 when the filter wheel stuck between positions 5 and 6. S054 operation continued; however, the exposures taken during the failed period were limited to features with relatively high surface brightness. Repair during EVA on DOY 359 enabled instrument operations with expsoures taken with the filter wheel in position 3 (no filter). See page 63 for a discussion of this anomaly.

Exposure range switch position	Sequence Exposure sequence cycle Executed by camera 1/64 1/16 1/4 1 4 16 64 256	Total time for sequence High rate ΔT = 0.3 sec	Total time for sequence Low rate ΔT = 12 sec
1		2.5 sec	49.3 sec
4		6.8 sec	65.3 sec
16		23.1 sec	93.3 sec
64		87.4 sec	169.3 sec
256		343.7 sec	437.3 sec
Auto	Note 1		

Shutter open time
Time delay between exposures = ΔT

Note 1: In auto, proper exposure sequence is automatically selected by flare detection system, per relationship below.

Photomultiplier exposure count	Exposure range
0-239	256
240-479	64
480-599	16
600-839	4
840-960	1

Picture rate switch position	Rate Determines rate (high or low) and duration (single or repetitive) of exposure sequence Manual mode *	Flare auto mode **
Single	1 sequence @ high rate (ΔT = 0.3 sec)	1 sequence @ high rate (ΔT = 0.3 sec)
Low	Sequence repeated @ low rate (ΔT=12 sec) for 13 min or until stop command issued	Sequence repeated @ low rate (ΔT=12 sec) as long as flare threshold exceeded or until flare auto-inhibit command issued
High	Same as low rate above with ΔT=0.3 sec	Same as low rate above with ΔT=0.3 sec
Program	1st 4 min @ high rate then low rate for 9 min or until stop command issued	1st 4 min @ high rate then low rate as long as flare threshold exceeded or until flare auto-inhibit command issued

*Initiated by "start" command
Terminated by "stop" command

**Initiated by flare signal with flare auto switch enabled.
Terminated by flare auto-inhibit command

FIGURE 30. S054 CAMERA EXPOSURE SEQUENCES AND PICTURE RATES

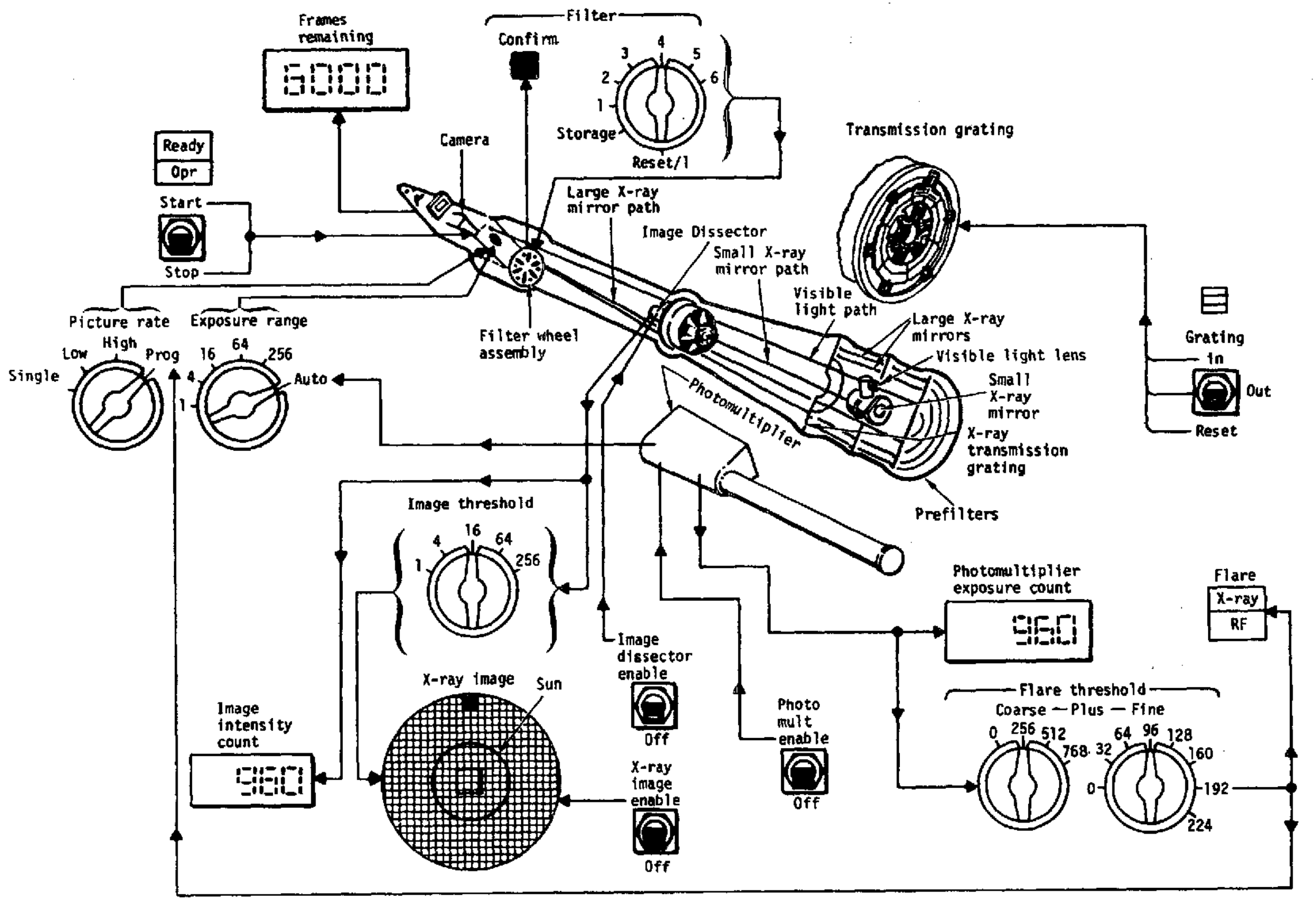


FIGURE 31. S054 X-RAY CONTROLS AND DISPLAYS CONCEPTIVE REPRESENTATION

The instrument pointing system (image dissector, X-ray image monitor, and image intensity counter) performed as required. Operation was stable through the mission until the latter part of Skylab 4. On DOY 350 the crew reported that the lower 40 percent of the display on the X-ray image monitor intermittently disappeared. ATM operations were not hampered and no repair action was necessary. A detailed discussion of this anomaly is on page 67.

The photomultiplier and flare detection system performed as designed. No degradation was observed on the onboard monitor or photoelectric data received on downlinked telemetry. No change in resolution, sensitivity, or efficiency was noted throughout the mission. The photomultiplier detected X-ray radiation within a 6-degree field-of-view and provided a proportional pulse count to the S054 flare detection system. The crew selected a flare threshold which, when exceeded by high energy flux, provided a flare alert signal.

The S054 TCS performance was optimum throughout the mission. All instrument temperatures were maintained within the prescribed limits by the primary TCS. The location of the temperature sensors is shown in figure 32. Typical instrument temperatures are shown in figure 33 and representative of the entire mission. The secondary TCS was not used.

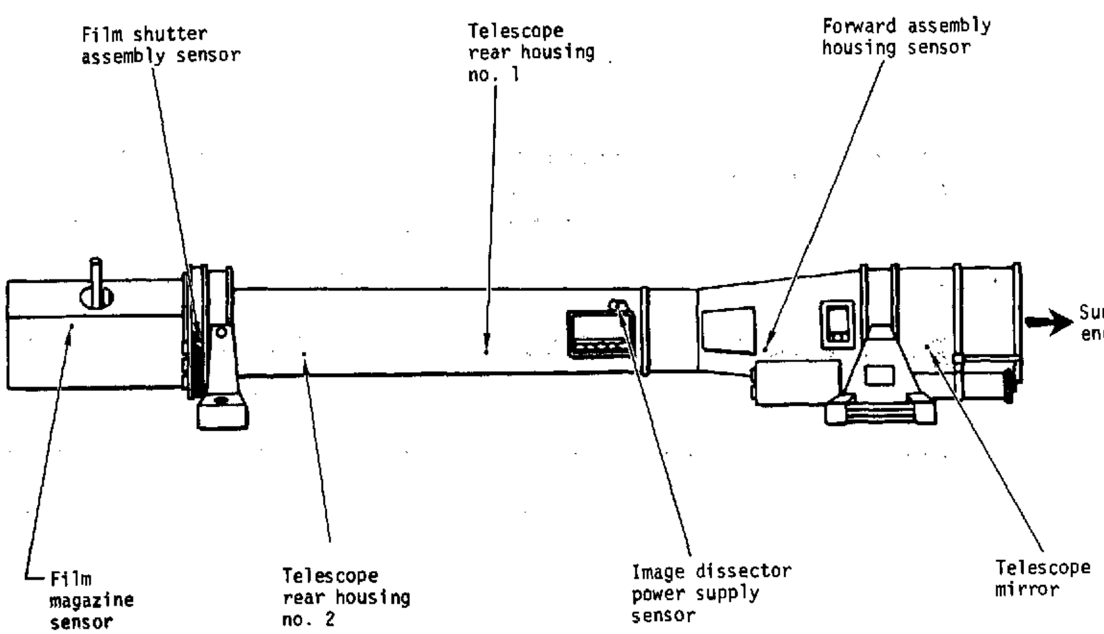


FIGURE 32. S054 TEMPERATURE SENSOR LOCATIONS

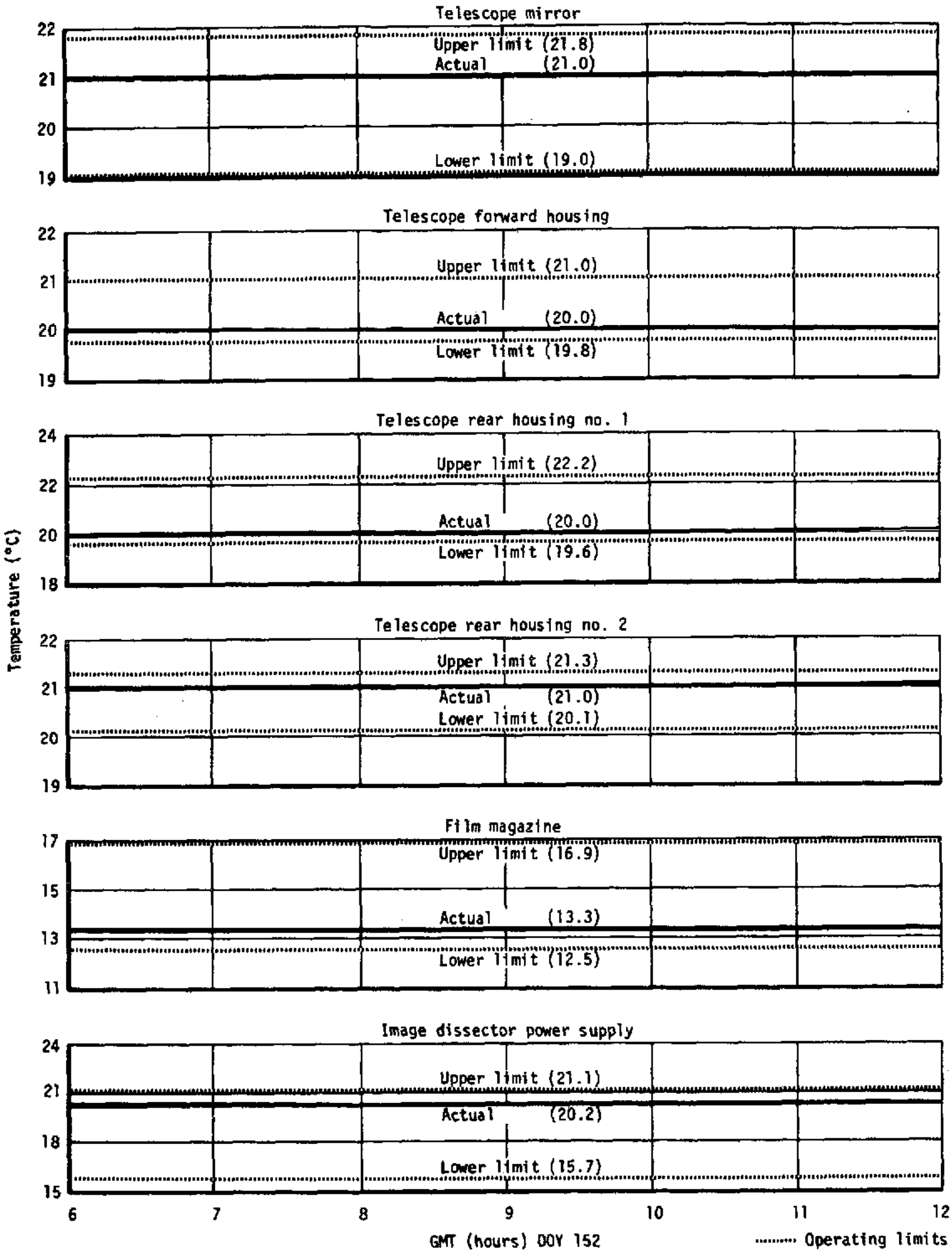


FIGURE 33. S054 TYPICAL MISSION TEMPERATURES

Telemetered voltage data indicated that S054 power supplies were stable and within the required limits. Table 9 shows a comparison of voltage readings obtained during ground test, early mission, and late mission.

TABLE 9. S054 COMPARISON OF TELEMETERED VOLTAGES

Measurement	Ground Test Average (Vdc)	Early Mission Average (Vdc)	Late Mission Average (Vdc)
Calibrate, High	4.74	4.73	4.73
Calibrate, Low	2.56	2.56	2.56
Main Electronics +5	5.15	5.15	5.11
Main Electronics +10	10.36	10.31	10.31
Main Electronics +15	15.15	15.15	15.15
Main Electronics +20	19.7	19.6	19.6
Main Electronics +35	35.3	35.1	35.1
Main Electronics +150	150.0	150.0	150.0
Main Electronics -5	-5.05	-5.05	-5.05
Main Electronics -15	-15.38	-15.31	-15.31
Main Electronics -20	-20.7	-20.5	-20.5
Main Electronics -45	-45.7	-45.9	-45.9
Main Electronics -150	-152.3	-152.3	-152.3
+X Amplifier Deflection	151.8	152.5	152.5
-X Amplifier Deflection	-152.7	-151.8	-152.7
+Y Amplifier Deflection	139.4	139.2	139.2
-Y Amplifier Deflection	-137.8	-136.7	-136.7
C&D +5	5.04	5.05	5.05
C&D +10	10.2	10.2	10.2
C&D +150	150	150	150
Image Dissector +3K	2100	2114	2114
Image Dissector -3	-3.02	-3.01	-3.01
Photomultiplier -3K	-2140	-2137	-2137
Image Dissector -500	-421	-419	-419
CRT -1500	-1538	-1520	-1520
C&D -20	-20.0	-20.0	-20.2
CRT -225	-222	-219	-217
Image Dissector -1K	-1080	-1080	-1073
C&D +15	14.8	14.9	14.9
C&D -15	-15.0	-15.0	-15.0
Reference No. 1	6.36	6.38	6.38
Reference No. 2	6.39	6.38	6.38
Reference No. 3	6.39	6.35	6.35

On DOY 169 an instrument logic reset occurred which affected two telemetry measurements, picture count and X-ray shutter duration. The resets continued randomly throughout the mission; however, no scientific data were lost. The cause of the resets could not be determined. Details of this anomaly are given on page 67.

ATM Interface. Interface support provided to the S054 instrument was adequate. However, some conditions developed which resulted in some data loss.

On DOY 147 it was discovered that main power to the S054 instrument could not be turned off. Unsuccessful attempts were made through ground and C&D console commands to power down the instrument. The probable cause of this anomaly was a relay failure or associated wiring within the ATM networks. Instrument power remained on until the end of the mission.

Telemetry data generally were adequate but some data loss during Skylab 2 was evident because of ground-site telemetry synchronization problems.

The thermal shield door subsystem presented a problem after 5 days of operation. The S054 thermal shield door failed to open on DOY 153, and after performing a door malfunction procedure, the crew obtained a panel indication that the door was open. The decision was made to discontinue all S054 thermal shield door operations. Because of the ATM thermal shield door interface design characteristics, S052 and H-Alpha operations were affected (reference Sections IV and X). S054 instrument operations continued and approximately 1,500 frames of film were transported. The crew, during EVA on DOY 158, reported that the thermal shield door was in the closed position. The panel indication had been erroneous, and the film advanced during this period was unexposed. The crew implemented a backup procedure which allowed the door to be permanently latched open. Loss of the thermal shield door cycling function did not thermally affect the instrument, but created an operational problem. The door circuitry provided a signal level to the ready/operate logic. With the door permanently open and electrically disabled, the door-open signal was not generated and the ready/operate indication on the C&D console was inhibited. This created a crew inconvenience since they had no indication of camera mode status. A timer was supplied on Skylab 3 to provide camera operating status to the crew.

On DOY 197 ATM experiment pointing control system problems necessitated use of the solar inertial mode of operation until DOY 210. The solar inertial mode had less pointing stability than the experiment pointing mode, resulting in some loss of resolution in the film exposures made during this time. Approximately 380 exposures were made during solar inertial pointing. Approximately 10 percent of these exposures showed noticeable jitter or drift.

During the extended EVA on DOY 218, involving film magazine exchange, both the exposed film in the magazine removed and the unexposed film in the magazine for installation were subjected to excessive temperatures. After installation, the telemetered temperature of the installed film magazine was 6.9°C (12.4°F) above the maximum allowable temperature for the film. Calculations indicated the temperature of the exposed film was 19.1°C (35.2°F) above the maximum allowable. Subsequent analyses of background and fog levels on the returned film indicated no significant fogging due to the high temperatures.

Man/Machine Interface. Significant crew accomplishments relative to the S054 instrument were latching open the thermal shield door, clearing the jammed filter wheel, and loading a film cassette into a spent magazine to allow exposure of a fifth film load.

Scientific Data Quantity and Quality. Optical quality of the developed film was excellent, indicating that alignment of the telescope optical elements was maintained. Five film loads were used and 31,785 solar images were obtained. Table 10 illustrates film usage per mission.

TABLE 10. S054 FILM LOAD USAGE

Film Load	Skylab Mission	Frames Available (1)	Frames Exposed		Installed (DOY)	Removed (DOY)
			Unmanned	Manned		
1	2	6970	---	5155 (2)	Prior to Skylab 1 Launch	170
2	3	6970	2000	4595	170	236
3	3	6970	---	6730	236	265
4	4	6970	2201	4359	265	359
5	4	6970	---	6745	359	034

(1) Frames available varied slightly with the amount of film in each load.
(2) An additional 1,500 frames were transported with the thermal shield door closed.

Evaluation of film data revealed that spatial resolution was better than 2 arc-seconds, which compares favorably to the design requirement of 3 arc-seconds. Spectral resolution, $\lambda/\Delta\lambda$, was 50, at 7 angstroms. The design requirement was 30, at 7 angstroms. No noticeable jitter or drift was evident on the photographs except, as anticipated, when the ATM experiment pointing control was disabled. Figure 34 is a photograph of the solar disk taken on DOY 148 showing details of the corona and bright points.

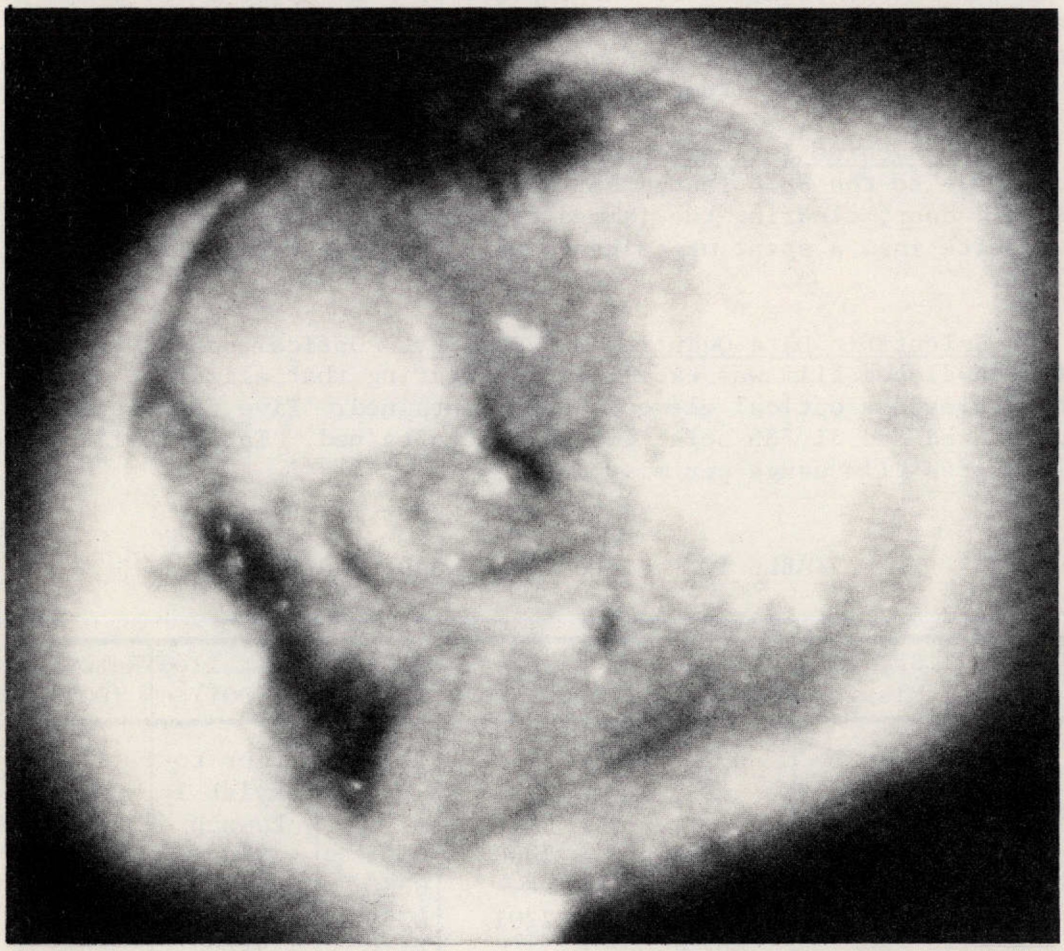


FIGURE 34. S054 FILM CAMERA PHOTOGRAPH OF SOLAR DISK

Dispersed images from 3 to 60 angstroms were recorded during Skylab 3 and 4. No dispersed images were obtained during Skylab

2 since the X-ray transmission grating was not used during that mission.

The first solar flare detected on Skylab occurred on DOY 166. Approximately 380 exposures were obtained on S054 film showing flare growth in the X-ray region. Photoelectric flare data were received via telemetry and recorded. Figure 35 is a response curve showing the telemetered photoelectric data during the flare. The figure also illustrates the effect of the SAA radiation. Figure 36 is a response curve of the intensity monitor output during the flare.

During the latter portion of Skylab 4 when the camera shutter blade was disabled, the film showed some image blurring on the shorter exposure times. However, two modes of operation were created that provided better temporal resolution and data correlation with the S052 instrument (reference Section IV). The open shutter allowed long exposures which had been previously prevented by the inability to turn the main power off. With long expsoure, data were obtained out to 1.5 solar radii. These data can be compared with those of the S052 instrument to obtain electron number density and electron temperature independently. Use of the LOW/64 mode provided many closely spaced 12-second exposures which yielded improved time resolution data on rapid changes in the core of active regions and coronal bright points.

Anomalies

<u>General</u>. An S054 anomaly occurred during Skylab 4 that resulted in degraded data on both film loads used during that mission. The filter wheel stuck between filters 5 and 6. When the crew moved the filter wheel, the shutter was bent and moved into the optical path. This resulted in some data loss. Two other anomalies occurred; an instrument logic reset; and a slightly degraded X-ray TV image. These had no significant impact on instrument operations. Details of these anomalies are discussed below.

<u>Filter Wheel Failure</u>. On DOY 331 during initial checkout of the ATM systems for Skylab 4 manned operations, the filter wheel stopped between filters 5 and 6. Filter 5 is a 2-mil beryllium filter; filter 6 is a 1-mil beryllium filter. Since these were the most dense filters in the filter wheel, data taken from DOY 331 until the EVA repair on DOY 359, were limited to features with relatively high surface brightness. Flares, active regions, and coronal bright points typically have high surface brightness. The S054 photograph shown in figure 37 illustrates the field-of-view with reduced intensity resulting from the filter wheel being

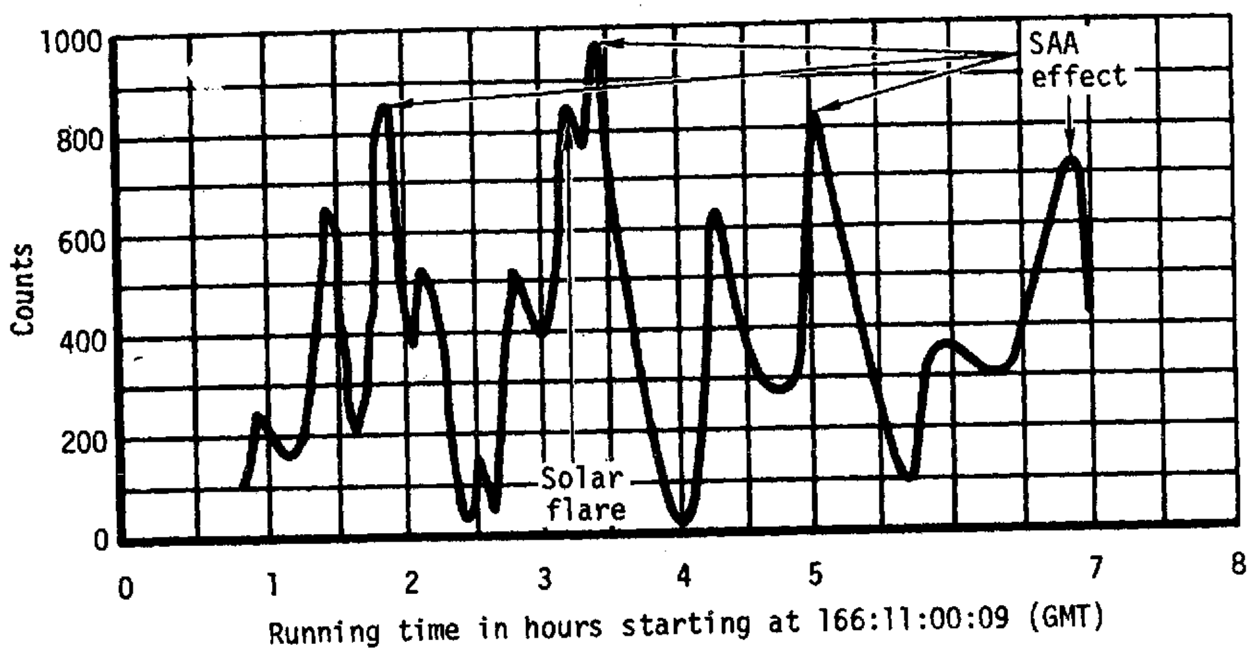


FIGURE 35. S054 PHOTOMULTIPLIER X-RAY RESPONSE

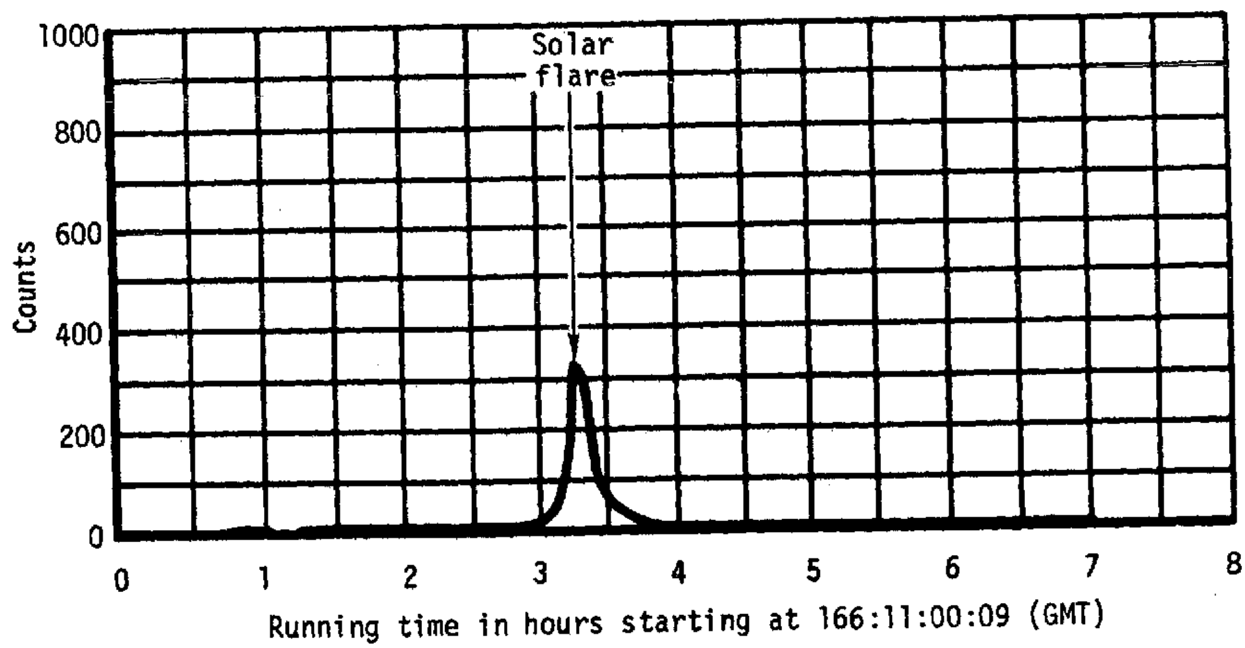


FIGURE 36. S054 X-RAY INTENSITY MONITOR RADIATION RESPONSE

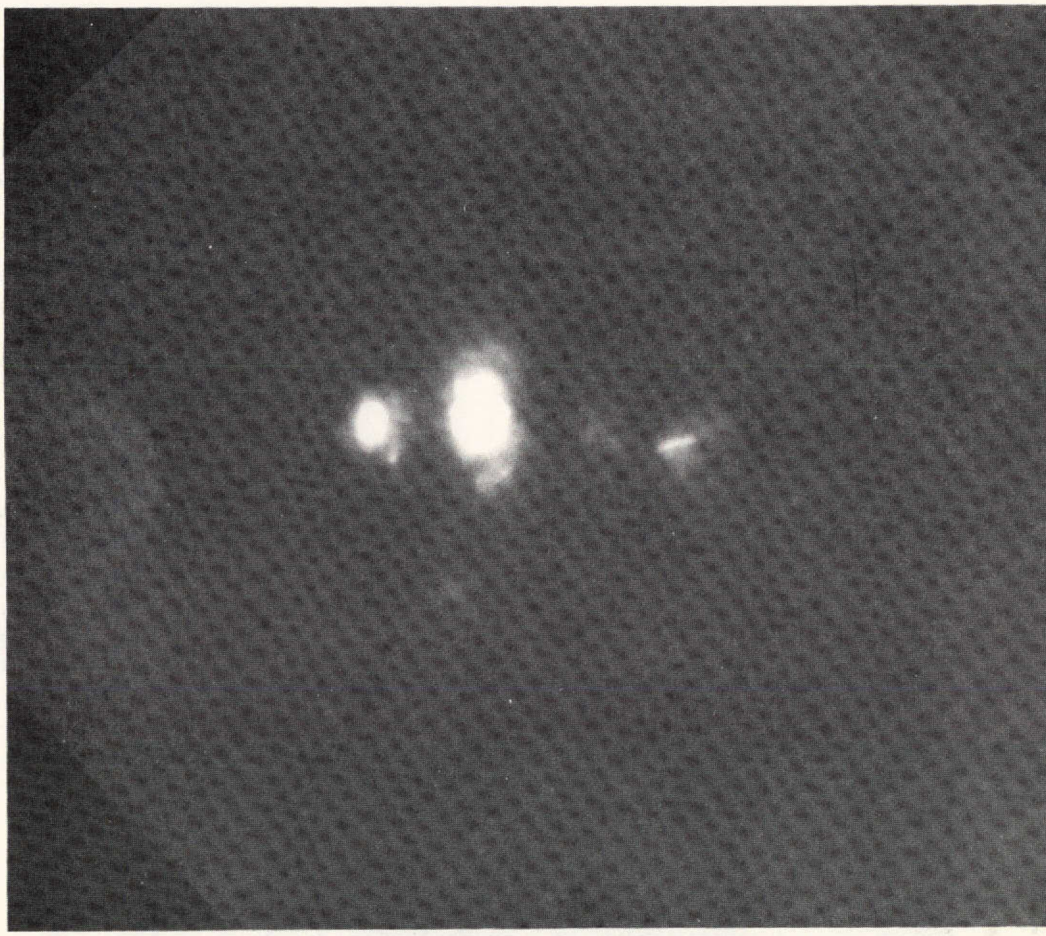


FIGURE 37. S054 SOLAR IMAGE THROUGH FILTER 5

stuck between positions 5 and 6. Simulation tests verified that it was possible for the crew to move the filter during EVA. EVA procedures were developed for this purpose, and on DOY 359 the EVA filter repair was attempted. The procedure involved manually opening the shutter, and moving the filter wheel with a modified existing tool. During the EVA, the shutter was bent out of its guides making it impossible to operate the shutter. The shutter opening was cleared by bending the shutter out of the way. The filter wheel was subsequently moved to position 3 (no filter).

Associated with each S054 film magazine was a contingency device known as a shutter override actuator. Installation of this device on the film magazine allowed camera operations, in the event of a shutter failure, by bypassing the shutter logic in the camera electronics. The crew installed the shutter override actuator on the S054 film magazine, prior to the EVA for replacing the film magazine and repairing the S054 filter wheel. The shutter override actuator was installed as a precaution against a broken shutter drive belt or other shutter damage that might occur during the repair of the filter wheel. However, analysis of load 5 film indicated that the bent shutter blade partially obscured the optical path. This produced several shadows on the X-ray image, resulting in some data loss. The effect of the bent shutter in the optical path is illustrated in the S054 photograph shown in figure 38.

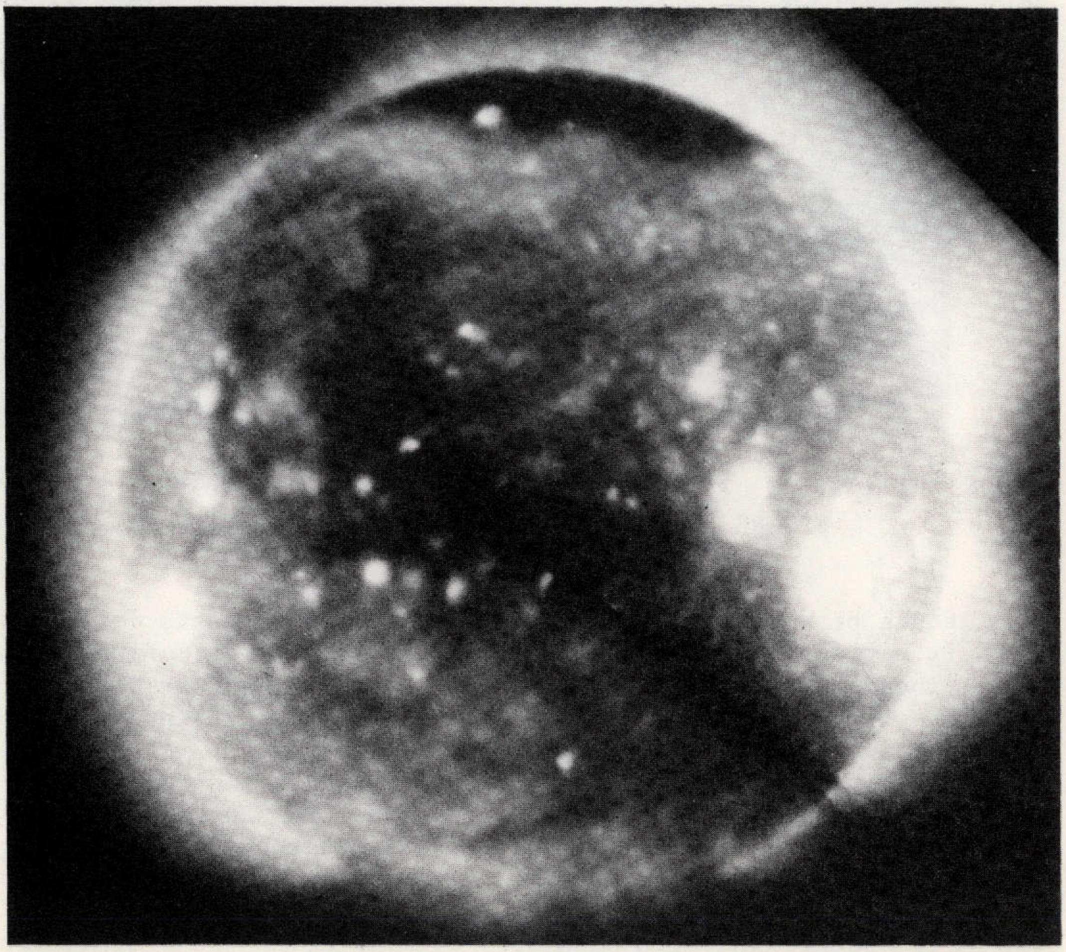


FIGURE 38. S054 DEGRADED SOLAR IMAGE CAUSED BY BENT SHUTTER BLADE

During ATM closeout activities at the end of Skylab 4, the filter was commanded from position 3 to position 1. It drove normally through positions 4, 5, and 6 at that time. The conclusion was that the filter mechanism was jammed mechanically at the time of the repair and that moving the wheel manually cleared the jam.

A secondary problem with the shutter duration counter developed after installation of the magazine with the shutter override actuator. All values of shutter duration readout, except the 4-second value, were 4 seconds longer than normal. This was attributed to a failure of the 4-second bit to reset because of the shorter reset pulse generated when the camera shutter electronics were bypassed with the shutter override system. Actual camera exposures were as designed and the telemetry error was due to the short reset pulse, combined with a marginal logic element in the 4-second bit of the shutter duration counter.

X-Ray Image Degradation. On DOY 350 the crew reported that the lower 40 percent of the S054 X-ray image would intermittently disappear. Malfunction procedures determined that the -Y deflection voltage to the X-ray image monitor was being lost. Analysis indicated the problem was caused by an intermittent connection between the rack-mounted main electronics assembly and the C&D console. It was impossible to determine the exact location of the intermittent connection. The crew did not feel that this malfunction greatly handicapped ATM operations; therefore, no corrective action was attempted.

Logic Resets. On DOY 169 an experiment logic reset occurred. The logic reset affected two telemetry measurements, binary picture count and X-ray shutter duration count. The periodic loss of the cumulative picture counts had no impact on accomplishing experiment objectives, but did require manual logging of film utilization by ground operations.

During the Skylab 3 unmanned phase, the logic reset became more frequent. The reset condition occurred approximately 20 times during this period. The reset continued during Skylab 3 manned and unattended operations. Ground support personnel manually tracked the number of frames exposed.

An attempt was made to correlate the reset with ATM events. The reset occurred most often, but not always, during the transition period from day to night. At this time, the fine sun sensor thermal shield door closes, the ATM spar gimbals are returned to the orbital lock position, and the attitude and pointing control system mode switches from experiment pointing to solar inertial. Analysis of the data available did not determine the cause of the reset problem. A best guess as to the cause of the reset was an intermittent short circuit of the S054 +5-volt power supply in one of three cables. The cables suspected were flat cables connecting the ATM canister with the ATM rack. Under certain conditions, canister motion could cause a momentary short circuit. Tests verified that an intermittent short circuit would cause a logic reset. There was no conclusive evidence to implicate the indicated cables.

Conclusions

The S054 instrument exceeded its designed performance life time. The spatial resolution of the X-ray images and the spectral resolution of the gratings were better than specified and overall image quality was excellent. The hardware, including the contingent shutter override mechanism, performed as designed.

The successful operation of the S054 instrument during the Skylab mission resulted in a major advance in solar X-ray imagery. It expanded the high-resolution observing time in X-ray from the previous all-time total of minutes to hundreds of hours. Not only was the quantity of data increased, but also the quality, because of improved resolution and sensitivity of the optics and because of the opportunity for time resolved studies.

The success of the instrument was in a large part due to the assistance of the crew. This was demonstrated by their ability to operate the instrument based on real time solar observations, to pin open the aperture door, to manually reposition the filter wheel, and to load a resupplied roll of film on board the Skylab.

SECTION VI. ULTRAVIOLET SCANNING POLYCHROMATOR SPECTROHELIOMETER (S055A)

Description

General. The Ultraviolet (UV) Scanning Polychromator Spectroheliometer, shown in figure 39, was designed to measure the intensity of solar radiation from selected regions of the Sun in the XUV wavelength region of 1350 to 296 angstroms with a 5 by 5 arc-second field of view. Simultaneous raster patterns of seven atomic lines were used to construct spectroheliograms. These were used to examine temperature changes between regions of super granulation, measure the apparent size of the Sun at

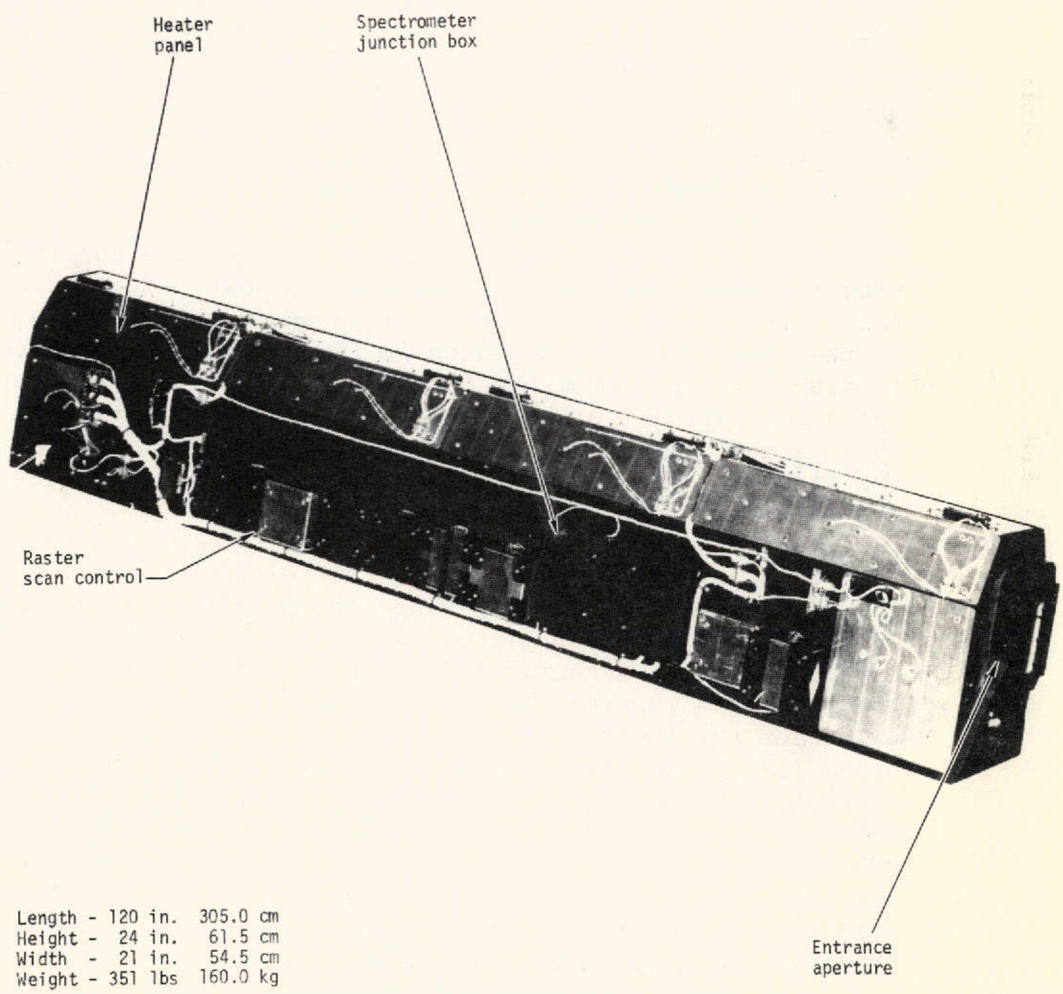


FIGURE 39. S055A UV SCANNING POLYCHROMATOR SPECTROHELIOMETER

various wavelengths, and determine the temperature and density structure of the low corona. Active regions of the solar atmosphere were examined by wavelength scan, selected single-line scans, and raster patterns. The instrument weighed approximately 160 kilograms and was 305 by 54.5 by 61.5 centimeters in length, width, and height, respectively.

Unlike other ATM instruments, this instrument carried no film. Data in various wavelengths were obtained by seven photomultiplier detector units (PDUs). The conditioned PDU outputs were telemetered to ground throughout the mission.

Control of the instrument was maintained through ground command or the C&D console. The C&D console enabled the crew to select the mode of operation, the spectral line(s) to be observed, and PDU(s) to be activated. The C&D console also provided the capability to monitor instrument status, grating and mirror position, internal instrument pressure, and the digital output from PDU 1 or 3. The H-Alpha Telescope TV displays (see Section X) provided means to direct the S055A instrument and other solar observing instruments to regions of interest. The S055A instrument consisted of the telescope, spectrometer, electronics, and TCS.

Telescope. The primary purpose of the telescope was to provide the instrument optical bench and primary mechanical structure. The telescope optics provided an image of the solar disk to the spectrometer. As shown in figure 40, this was accomplished by allowing light from the Sun to enter the instrument through the entrance aperture to the primary mirror. The mirror was an off-axis paraboloid, controllable in two axes, which then reflected the light back to the spectrometer entrance slit where an image of the solar disk was formed.

The operational elements of the telescope were the instrument housing, external alignment supports, primary mirror assembly, and optical heat-rejection mirror assemblies. The instrument housing formed the basic structure to which all other assemblies were mounted. The external alignment supports provided the attachment points of the instrument to the ATM spar. The supports also provided instrument thermal isolation and an adjustable alignment capability between the instrument and ATM optical axis. A flexible boot was provided between the instrument front-end and the ATM canister for contamination isolation. Structural support for the heat rejection mirror assemblies was provided by the telescope structure. The primary mirror assembly provided a raster scan image of the solar image at the spectrometer slit. The raster

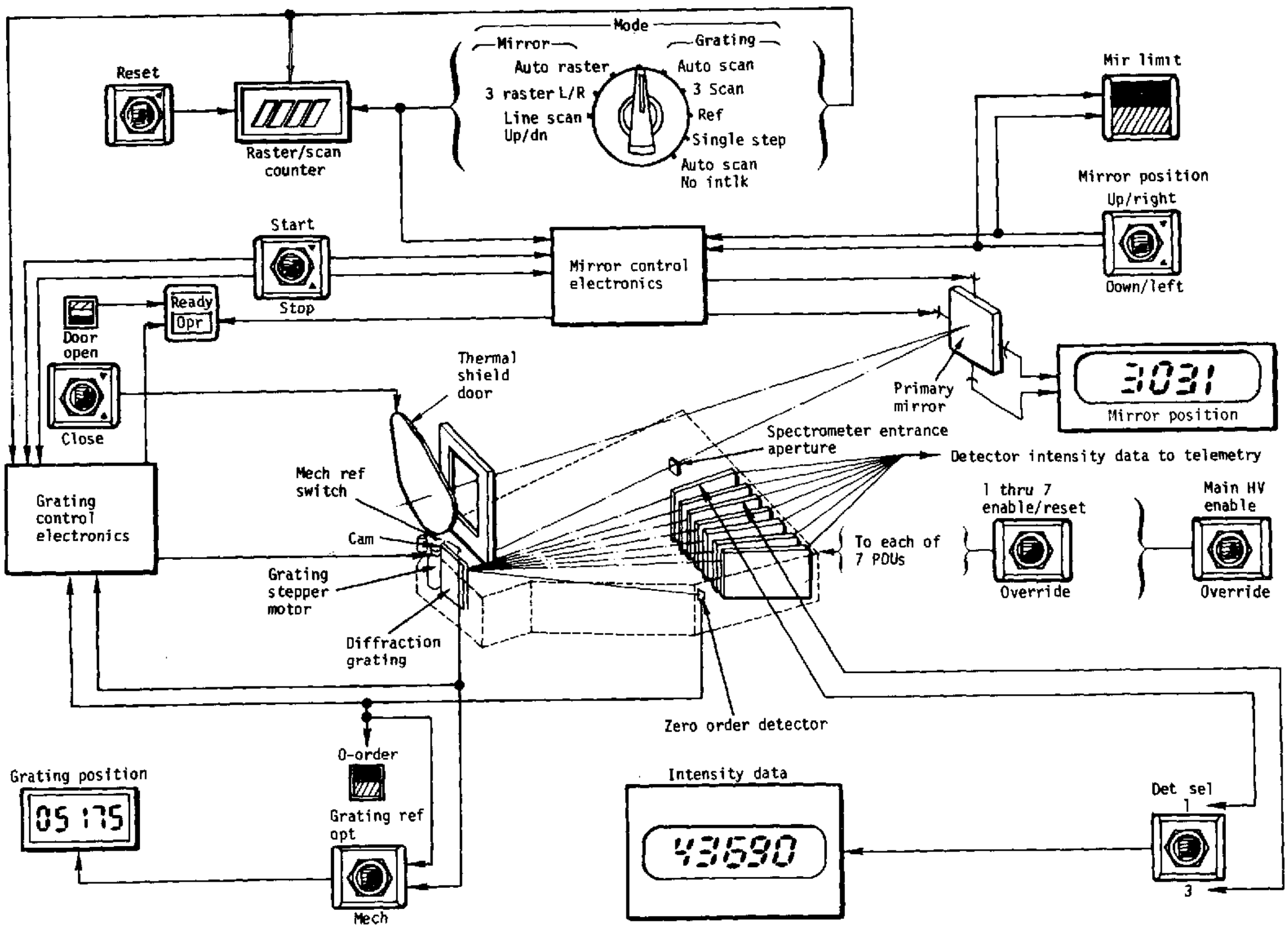


FIGURE 40. S055A OPTICAL SCHEMATIC AND CONTROLS & DISPLAYS CONCEPTIVE REPRESENTATION

pattern was formed from 60 lines, 5 arc-seconds apart and 5.5 arc-minutes long. The lines were scanned in alternate directions across the pattern. Details of the raster are shown in figure 41.

<u>Spectrometer</u>. The primary purpose of the spectrometer was to diffract the solar energy which was admitted through the entrance slit, to measure intensity of the resultant spectral array at seven preselected lines, and to scan the UV spectrum across PDU 1.

Major operational elements of the spectrometer were the grating assembly, zero order detector, pressure gauge, and detector assembly. The grating was mechanically driven to scan the selected portion of the spectrum. The grating, upon command, stopped at a preselected reference position. The zero order detector assembly provided an optical reference signal when the zero-order image, reflected by the grating, crossed a white-light detector. The selectable mechanical and optical references provided an accurate method of locating the grating position at the high end of the spectral range. A cold cathode ion gauge provided a measurement of the pressure within the spectrometer case to detect safe operating pressure for the PDU high voltage power supplies. The detector assembly consisted of seven PDUs, located with their slits on the Rowland circle. Their individual high voltage supplies were mounted external to the spectrometer.

As shown in figure 40, solar energy passed through a 5 arc-second by 5 arc-second entrance slit to the spectrometer grating. The light was diffracted by the movable grating so that the slit images fell on the entrance apertures of seven PDUs which measured the light intensity. The outputs of the PDUs, sampled 24 times per second, provided the intensity measurements in terms of counts per unit time.

<u>Electronics</u>. The instrument electronics subsystem provided the power, and control and monitoring capabilities necessary for operation. The electronic elements included data handling electronics, temperature monitoring electronics, low voltage power supplies, the electrical distribution system, and the test pulse generator.

The instrument data handling electronics accepted the simultaneous pulse outputs of the seven PDUs, counted the pulses, and conditioned the pulse counts, as necessary, for presentation to the ATM telemetry system. The output (selectable from PDU 1 or 3) was also displayed on the C&D console.

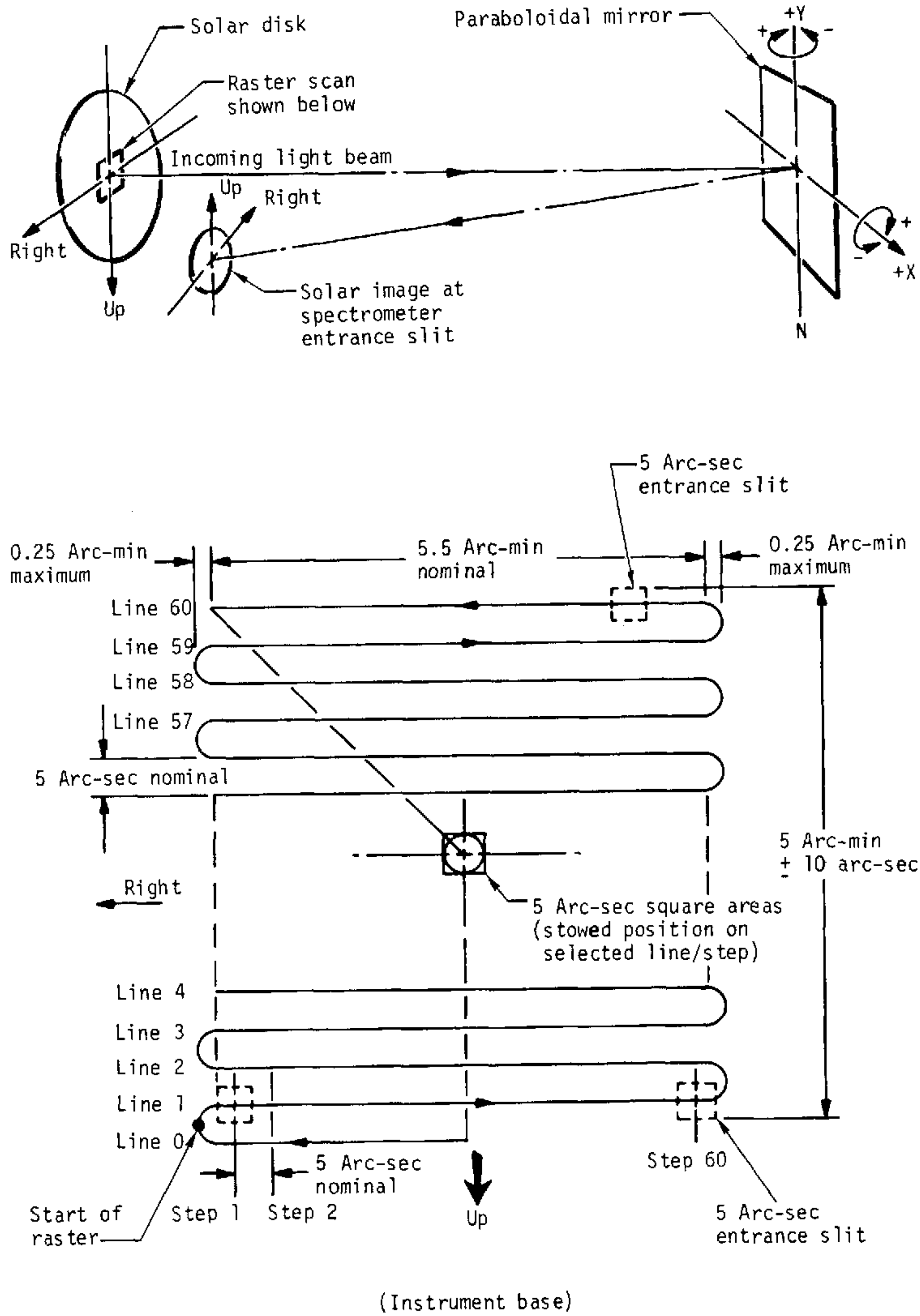


FIGURE 41. S055A PRIMARY MIRROR RASTER PATTERN

The temperature monitoring electronics provided the temperature monitoring of critical elements of the instrument via telemetry.

The instrument electronics included two completely redundant low-voltage power supplies. Either power supply was capable of supplying the power necessary to operate the instrument.

The S055A electrical distribution system distributed power and control signals throughout the instrument. It also provided an electrical interface with the ATM, and operational information and control capabilities to the crew.

A crew activated test pulse generator provided an input pulse to the detector electronics for verification of the performance of the amplifiers and data handling system.

Thermal Control System. The TCS consisted of sensors, thermal panels, heat rejection mirrors, a control system and insulation. The TCS was designed to automatically maintain instrument temperatures of 18.3°C to 25°C (64°F to 77°F). Over-temperature sensing was included to prevent overheating in the event of failure of the control circuitry.

Operation. The basic design of the instrument included the capability of moving both the primary mirror and the grating, such that four basic modes of operation could be obtained: raster scan, line scan, wavelength scan, and wavelength select.

The raster scan mode was the primary operating mode of the instrument. In this mode the grating was stationary at a point in the wavelength scan range so that preselected spectral lines were focused at the entrance slits of the PDUs. Many grating positions were used to provide a variety of lines at the PDU slits. The instrument was pointed at the desired location on the Sun and the PDUs were activated. The primary mirror then executed a raster pattern to scan a nominal 5 by 5.5 arc-minute region of the 32 arc-minute diameter Sun across the spectrometer entrance slit.

The line scan mode was similar to the raster scan mode relative to instrument setup and operation. In this mode, one of the 50 lines that formed the raster pattern was selected by the crew. The instrument then continuously scanned this line across the spectrometer entrance slit. This mode was used for events when the instrument was operating in conjunction with S082B (reference Section IX) and the line selected was that line which best brought the two instruments into coalignment. This mode was used for events requiring high temporal resolution, such as flares.

In the wavelength scan mode the primary mirror remained in a fixed position selected by the crew, and the grating was rotated through 6 degrees to scan the wavelength range from 1350 to 296 angstroms across PDU 1. The remaining PDUs were not energized (PDU 3 was available as a backup to PDU 1).

In the wavelength select mode the crew used the grating drive and the intensity display to position a desired spectral line at the entrance slit of the selected PDU (1 or 3). A numerical display on the C&D console indicated grating position relative to optical or mechanical reference. When operating in the wavelength select mode, the crew was able to stop the grating drive in the vicinity of the desired wavelength. The grating position was then advanced in single steps, while observing the detector intensity numerical display on the C&D console, to position the grating for maximum response. Once the grating was positioned, the instrument was operated in either the raster scan or the line scan mode.

Mission Performance

General. The UV Scanning Polychromator Spectroheliometer performed successfully throughout the Skylab mission. The primary objective, to obtain data in the XUV wavelength region to construct spectroheliograms, was accomplished. The quality of data obtained was excellent and indicated good optical and electrical instrument performance. Although the instrument was designed to an orbital life requirement of 56 days, the instrument performed within design specifications through the 270 day mission.

Instrument Performance. The total operating time for the instrument was 2,292 hours. Of this total, approximately 1,719 hours were utilized performing mirror raster scans and approximately 573 hours were sepnt performing grating scans. This equates to approximately 18,750 raster scans and approximately 9,880 grating scans. The primary mirror raster system performed as designed throughout the Skylab mission. Figure 42 represents a plot of a raster pattern taken on DOY 164 illustrating the scan pattern of the primary mirror. The basic raster size was 320 arc-seconds (steps) by 300 arc-seconds (lines). Because of telemetry characteristics, extraneous noise, crew motion, and other mechanical perturbations, line-to-line separation was detected to be 3 to 7 arc-seconds, as indicated by the fluctuations in the horizontal scan lines in figure 42. The averaged line separation measurements for each line

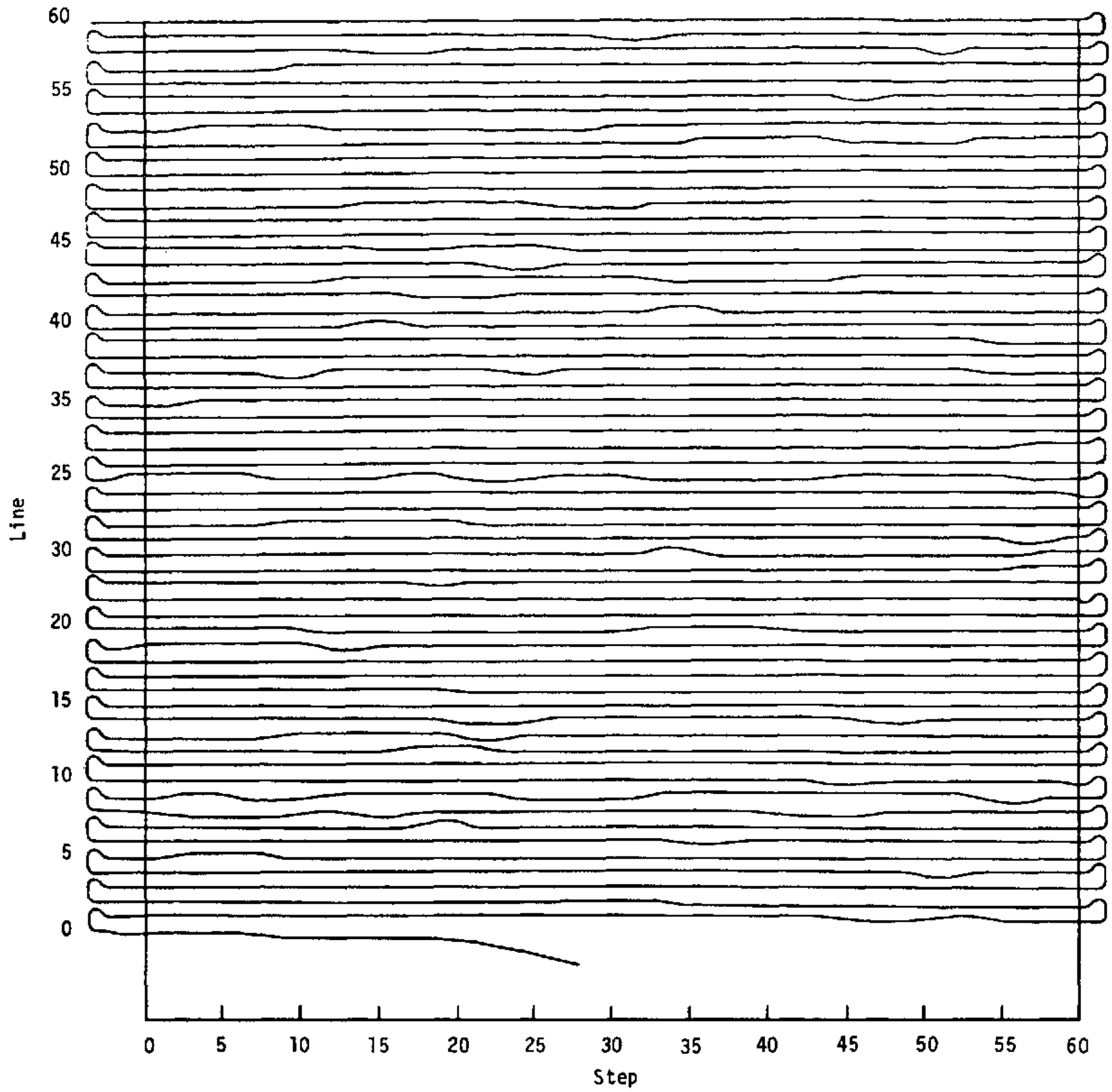


FIGURE 42. S055A RASTER PATTERN PLOTTED FROM TELEMETRY DATA (TYPICAL)

show stable performance within specification. Due to the low telemetry sampling rate, this is not an exact representation of the primary mirror mechanical motion.

The scan rate was determined to be 1.015 arc-minutes per second. This rate was 0.5 percent high; however, it was stable throughout the mission. The 5 by 5.5 arc-minute raster time period was 5 minutes and 33 seconds. This included the 3.08 second fly-back from end of line 60 to start scan at line 1. Table 11 is a comparison of selected parameters that reflect the performance of the mirror raster system, and illustrates remarkable long term stability.

The primary mirror stepping and line selecting features were utilized to establish coalignment with the S082B instrument, the Fine Sun Sensor, and the H-Alpha 1 reticles (reference Section III). Instrument coalignment remained stable throughout orbital operations. Pointing data obtained by using the 4-limb coalignment procedure provided the instrument orientation parameters necessary for scientific data reduction.

The spectrometer subsystem performed as designed. Review of telemetry data indicated that a complete grating rotation consisted of 5,497 steps from either mechanical or optical reference. Optical reference was nominally 102 grating steps from mechanical reference. Optical reference width was nominally 38 steps and mechanical reference width was nominally 600 steps. These values were comparable to those observed during ground testing and provided evidence that no deterioration of mechanical linkages, surfaces, or alignment occurred.

PDU performance exceeded expectations. By the end of the mission, PDU sensitivity was observed to be a factor of 2 lower at shorter wavelengths and a factor of 3 lower at longer wavelengths than that observed during ground testing.

During the Skylab mission several PDU high voltage tripouts occurred. The PDUs were designed with a built-in current sensing overload protection device with automatic cutoff and manual reset. This turn-off (tripout) could have been caused by high voltage corona breakdown, a faulty trip circuit, or external sources. Analysis led to the probability that the majority of tripouts were related to the ATM proximity to the SAA. It was concluded that PDU 5 was most susceptible to tripout; PDU 5 was subsequently left off. However, by placing lines of interest on other detectors and using second and third order emissions, the data loss resulting from PDU 5 tripout was minimized. See page 84 for a detailed discussion of this anomaly.

The pressure gauge functioned properly throughout the mission. At initial gauge activation, a reading of 7 x 10^{-5} torr was detected. Subsequent activations indicated pressures of 5 x 10^{-7} torr, which is well below the maximum high voltage power supply operating pressure of 1 x 10^{-5} torr.

TABLE 11. S055A MIRROR RASTER PARAMETERS

Skylab Mission	Size	Duration	Line Separation (1)(2)	Scan Rate (2)
2	320 arc-sec (X axis) 300 arc-sec (Y axis)	5 min 33 sec	5.0 ± 0.75 arc sec	1.015 arc-min/sec
3	320 arc-sec (X axis) 300 arc-sec (Y axis)	5 min 33 sec	5.0 ± 0.75 arc-sec	1.014 arc-min/sec
4	320 arc-sec (X axis) 301 arc-sec (Y axis)	5 min 33 sec	5.0 ± 0.75 arc-sec	1.014 arc-min/sec
Design Requirement	330 arc-sec nominal (X axis) 300 ± 10 arc-sec (Y axis)	5 min 30 sec	5.0 ± 1 arc-sec	1.0 ± 0.01 arc-min/sec

(1) Line separation measurements could not be computed accurately because of the low telemetry sampling rate, system noise, crew motion, and other mechanical perturbations.

(2) Values were averaged over a complete raster.

The telemetered temperature data indicated that the S055A TCS functioned as designed and that the temperature measurements of the instrument were within the operating limits. Slight temperature variations (less than 1°C) were time-related to the thermal shield door open/close cycles. The location of the S055A temperature sensors is shown in figure 43.

Throughout the time for which telemetered data were available during Skylab 2, the temperature sensors indicated excursions shown in Table 12. The lowest temperatures were measured just after the PDUs were activated. During the period of high Beta angles, when the S055A thermal shield door remained closed (DOY 173 to DOY 176), only the case back measurement again reached its lowest temperature value of 17.8°C (64°F).

TABLE 12. S055A TEMPERATURE DATA

Measurement	Actual Flight Excursion (°C)	Operating Limits (°C)
Detector Housing	22.2 to 23.9	21.0 to 27.1
Spectrometer Bottom	21.1 to 22.2	16.6 to 25.0
Spectrometer Side	21.1 to 22.2	18.3 to 25.0
Case Bottom #1	19.4 to 21.1	18.3 to 25.0
Case Bottom #2	21.1 to 22.2	18.3 to 25.0
Case Side #1	18.9 to 20.6	18.3 to 25.0
Case Side #2	20.6 to 21.7	18.3 to 25.0
Case Back	17.8 to 23.3	17.8 to 25.0

A tabulation of comparative temperatures for the various measurements is presented in Table 13.

Temperature measurements sampled at random times coincided with expectations and prior experience except for the higher temperatures during Comet Kohoutek observations. These operations required pointing away from the Sun at an angle such that the efficiency of the heat rejection system was reduced. This resulted in instrument temperatures above those which were experienced during nominal Sun-centered instrument operations.

The S055A power supply performance was satisfactory. Table 14 illustrates typical power supply output values experienced during the mission. Operations of the electrical distribution system

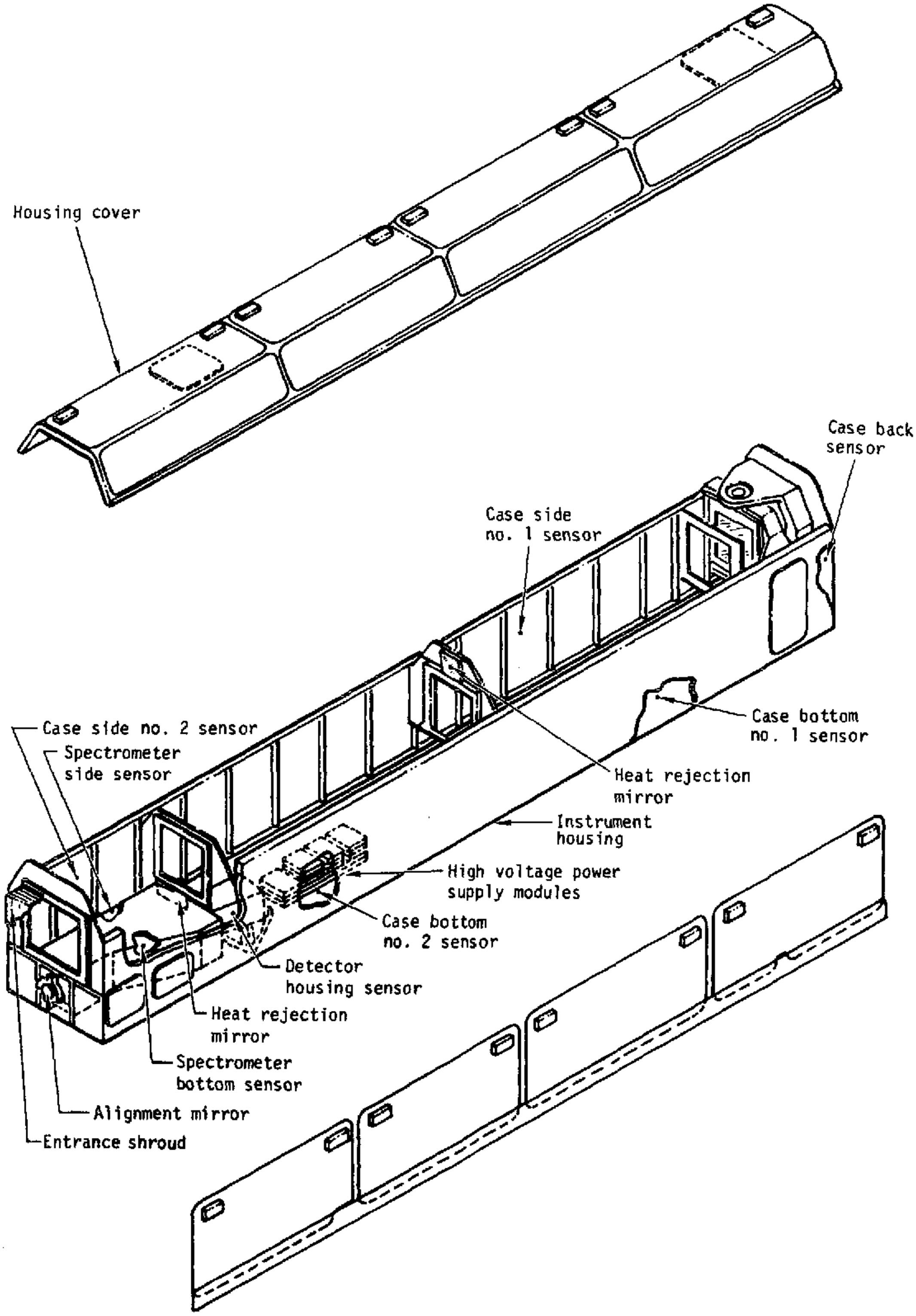


FIGURE 43. S055A TEMPERATURE SENSOR LOCATIONS

TABLE 13. S055A ACTUAL AND PREDICTED TEMPERATURES (TYPICAL)

Measurement	Temperatures (°C)		
	Analytic Prediction	DOY 210	DOY 335
Detector Housing	22.6	22.9	22.7
Spectrometer Bottom	20.8	21.4	21.7
Spectrometer Side	20.8	21.5	21.7
Case Bottom #1	19.2	19.4	19.7
Case Bottom #2	20.5	21.1	21.3
Case Side #1	18.6	18.9	19.1
Case Side #2	20.6	21.0	21.1
Case Back	16.8	18.3	18.5

TABLE 14. S055A POWER SUPPLY TELEMETERED VOLTAGES (TYPICAL)

Power Supply	Actual Flight Values (Vdc)	Operating Limits (Vdc)
+10 V Thermal	+10.03	+ 8 to +12
-10 V Thermal	- 9.85	- 8 to -12
+15 Vdc	+15.15	+14.25 to +15.15
-15 Vdc	-15.15	-12 to -15.75
+10 Vdc	+10.01	+ 8 to +12
-10 Vdc	- 9.65	- 8 to -12
+ 5 Vdc	+ 4.84	+ 4 to + 6
- 5 Vdc	- 4.98	- 4 to - 6
+ 5 V Digital	+ 5.20	+ 4 to + 6
Low Voltage Pwr	+20.50	+18 to +22
Low Voltage Pwr	-20.50	-18 to -22

were analyzed and long term plots were made showing the various voltage levels and their excursions within six hour increments of time. Although the system continued to perform as designed, changes in telemetered power supply voltage measurements on DOY 277 indicated that the low-voltage (28-V) power supply in the instrument probably switched from primary to secondary. It was also noted that the instrument would not respond to "Main-Power-Off" or "Main-Power-Primary" ground or C&D console commands. Checkout proved instrument operation was unaffected; therefore, normal planned operations were continued. Details of this anomaly are reported on page 88.

Review of the long-term plots showed slight drift in the output of some of the voltage measurements as the mission progressed. Also, some of the PDU high-voltage power supplies exhibited apparently random drops in output. Some of the changes correlated with operational modes. For example, one of the -10-V power supply monitors displayed unusual excursions (0.25 V versus the usual 0.10 V) on DOY 355, 357, 365, 368, and 370. Analysis showed that these excursions coincided with changes in the instrument side differential temperature. It was known that these temperature changes would be caused by pointing the instrument slightly away from the Sun, as in the Comet Kohoutek observations. A review of the pointing data indicated the instrument was pointed away from the Sun significantly more than the 22 arc-minutes considered allowable for normal instrument operations during the times in question. Additional analysis showed that these pointing conditions allowed direct sunlight to enter the instrument where it impinged on one of the more critical areas. Thus, it was assumed the voltage excursions noted were due to unusual localized heating of one of the power supplies. Since the magnitude of the changes was not sufficient to impair system performance, further investigation was considered unnecessary except for continued close observation.

ATM Interface. For the most part ATM interfaces adequately supported the S055A instrument. There were several occurrences, however, which temporarily interrupted instrument operations but did not prevent achievement of S055A objectives.

On DOY 164 the ATM thermal shield door failed to open at sunrise. The crew performed the malfunction procedure and cleared the problem. A similar incident occurred on DOY 172, 211, 214, and 216. An investigation of the problem utilizing ground simulators concluded that lubricant deterioration caused frictional forces to increase at the ramp latch surface. Off-nominal two-motor operation was sometimes required to achieve proper door operation. On DOY 218 the crew removed the ramp latch, and door operations returned to normal.

On DOY 197 a problem occurred in the ATM experiment pointing control system. The solar inertial mode was employed until Skylab 3 activation on DOY 210. Because of less stability in the solar inertial mode, as compared to the experiment pointing mode, S055A data collection was curtailed to the extent of operating only to ascertain that the instrument remained operable.

The ATM electrical system supported the instrument as required, with the possible exception of a power surge on DOY 277 which apparently caused the instrument low-voltage power supply to switch from primary to secondary operation, and resulted in the inability to command a change of instrument power status.

The ATM TCS support to the instrument was excellent. The only large thermal excursions noted were experienced during off-the-Sun pointing.

Contamination was not evident during any S055A operations throughout the Skylab mission.

Man/Machine Interface. Crew participation in solar observing programs greatly enhanced collection of S055A scientific data. The value of manned operations was demonstrated by non-routine observations such as flares, prominences, surges, and precise pointing in active regions.

S055A pointing was made available to the crew through the use of the primary mirror position readout. This feature was of particular value for detecting points of maximum intensity in mirror modes, and then returning to those locations and initiating a grating scan for further study. This technique was utilized during off-limb observations to detect prominences or loops, and during on-disk observations to study bright spots.

Of particular significance was the crew discovery that S055A provided a flare precursor. When solar bright points began changing location and magnitude, and high intensity counts were indicated by S055A at the Oxygen VI line (1032 angstroms), flare activity could be expected.

The crew performed troubleshooting and repair of the S055A ATM thermal shield door and reported real-time observations of solar conditions not visible from Earth observatories.

Scientific Data Quality and Quantity. The quality of the data obtained by the S055A instrument was excellent and indicated extremely good optical and electrical performance.

Of the total operating time of 2,292 hours, approximately 75 percent was utilized for mirror modes and 25 percent for grating modes. Table 15 identifies operating time per mission. The S055A total operating time significantly exceeded the premission objectives.

TABLE 15. S055A OPERATING TIME

Mission	Operating Time		
	Unmanned	Manned	Total per Mission
Skylab 2	---	153 hrs	153 hrs
Skylab 3	191 hrs	581 hrs	772 hrs
Skylab 4	556 hrs	811 hrs	1367 hrs
	Total Skylab Time 2292 hrs		

Figure 44 is an example of a spectroheliogram constructed from S055A data. Spectral resolution obtained compared favorably to the design requirement of 2 angstroms. Spatial resolution was fixed by design and was 5 x 5 arc-seconds.

Anomalies

General. The S055A instrument experienced only two anomalies throughout the Skylab mission. Neither had any significant effect on instrument operations. The impact of PDU 5 tripouts which occurred throughout the mission was minimized by an operational procedure change, which prevented tripping the other six PDUs when PDU 5 tripped out. An electrical problem, which caused an apparent switch of the low-voltage power supply from primary to secondary, had no impact as the instrument continued to operate normally. Details of these anomalies are discussed below.

Photomultiplier Detector Tripouts. On DOY 150 during the Skylab 2 mission, the first PDU tripout occurred. The PDUs were designed with a built-in current-sensing overload protection device. When this circuitry sensed a higher-than-allowable current, the affected PDU turned off (tripout). The PDU then had to be reset by the crew. In normal high voltage operation a ganged-tripout property existed, i.e., tripout of one PDU automatically turns off all others. Tripouts were occasionally experienced during PDU turn-on sequences. This was not considered a problem, C-2

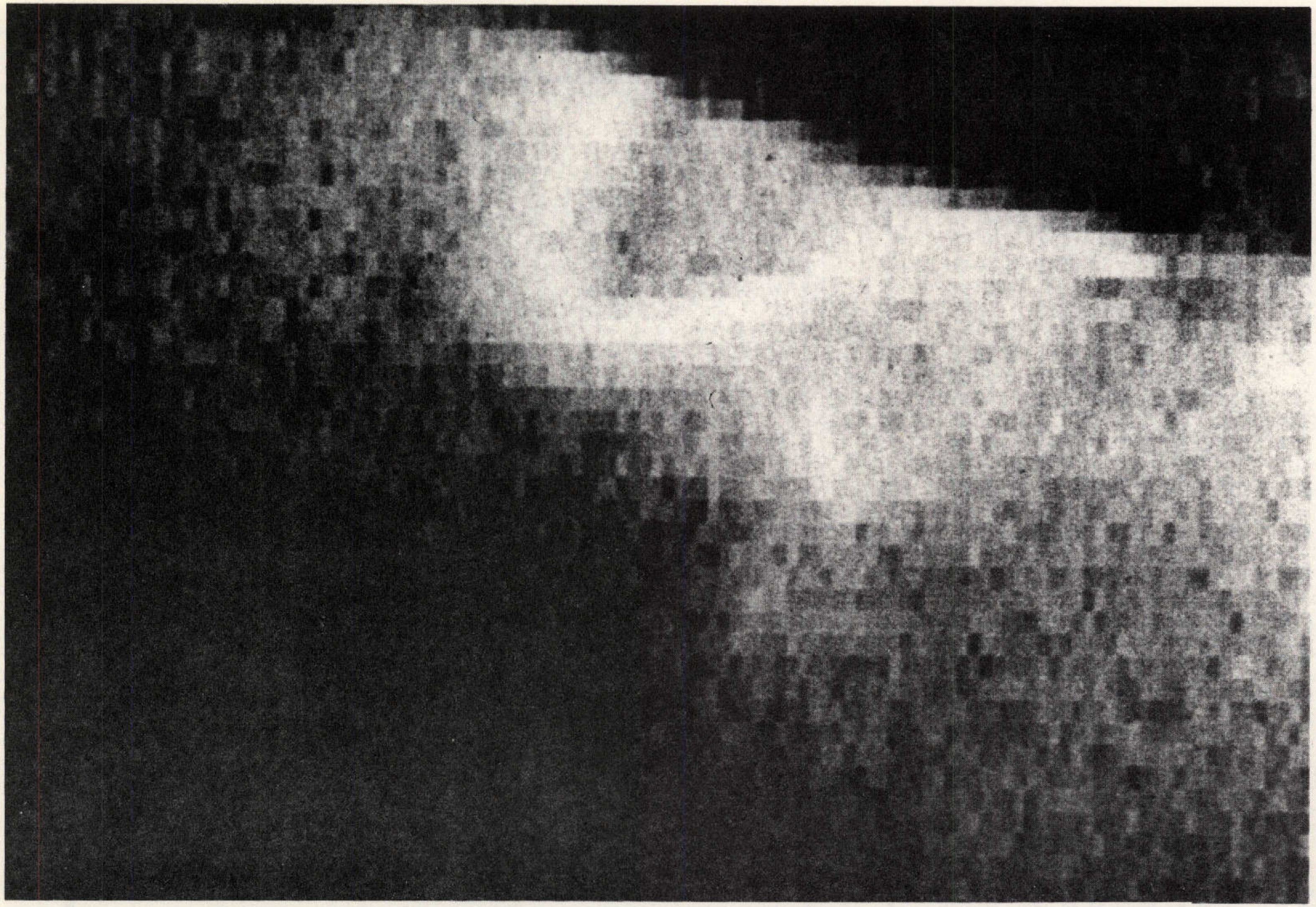


FIGURE 44. S055A SPECTROHELIOGRAM

since the PDUs were reactivated and operated normally on subsequent turn-on.

During Skylab 2 an attempt was made to correlate tripouts with a particular phenomenon or occurrence. A history was compiled defining time, location, cycle, operating modes, etc. A pattern related to vehicle geographic location seemed to exist; however, insufficient tripouts occurred to substantiate this theory. The known tripouts (excluding those during turn-on) that occurred during Skylab 2 are summarized in Table 16.

TABLE 16. S055A PHOTOMULTIPLIER DETECTOR UNIT KNOWN TRIPOUTS DURING SKYLAB 2

GMT DOY:Hours:Min:Sec	Location Longitude-Latitude
150:04:30:00	18:31S 22:25W (SAA)
158:06:19:59	50:01S 166:28W (South Horn)
159:17:54:00	41:46S 37:06W (SAA)
161:07:14:50	48:53S 137:51E (South Horn)
166:06:56:00	47:10S 153:31E (South Horn)
166:14:20:35	31:51S 75:04E (SAA)
177:07:57:00	49:52S 75:04E (SAA)
172:19:53:00	32:53S 46:50W (SAA)
149:11:52:07	Close to SAA and/or Horns
153:08:48:47	Close to SAA and/or Horns
157:11:05:00	Close to SAA and/or Horns
161:12:39:17	Close to SAA and/or Horns
169:05:56:00	Close to SAA and/or Horns
150:09:39:30	Unknown Correlation
152:11:11:12	Unknown Correlation
153:15:40:00	Unknown Correlation
166:00:17:32	Unknown Correlation

During Skylab 3 the tripouts occurred with increasing regularity, PDU 5 being the most susceptible to tripout. Very often the tripout occurred during a flare. Because of the increasing inconvenience in having to reset the PDUs each time PDU 5 tripped out, two high-voltage tests were performed by the crew. The tests were designed to determine why PDU 5 tripped out during normal operating modes and whether the instrument could be operated successfully with the ganged-tripout circuitry disabled.

The first test was performed on DOY 251. The main high voltage switch was placed in the OVERRIDE position. The override configuration was selected in order to bypass the protective tripout circuitry and thus allow observations of the effects on adjacent channels. PDU 5 was turned on by placing the high voltage number 5 switch to OVERRIDE for 20 seconds four successive times immediately following a tripout. All the other PDUs were off. During the first turn on, counts of up to 225 were seen on the outputs of the other PDUs except PDU 2. The counts began appearing as the voltage reached 3344 Vdc. The counts continued with decreasing magnitude for about 2.5 seconds. After the counts decreased to zero, bursts of low magnitude counts from 2 to 25 for three to seven integration periods were noticed five times during the remainder of the 20-second test. The second turn on showed two small bursts of low magnitude counts from 1 to 18 on all PDUs, except PDU 2, for eight to nine integration periods, just prior to PDU 5 attaining operating voltage. Following this, the next two turn-on's exhibited normal operation.

The next test was performed on DOY 255. This test was essentially the same as the first test except that the PDU 5 on-time in override was lengthened to 40 seconds and it was turned on five times. The second time, a 2-second burst of counts of up to 84 was seen on the output of all PDUs again except PDU 2. The 2-second burst appeared approximately 9 seconds after PDU 5 came up to nominal operating voltage. The high voltage monitor exhibited a voltage drop of about 40 volts for one sample during the noise burst. In order to provide a comparison with PDU 5, PDUs 6 and 7 were subjected to the same test. Both operated normally.

Analysis of the test data implied that the cause of the tripouts was high voltage breakdown or corona because of counts on the other PDU outputs (radio frequency energy). If, however, PDU 5 was causing the high-voltage breakdown, the voltage would have dropped immediately to where the arc would extinguish and the power supply would begin recovery to the point where breakdown would again occur. Since this did not occur, one possible explanation was a high-voltage breakdown through a high resistance or faulty component in the high-voltage power supply. Regardless of these ambiguities, the tests verified that operation of PDU 5 would cause degradation of the data in the other six PDUs. However, the test data obtained were not sufficient to establish the extent or frequency of the degradation.

As a result of the test data analyses, it was decided to operate with PDU 5 overload sensor protection circuitry enabled and the main high voltage in override. This mode of operation prevented all other PDUs from tripping off when PDU 5 tripped off, and resulted in a loss of data from PDU 5 because it tripped off almost immediately and was off for long periods. However, by placing lines of interest on other detectors and using second and third order emissions, the data loss resulting from PDU 5 tripping out was minimized. PDU 5 was commanded off at the end of the Skylab 3 mission to preclude any perturbations from occurring during the unmanned Skylab 4 observation period, and was left off throughout the manned Skylab 4 mission. At the end of the mission when special tests were permitted, PDU 5 was turned on again, once with all other detectors off and once with all other detectors on. One mirror raster was run in each of these configurations. The demonstration was not conclusive; it merely showed that PDU 5 (in override) remained operable and apparently had not degraded.

Electrical Problem. On DOY 277 the low-voltage (28-volt) power supply on the instrument apparently changed from the primary to the secondary converter as indicated by a change in telemetered power supply voltages. At the same time the instrument would not respond to the "Main-Power-Off" or "Main-Power-Primary" ground commands.

Close monitoring of the low-voltage power supply indicated no further anomalies, and good stable voltage outputs from the low-voltage power supply after 277:20:19 GMT. Playback of telemetry data verified that the monitors were stable throughout the period in question. Tests were conducted on each of the detector systems. No discernible change in any of the PDUs from before to after the problem were evidenced.

The mirror stow position was operationally verified to have changed from line 30,step 31 to line 0, step 30; however, the primary mirror raster and grating scan systems were checked out and no other abnormal conditions were noted. System operations were normal after the anomaly.

The instrument did not respond to ground commands which had been received and verified. The "Main-Power-Off" command was sent 3 times. This command had not been sent prior to that time. It had been sent, verified, and accepted by the instrument during final ground system testing.

The exact cause of the problem was not determined. Possible causes are listed below:

1. A transient occurred on one of the main ATM Experiment power buses. This could not be verified due to the low sample rate of the power bus telemetry data.

2. A transient was generated within the S055 instrument.

3. A transient caused switchover from primary to secondary low voltage power supply system.

4. A ground command momentary relay not functioning.

5. A diode failure in the power line prevented receipt of command signal.

6. An improper ground command.

7. Lock up of the power switch latching relay.

After the time of the transient, the instrument operation was nominal and all voltage monitors were stable. Therefore, no trouble shooting operations were planned with the instrument in the unmanned mode.

All subsequent proposed in-flight tests involved the risk of the loss of some scientific data if the instrument failed to respond after the tests. The final disposition was to take no further action. The instrument was left in the same power configuration throughout the remainder of the mission, with no impact on instrument operation.

Conclusions

Instrument operation was exemplary throughout the mission and the scientific goals of the experiment were accomplished.

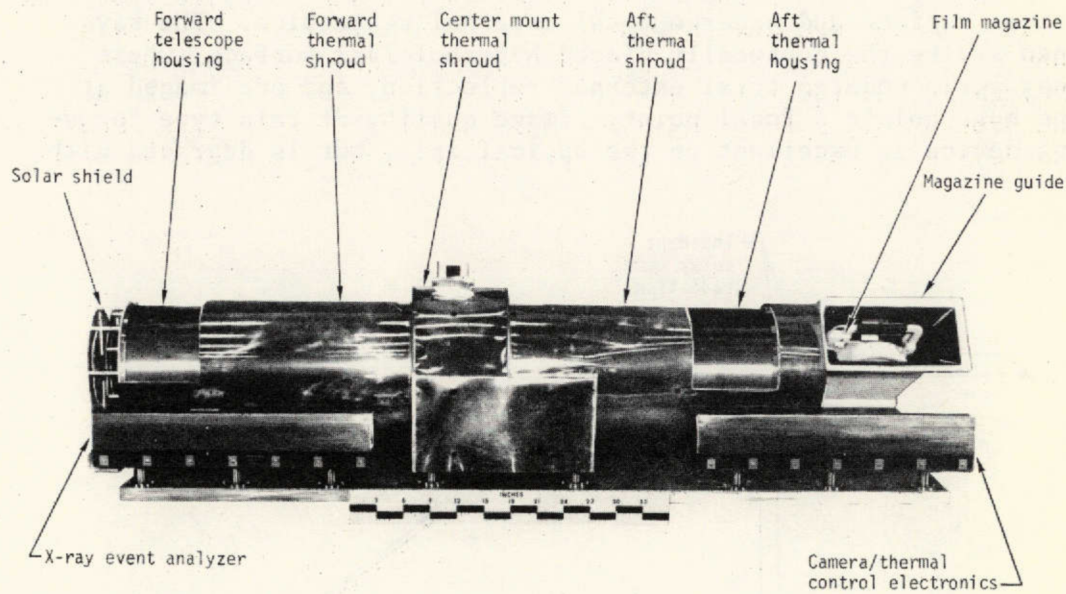
All instrument functions and electrical/mechanical interfaces were verified except for (1) the High Voltage/Door Interlock Override, (2) High Voltages 1, 2, 3, 4, 6, and 7 Overrides, and (3) Grating Motor Drive Secondary functions. These functions were not exercised by the crew or ground control throughout the mission.

All operational requirements were satisfied and there were no failures that significantly restricted the scientific data gathering ability of the instrument.

SECTION VII. X-RAY TELESCOPE (S056)

Description

General. The X-Ray Telescope, shown in figure 45, incorporated two separate and independently operated instruments; the X-ray telescope and the X-ray event analyzer (X-REA). The telescope design provided for X-ray filtergrams (solar images of narrow wavelength intervals) in five wavelength bands from 5 to 33 angstroms and one in visible light (6328 $\pm$ 40 angstroms). The X-REA design provided for spectral data (intensity versus wavelength in 10 wavelength bands from 2.5 to 20 angstroms.



Length -	105.0 in.	267.0
Height -	24.5 in.	62.2
Width -	23.0 in.	58.0
Weight	354.0 lbs	161.0

FIGURE 45. S056 X-RAY TELESCOPE

Optics. The X-ray telescope consisted of two major assemblies; the telescope and camera assembly, and the camera/thermal control electronics assembly. The telescope was the prime structural unit of the instrument. It formed the X-ray images of the Sun and provided the physical support for the camera. The glancing-incidence mirrors, supporting tubes, centermount, and thermal control components were parts of the telescope. The glancing-incidence optics provided an image of the Sun to one of the six different filters of the film camera. Soft X-ray solar images were formed using the two-element, double-reflection aplanatic telescope. Figure 46 illustrates the instrument optical arrangement. The optics consisted of paraboloidal and hyperboloidal elements placed confocal to each other. The optical elements surfaces were almost parallel to their axes of revolution forming surfaces of high incidence angles to the incoming solar photons. Incoming paraxial rays first strike the paraboloidal surface and undergo total external reflection. The rays then strike the confocally placed hyperboloidal surface, where they again undergo total external reflection, and are imaged at the hyperboloid's focal point. Image quality of this type focusing device is excellent on the optical axis, but is degraded with

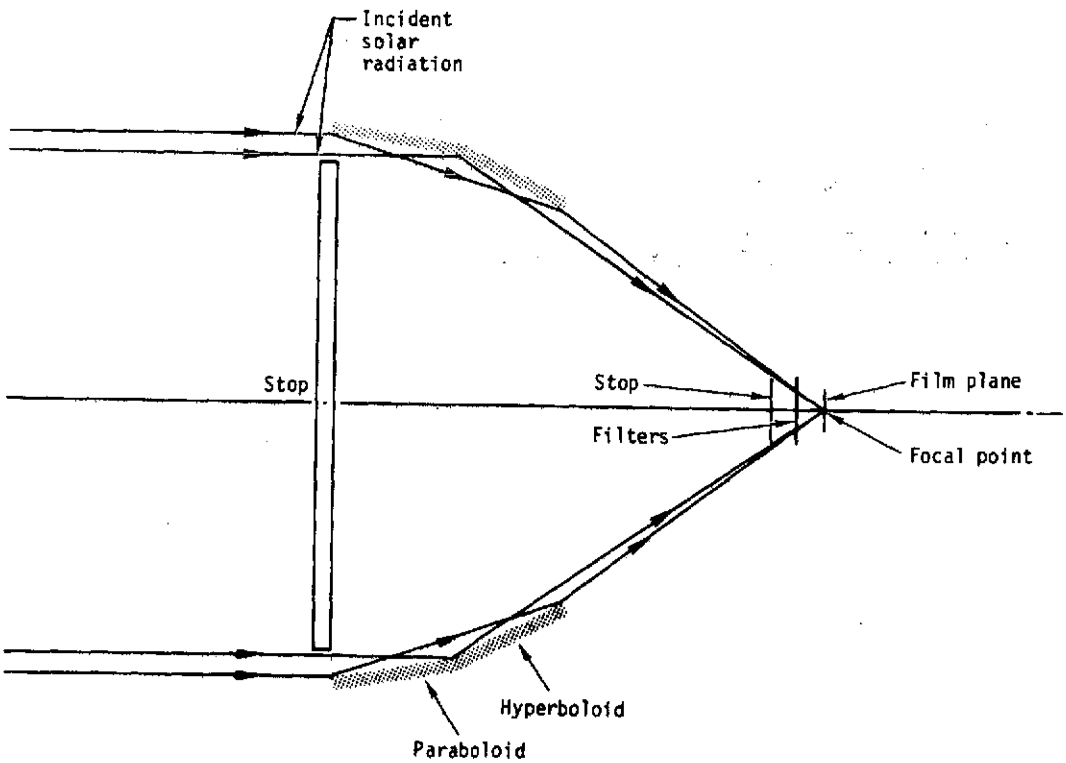


FIGURE 46. S056 OPTICAL SCHEMATIC

angular deviations from the optical axis greater than seven arc-seconds.

Mounting on the ATM spar was such that during zero-gravity conditions, the optical alignment reference of the telescope was aligned in pitch and yaw to the fine sun sensor within $\pm$ 1 arc-minute.

Film Camera. The film camera was designed to place the film plane coincident with the focal point and to alternately position six different filters ahead of the film plane. The resulting data consisted of five solar filtergrams in the 5 to 33 angstrom region and one in visible light. The camera, consisting of the film magazine guide, the interface plate, the shutter and filter wheel, and associated drive mechanisms, recorded the X-ray image on film along with the ancillary data describing the experiment conditions that existed at the time of exposure. One loaded film magazine was placed in the camera prior to Skylab 1 launch, three were stored in the MDA film vault for replacement by the crew during EVA, and one magazine was launched on Skylab 4. Four of the magazines were loaded with 35-mm, SO-212 black and white roll film and the fifth magazine launched on Skylab 4 was loaded with SO-242 color roll film. Each magazine contained approximately 1000 feet of film. The magazines were returned to Earth in the Command Module.

Electronics. The camera/thermal control electronics assembly controlled the operation of the electromechanical components within the camera and the operation of the telescope TCS. It consisted of exposure sequencers, timers, mode logic circuitry, motor-drive power generators, and thermal control units.

X-Ray Event Analyzer. The X-REA was mounted adjacent to the telescope on the ATM spar. It consisted of two, gas-filled proportional counters with thin metallic windows (one of beryllium and one of aluminum), aperture size control, pulse-height analyzers (PHA), digital-channel counters, rate meter and activity history recorder drive circuits, signal conditioners, and power supplies. The proportional counters produced linear outputs proportional to the intensity of the energy detected. The PHA electrically sorted the output of the proportional counters, relative to the voltage amplitude of the pulses, into six energy levels (beryllium) and four energy levels (aluminum), to give the spectral distribution of the solar X-ray intensity. These data were transmitted via telemetry to ground. The level of the X-ray energy passing through either the aluminum or beryllium filter could be numerically displayed on counters and recorded on the activity history plotter on the C&D console. These displays were designed to aid the crew in selection of the camera modes of operation.

The X-REA obtained X-ray spectral data when the aluminum and beryllium high voltages were on. With the aluminum and beryllium high voltages off, the proportional counters were disabled, permitting a calibration signal to be processed by the electronics. Both the X-ray spectral data and the calibration data were displayed on the C&D console and telemetered to ground.

Thermal Control System. The instrument TCS used both active and passive elements to maintain temperature control. The passive elements of the system consisted of 20 layers of super insulation wrapped around the two telescope tubes, four thermal isolation mounts supporting the telescope on the ATM spar, two thermal radiators at the extremities of the telescope tubes, and the solar shield mounted at the front of the telescope.

The active elements for the system consisted of two redundant and identical thermal control units, primary and secondary, each having two electrical thermofoil heaters wrapped around the extremities of the telescope tubes, and a chain of six power resistors placed at the centermount casting. Each of these three heaters was capable of delivering 10 watts to the telescope. Control for the heaters was derived from a series of thermistors placed about the telescope to sense minute variations in temperature. To prevent a thermal runaway condition, current for the three heaters was supplied through thermostats preset at a temperature slightly above the maximum permissible operating telescope temperature. Either the primary or secondary TCS could be selected at the C&D console by the crew or by ground command. The telescope temperatures were telemetered to ground.

Operation. The camera and X-REA were operated by the crew from the C&D console using the controls and displays as shown in figure 47. The camera electronics automatically sequenced the camera through each mode of operation. The modes available were single frame 1 through 6, patrol, active 1, active 2, active 3, and auto, and were selectable from the C&D console. Each mode action included shutter open/close, filter movement, and film advance. The crew could lengthen or shorten the normal exposure time, by a factor of 3.2, by selecting long or short exposure.

The single frame mode provided the capability to make single exposures with any of the six filter positions selected. Filter bandpasses and exposure durations were selected to correspond with

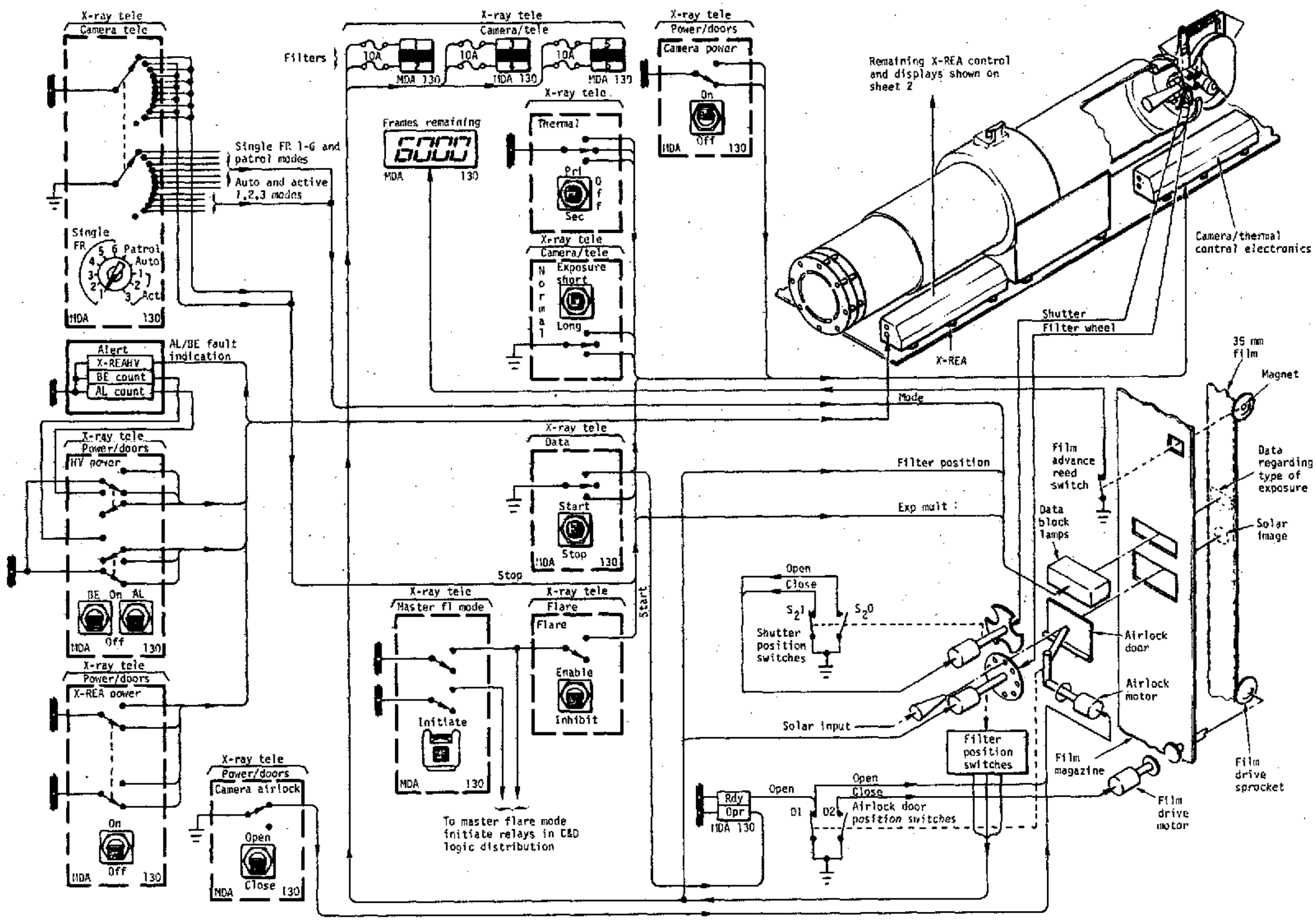


FIGURE 47. S056 CONTROLS AND DISPLAYS OPERATION SCHEMATIC (SHEET 1)

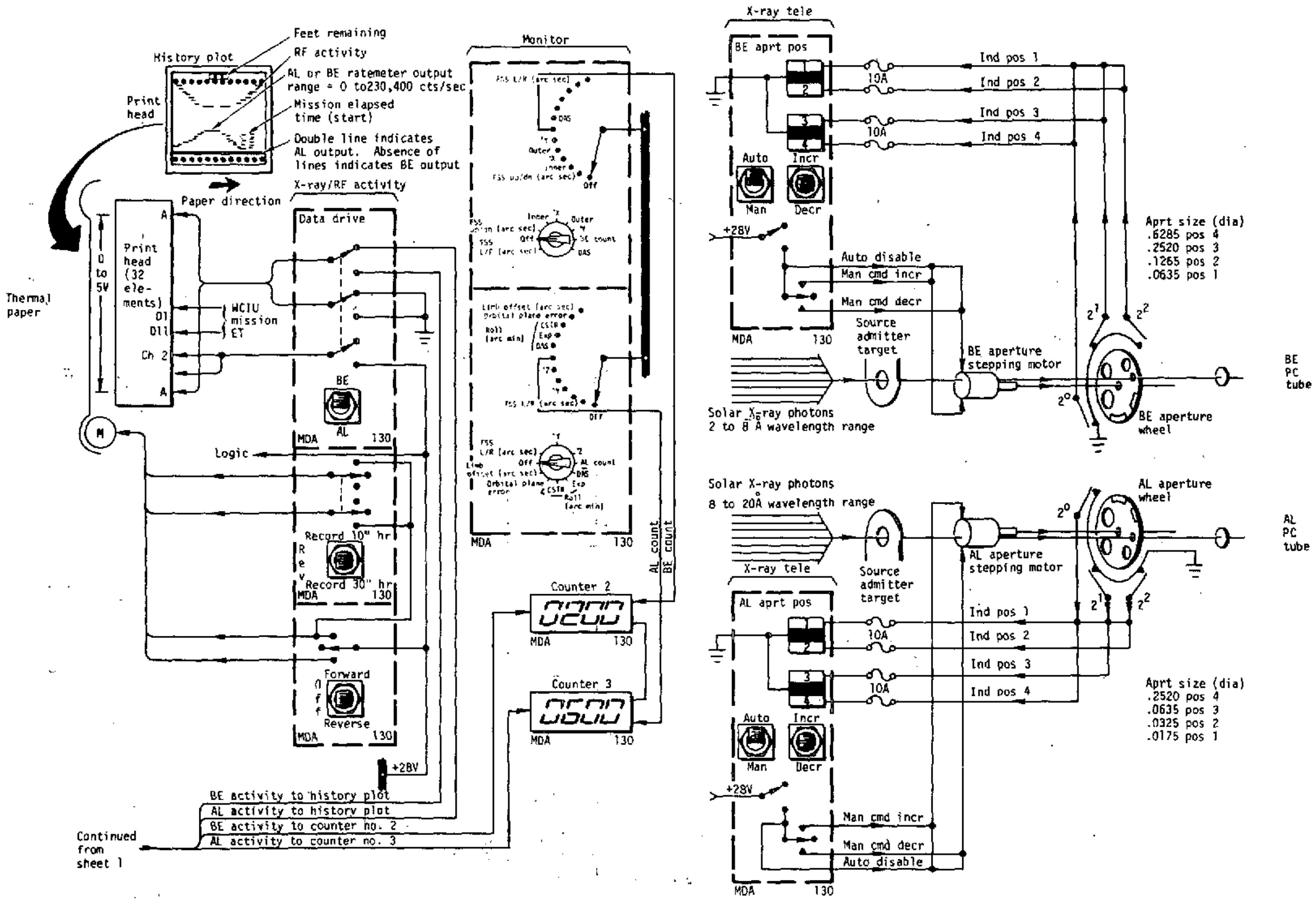


FIGURE 47. S056 CONTROLS AND DISPLAYS OPERATION SCHEMATIC (SHEET 2)

X-ray intensity levels expected from the quiescent Sun. This mode was used to conserve film, to check out the instrument, and to provide a backup in case of failure of the patrol mode automatic sequencing control.

In the patrol mode, six exposures, one at each of six filter positions, were made in sequence. Associated with each filter was a programmed exposure time equal to the single frame mode exposure times.

The active 1 mode was intended for use during periods of high solar activity and the initial stages of flare development. To allow the short-duration events to be recorded, exposures were made in rapid sequence for approximately 5 minutes. Three filters (numbers 1, 3, and 5) were used. These filters and their corresponding exposure times (different than exposure times of the patrol mode), were selected to match the X-ray intensity levels expected during flares. A total of 33 short, 36 normal, or 15 long exposures, depending upon the exposure setting, were scheduled over a 5-minute period.

In the active 2 mode, the same filters and exposure times were used as for the active 1 mode. The rate of exposures was, however, reduced to one set of three exposures (one exposure at each filter position) per minute. A total of 60 exposures were scheduled over approximately 25 minutes.

The active 3 mode also utilized the same filters and exposure times as the active 1 mode. The rate of data taking was further slowed to one set of three exposures (one exposure at each filter position) in 10 minutes. A total of 18 expsoures were made over approximately 60 minutes.

The auto mode sequentially combined the active 1, active 2, and active 3 modes. The total sequence of observations extended over 85 minutes; however, solar observations were truncated at the end of the solar day. The auto mode was used during flare activity.

Each of the preprogrammed modes described above contained fixed exposure times. However, the camera electronics design permitted the use of an additional unplanned operating mode which allowed the exposure time to be varied. Powering down the instrument, after a preprogrammed mode had been initiated, allowed the shutter to remain open until the instrument was again powered up, the mode reinitiated, and then manually terminated. This allowed the crew to obtain exposures of any desired duration. This mode is referred to as the extra long exposure mode and was used during Skylab 3 and Skylab 4.

Mission Performance

General. The X-Ray Telescope successfully accomplished mission objectives by obtaining X-ray filtergrams from 5 to 33 angstroms and X-ray spectral data from 2.5 to 20 angstroms. The filtergrams were recorded by the film camera and the spectral data were displayed on the C&D console and telemetered to ground.

Instrument Performance. The instrument performed as designed throughout the Skylab mission, and obtained over 27,000 X-ray photographs and over 1,100 hours of X-ray spectral data. The film camera utilized five magazines in accomplishing the mission. All film-camera exposure sequences were selected, as well as the normal, long, and short exposure settings to accommodate the JOPs (reference Section III) planned by the PI. The only problem associated with the camera operations was one of repeated, premature terminations. See page 103 for a detailed discussion of this anomaly.

During Skylab 3, the PI requested the use of the extra long exposure mode which permitted obtaining exposures of any desired duration. The filters normally selected were filter 2 (0.25 mil aluminum), filter 3 (0.086 mil titanium), and filter 4 (1.0 mil beryllium). The exposure times selected were normally from 8 to 15 minutes. Approximately midway in the Skylab 3 mission, it was suspected that filter 3 had developed a light-leak that allowed visible light to penetrate and partially expose the film. Evaluation of the film returned from Skylab 3 confirmed the light-leak in filter 3. During Skylab 4, filter 1 (0.5 mil aluminum) or filter 5 (3.0 mil beryllium) was used in place of filter 3 for the extra long exposures. All six filters were subjected to exposure times in excess of the premission operating requirements with only filter 3 experiencing damage. Details of this anomaly are discussed on page 103.

The X-REA gathered X-ray spectral data, and was used to detect solar flare activity. Following initial activation of the X-REA, the beryllium and aluminum high voltages were turned off each time the spacecraft passed through the SAA. Evaluation of the X-REA data with the high voltages on, telemetered to ground on DOY 153 during an SAA pass, indicated the radiation in the SAA was less than anticipated. Therefore, on DOY 155, the beryllium and aluminum high voltages were turned on and operated continuously during the remainder of the manned Skylab misssions. Analysis of the X-REA calibration counts verified no significant degradation of the electronics. Gradual degradation of the scientific data occurred as a result of instrument operation exceeding the life expectancy of the proportional counter tubes. The operational life of the X-REA was limited by the X-ray counting capacity of the proportional counter tubes. Therefore, the life expectancy was a function of time and count rate, which varied with solar activity. Based on actual solar activity, the operating life was determined to be approximately 1,000 hours. The X-REA was operated for approximately 1,174 hours. The telemetered calibration counts, current, and temperature data shown in Table 17 verified operation within design tolerances.

TABLE 17. S056 TELEMETRY DATA

Measurement	Thermal Vacuum Test	Actual Flight			Operational Allowable Limits
		Skylab 2	Skylab 3	Skylab 4	
Forward Tube Temperature	20.6° to 22.8°C	19.2° to 20.7°C	20.7° to 23.4°C	20.5° to 23.6°C	18.3° to 23.9°C
Center Tube Temperature	20.6° to 22.2°C	20.5° to 21.9°C	20.8° to 22.3°C	20.5° to 22.2°C	18.3° to 23.9°C
Camera Interface Plate Temperature	20.6° to 21.7°C	20.9° to 21.4°C	20.9° to 21.2°C	20.3° to 21.3°C	18.3° to 23.9°
Camera Electronics Package Temperature	19.4° to 20.6°	19.2° to 20.7°C	19.4° to 20.8°C	18.2° to 20.7°C	0° to 40°C
Camera Electronics Input Power	180 to 260 mA	196 to 297 mA	195 to 300 mA	188 to 302 mA	150 to 350 mA
Calibration Counts Aluminum Module	2210 to 2230	2217 to 2228	2211 to 2236	2223 to 2230	2000 to 2500
Beryllium Module	1480 to 1510	1470 to 1506	1480 to 1515	1468 to 1504	1300 to 1700
Beryllium Input High Voltage Supply	58 to 62 mA	55.7 to 62.8 mA	55.7 to 61 mA	55.8 to 62.8 mA	45 to 85 mA
Aluminum Input High Voltage Supply	58 to 62 mA	57.8 to 61.5 mA	57.8 to 61 mA	57.5 to 62.0 mA	45 to 85 mA
X-Ray Event Analyzer Input Power	600 to 620 mA	588 to 613 mA	570 to 610 mA	587 to 622 mA	550 to 750 mA
X-Ray Event Analyzer Temperature (Internal)	20.0° to 25.6°C	25.1° to 26.4°C	23.1° to 26.7°C	23.3° to 29.0°C	0° to 40°C

The camera electronics provided the required controls, power to the camera, and frame identification to the film. Telemetered data from the camera electronics verified operation within design limits, as shown in Table 17.

The TCS performed as designed. Telemetered data indicated that the telescope and X-REA temperatures were within the prescribed limits. A rise in the telescope forward-end temperature above the normal operating limit of 22.8°C (73°F) was experienced during Skylab 3 and 4. This was attributed to degradation of canister thermal coating and high beta angles. The instrument did not exceed the maximum allowable operational temperatures. Telemetered temperature data are shown in Table 17, and typical temperature sensor locations are shown in figure 48.

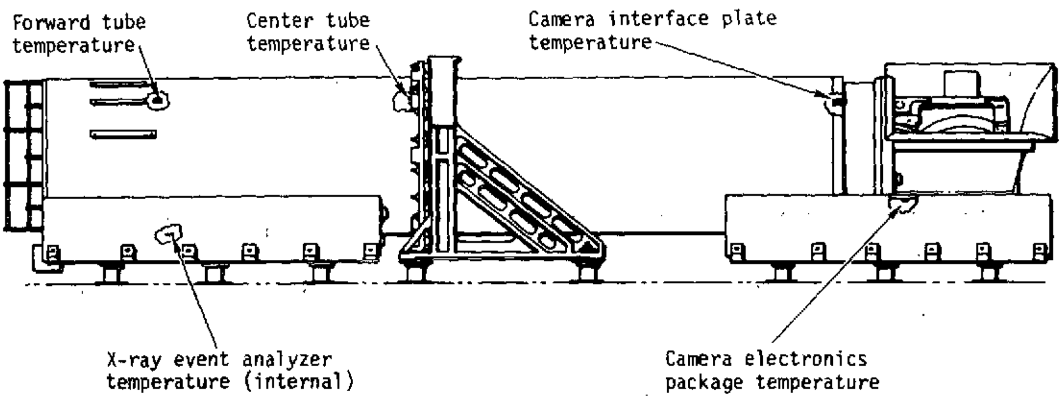


FIGURE 48. S056 TEMPERATURE SENSOR LOCATIONS

ATM Interface. All ATM interfaces provided satisfactory support to the instrument. Problems associated with the S056 thermal shield door, and the ability to display X-REA data onboard, created operational difficulty, but did not impact achievement of mission objectives.

The thermal shield door failed to open twice during Skylab 2, and repeatedly, during Skylab 3. Malfunction procedures corrected each anomaly. Removal of the thermal shield door ramp latch during the second EVA of Skylab 3 precluded further problems with the S056 thermal shield door.

During Skylab 2 the activity history plotter failed to transport paper following an inadvertant slewing of the paper past a tear that was in the paper prior to launch. The subsequent inability to record X-REA data onboard did not impact the scientific data return because the data were telemetered to ground; however, there was a significant impact on crew operations. The crew was unable to monitor long term trends of X-ray activity, or observe flare rise and fall times. The crew also had no records of X-ray activity that occurred during unattended periods, and therefore, had to rely on ground support for X-ray history data.

On DOY 330 (Skylab 4), the crew reported that the beryllium display counter on the C&D console failed to indicate any X-ray activity. Telemetered data verified that the beryllium detector was functioning. Thereafter, the beryllium data could only be monitored by ground personnel. The cause of this anomaly was not determined.

Limited ground data processing capabilities affected real-time planning. Real-time engineering analysis was hampered due to delayed retrieval of data.

Man/Machine Interface. Operation of the S056 instrument by the crew was excellent. Only two minor procedural errors occurred, which were the occasional failure to close the airlock door prior to unattended ATM operations, and failure to close the shutter after one extra-long exposure (reference page 97). Instrument performance was unaffected.

Scientific Data Quality and Quantity. Five film loads were used during the Skylab mission. Table 18 illustrates film usage per mission. Film load 4 contained SO-242 color film to obtain

TABLE 18. S056 FILM LOAD USAGE

Film Load	Skylab Mission	Frames (1) Available	Frames Exposed	Installed (DOY)	Removed (DOY)
1	2	6000	4184	Prior to Skylab 1 Launch	170
2	3	6000	5671	218	236
3	3	6000	5822	236	265
4	4	6000	5191	326	359
5	4	6000	6907	359	034

(1) Approximately 1200 additional frames per load were available for contingency use.

photographs of greater spectral resolution. The low number of exposures taken on film load 1 was attributed to the low level of solar X-ray activity during its period of use. The overall X-ray image quality of the film was good, and indicated stable optical performance of the telescope. Evaluation of the returned film and salt pads indicated that the film remained sufficiently moist. Spatial resolution on the order of 2 arc-seconds was attained as compared to the design goal of 2.5 arc-seconds. Figure 49 is a representative photograph taken by the S056 camera with SO-212 black and white film.

The light-leak that developed in filter 3 during the Skylab 3 mission resulted in the loss of all soft X-ray data for the

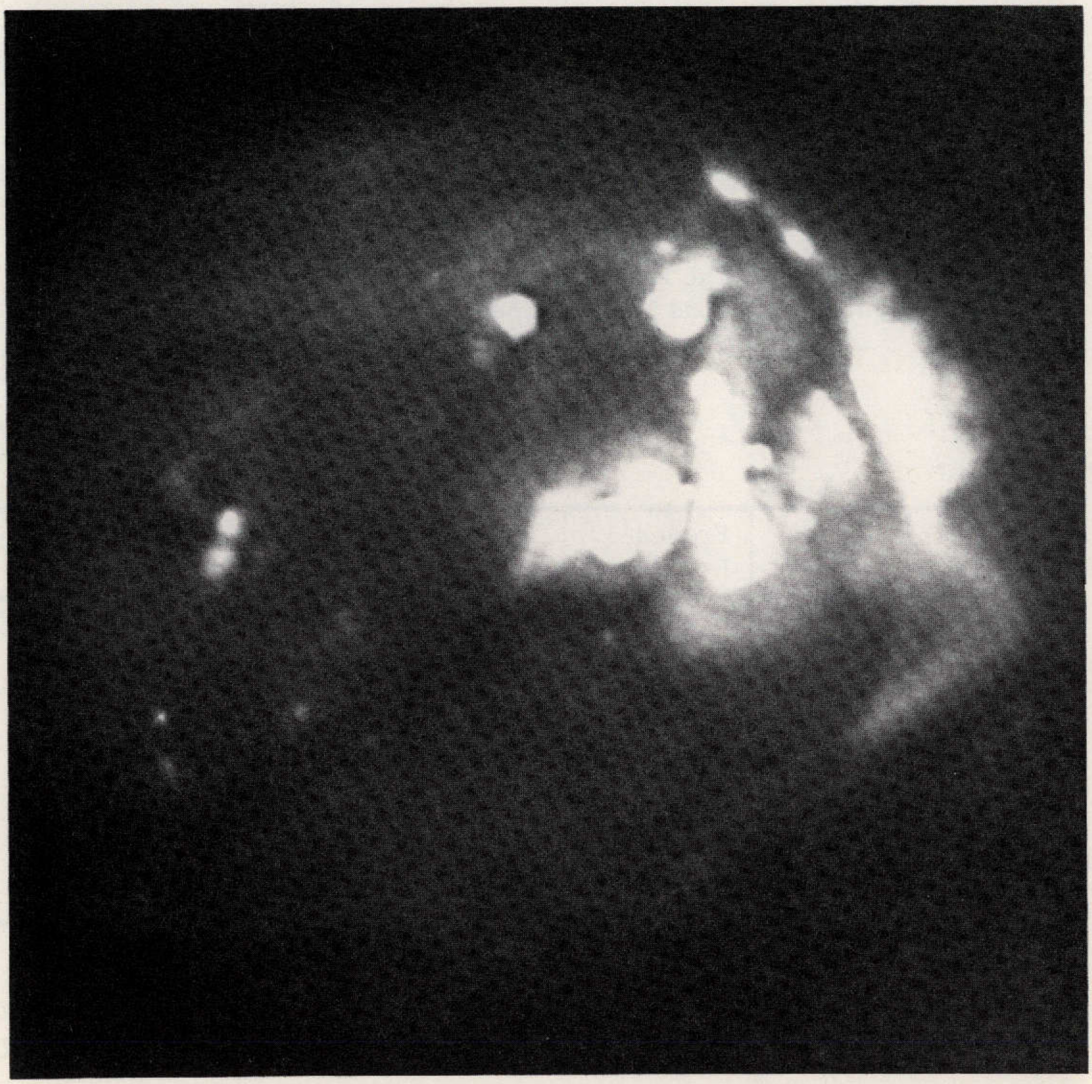


FIGURE 49. X-RAY IMAGE TAKEN WITH SO-212 BLACK AND WHITE FILM

remainder of the Skylab mission. Filter 3 was the only filter that covered the 27-to-33 angstrom spectral range of soft X-rays. The wavelength cut-off of the other filters was a maximum of 20 angstroms; therefore, X-ray data obtained following the failure of filter 3 were limited to 20 angstroms and below.

The X-REA obtained 1,174 hours of spectral data, and was the first instrument to detect the solar flare on DOY 166. During the flare on DOY 166, the X-ray flux data rose significantly, as shown by the plotted telemetered data in figure 50. The spectral resolution was equal to the design requirement of 2.5 angstroms. Throughout the mission, the X-REA continued to detect solar flare activity.

Anomalies

General. The S056 instrument experienced two anomalies during the Skylab mission. A light-leak that developed in filter 3 during Skylab 3 resulted in the loss of soft X-ray data from 27 to 33 angstroms for the remainder of the mission. Several operational modes terminated prematurely during a sequence of exposures. After premature terminations, operations were resumed simply by restarting the camera. Details of these anomalies are discussed below.

Filter 3 Light-Leak. During Skylab 3 a light-leak developed in filter 3. Evaluation of the film data from Skylab 3 revealed that the light-leak had allowed visible light to penetrate and partially expose the film. During Skylab 4 manual exposures using filter 3 were discontinued. However, during the automatic modes of operation, X-ray data were still recorded through filter 3, but were degraded. The condition of filter 3 degraded more during the remainder of the mission causing the film data to become progressively worse. The loss of filter 3 impacted the scientific data as it was the only filter that covered the 27-to-33 angstrom spectral range of soft X-rays. Following filter 3 failure, the X-ray data obtained were limited to wavelengths of 20 angstroms and below. Indications were that the damage to filter 3 was caused by thermal stress which caused perforations of the filter material; however, the problem could have been a result of a manufacturing defect which allowed the filter to lift out of the filter wheel. All six filters were subjected to exposure times in excess of the premission operating requirements with only filter 3 experiencing damage. The exact cause of the problem is unknown.

Premature Terminations. On DOY 160, during Skylab 2, the instrument experienced the first instance of a repeating anomaly. Initially, there were three premature terminations of the active 1 mode (two in active 1 long, and one in active 1 normal). The

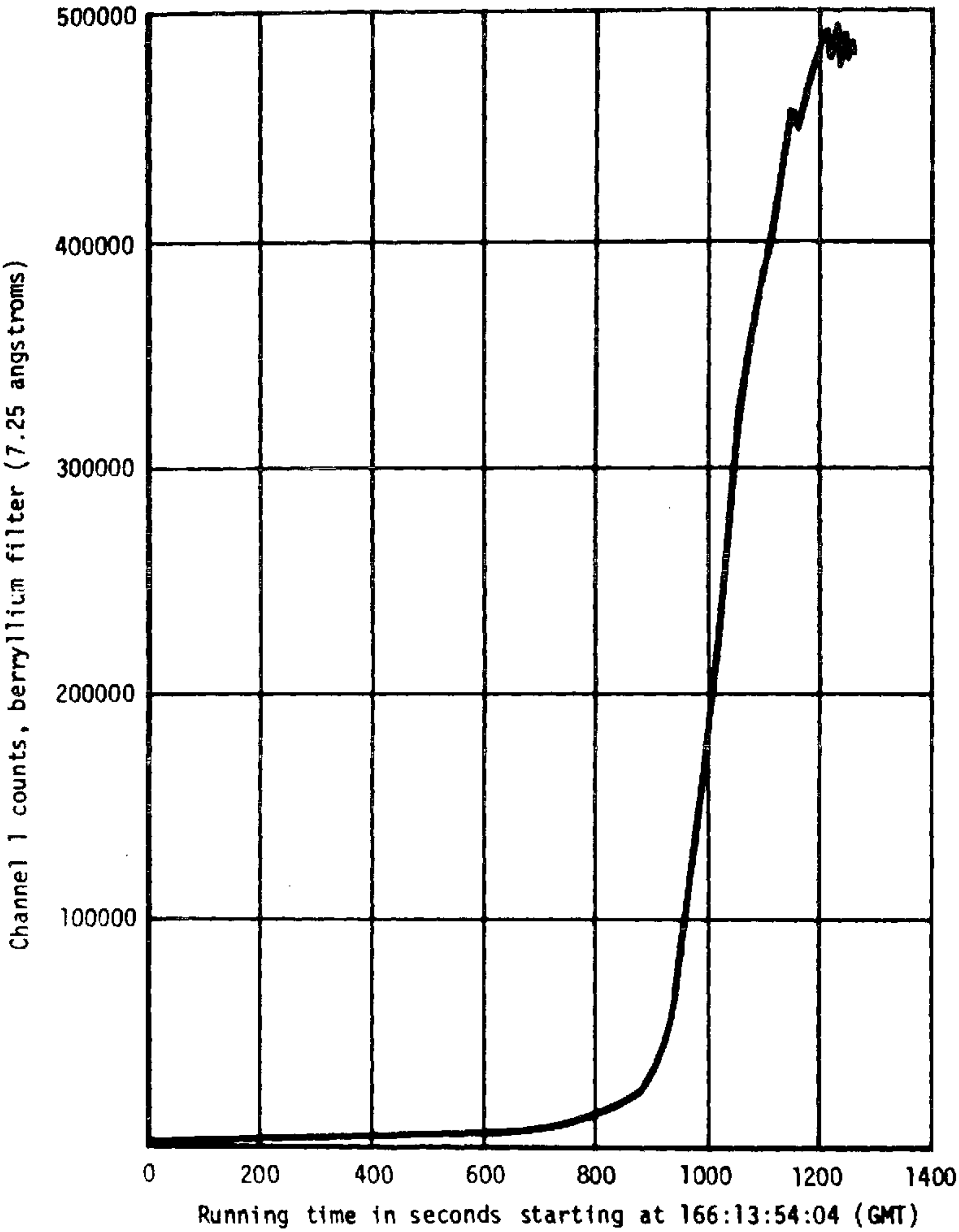


FIGURE 50. X-RAY EVENT ANALYZER FLARE RESPONSE

camera terminated prior to completing the full sequence of exposures (15 for long exposures, and 36 for normal exposures). In all cases, several exposures were taken. Prior to the first occurrence, the camera operated without error for 1,764 frames. After the first occurrence, the camera continued to terminate prematurely until the instrument was powered down for the unmanned period between Skylab 2 and 3.

The film magazine was removed during EVA on DOY 170, and returned with the Skylab 2 crew. Another magazine was installed during the first EVA of the Skylab 3 mission.

On DOY 234 and 235 (second film load), the S056 camera terminated prematurely in two patrol short modes and three active 1 long modes. These terminations occurred after approximately 5,177 frames had been successfully taken. Additional premature terminations occurred on DOY 244 and 245 (third film load) in the active 1 long modes, after approximately 3,000 frames had been successfully taken. The terminations occurred more frequently through the remainder of Skylab 3.

On DOY 359 (fourth film load), the S056 camera terminated prematurely in an active 1 normal mode. This termination occurred after approximately 5,000 frames had been successfully exposed, and was the only termination of the first Skylab 4 film load. This magazine was loaded with color film without the antistatic (rem-jet) backing, and the clutch surfaces had been coated with a dry lubricant to reduce drag. The number and frequency of premature terminations was reduced, but not eliminated.

On DOY 019 (fifth film load) the S056 camera terminated prematurely in the patrol and active modes. These terminations occurred after approximately 5,000 frames had been exposed, and continued to occur through the remainder of Skylab 4. However, the frequency of occurrence was less than that experienced on Skylab 2 and 3.

The returned Skylab 2 film magazine and film were examined. The drive torque was measured at 10 in.-oz. prior to removal of the film. This torque was not excessive. The film showed several short frames at the times of the anomalies, indicating improper film advance. There were no significant scratches or marks to indicate binding of the film. The film magazine was disassembled and each part thoroughly examined. No conclusive evidence was found that would determine the cause of the anomaly.

The magazine was tested using a flight-equivalent camera and electronics. The problem repeated after approximately 7,500 frames advanced. The frames were shorter than normal, but the torque values were still within an acceptable range.

On return of the Skylab 3 magazines, visual examination was performed under subdued light. No damage was found. The drive torque was measured. The measurements consisted of static torque readings over 10 feet of film. The torque on the first Skylab 3 magazine (film load 2) was 6.5 in.-oz. at the beginning, and as the 10 feet of film was advanced to the takeup roll, the torque increased to 11 in.-oz., and remained there. The torque on the second Skylab 3 magazine (film load 3) was 8.0 in.-oz. at the beginning, and as the 10 feet of film was advanced to the takeup roll, the torque increased to 11 in.-oz., and remained there.

The second Skylab 3 magazine film cover was removed in total darkness and the film compartment examined by feel. The film was cut between the film supply roll and the idler sprocket. The supply roll was removed from the magazine. The film cover was reinstalled and the magazine replaced in the return bag and the carrying case. The film in this magazine appeared to be wound tighter on the takeup roll, and had more tension on the film between the takeup roll and the film drive sprocket. The procedure was repeated for the first Skylab 3 magazine.

The Skylab 3 film magazines were down-loaded per procedure, leaving the piece of film in the film gate. Photography of the magazines revealed a small scratch between the sprocket holes and the edge of the film. After removing the film in the gate, a contamination sample was taken from the film side and the mechanism side of each magazine.

The first Skylab 3 film magazine was disassembled. The drag brake, takeup clutch, platen, and pressure plate were visually inspected and photographed at 40 X. The wear observed was less than on the Skylab 2 film magazine. Contamination samples were taken and found to be the rem-jet backing from the film.

Review of the flight film showed stress lines on the trailing edge of the film-sprocket holes. These stress lines indicated that the friction of the takeup clutch increased sufficiently to cause the film to be pulled by the takeup mechanism, rather than by the drive sprocket. This caused more load on the drive motor. Scratches were also detected on the film, similar to the scratches on the piece of film in the gate. Investigation of the Skylab 4 magazines revealed no additional information.

The premature terminations were caused by the loss of the film advance pulse. The film advance pulse originated within the film magazine through a magnet-reed switch arrangement directly coupled with the film transport from the supply side of the film roll as shown in figure 51. The magnet-reed switch assembly was an integral part of the idler sprocket; therefore, an increase in tension, torque, or difficulty in rotating the idler sprocket interrupted the film advance pulse.

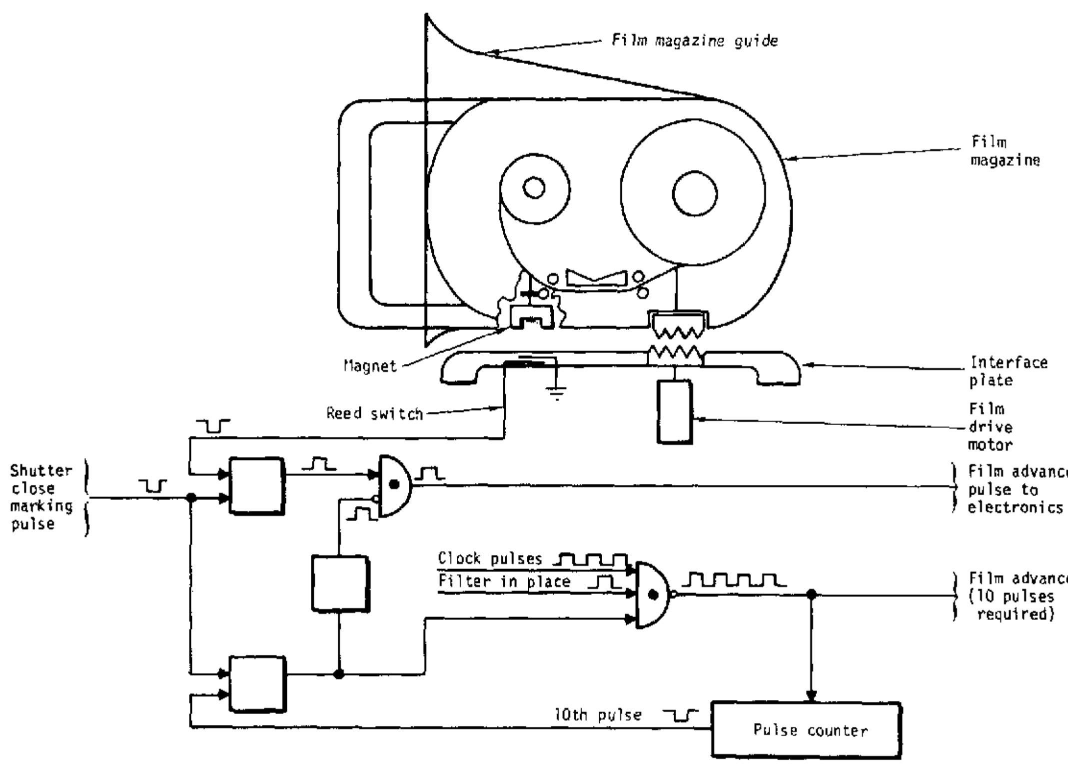


FIGURE 51. S056 FILM ADVANCE CIRCUITRY

Excessive mechanical drag in the magazine would prevent the film-drive motor from advancing the film a complete frame, thereby causing the film advance decoding system to indicate a short frame. Sufficient short frames in sequence would cause the film advance decoding system to indicate no film advance, terminating camera operations until the start/stop switch on the C&D console was reactivated.

The film-drive motor operated directly from digital circuitry, using a square-wave pulse. The motor was pulsed 36 degrees. At the start of the pulse, the motor had the capability of producing approximately 30 in.-oz. of torque, but fell rapidly to approximately 5 in.-oz. in the last 5 degrees of travel. The magazine film transport assembly was designed to depend on the momentum of the film and mechanisms, to lessen the torque required in the last few degrees of travel. Had the motor been capable of overcoming the slight increases in drag, the film would have moved the required distance.

The conclusion based on all data examined and tests performed, was that mechanical drag build-up within the film magazine was sufficient to stall the film drive motor.

Conclusions

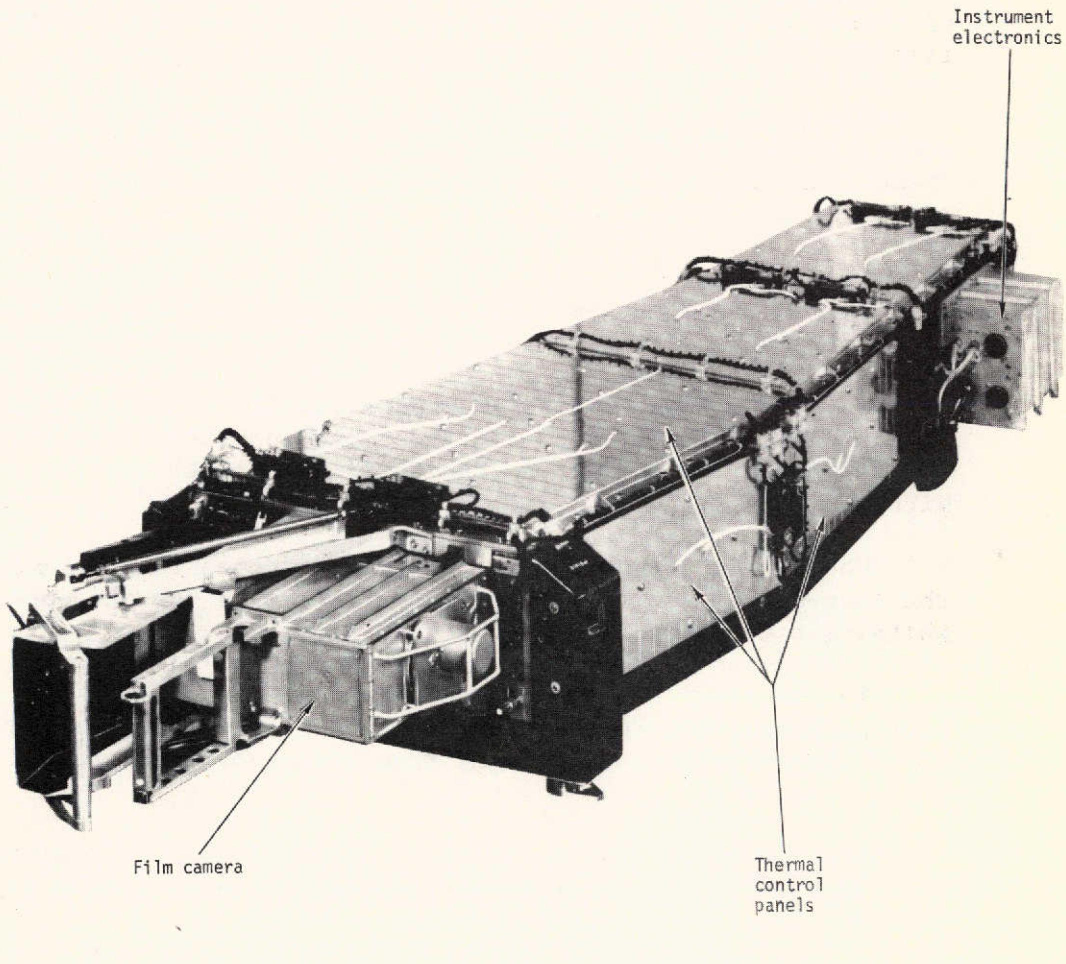
The S056 instrument performed exceptionally well throughout the Skylab mission. The spatial resolution of approximately 2 arc-seconds was better than the design specifications, and the overall image quality resulted in X-ray photographs of fine detail.

X-ray color film was exposed for the first time in the camera. While this data has not yet been processed, it is expected, based on preliminary development tests, that extremely good spectral resolution will be obtained. The quality of data was greatly enhanced by the assistance of the crew in performing a special procedure which allowed longer than designed exposure times. This was of special significance on Skylab 4 because of the relatively low solar activity. The data obtained from these long exposures are expected to reveal important scientific information on solar X-rays during quiet Sun conditions.

SECTION VIII. EXTREME ULTRAVIOLET SPECTROHELIOGRAPH (S082A)

Description

General. The Extreme Ultraviolet (XUV) Spectroheliograph, shown in figure 52, was designed to photographically record images of the solar chromosphere and corona to 1.5 solar radii (when Sun-centered) in the XUV wavelengths between 150 and 625



Length -	122.6 in.	312.4 cm
Height -	16.0 in.	41.0 cm
Width -	35.0 in.	88.9 cm
Weight -	252.0 lbs	114.3 kg

FIGURE 52. S082A XUV SPECTROHELIOGRAPH

angstroms on 35 by 258 millimeter film strips. The instrument was designed for operation from the ATM C&D console, or in an automatic mode by ground command.

The S082A housing was a light-tight, aluminum housing, consisting of a rigid case and removable cover enclosing the optical subsystem. The instrument weighed 114.3 kilograms and was approximately 312.4 by 88.9 by 40.6 centimeters in length, width and height, respectively.

Optics. The optical system, shown in figure 53, consisted of a main grating, three heat rejection mirrors and an aluminum filter. The filter was physically located in the camera.

The main grating was a finely-ruled (3600 lines per millimeter), concave, precision optical element mounted in a movable frame that allowed light, in either of two wavelength bands (150 to 335 or 321 to 625 angstroms), to be directed to the film camera.

Two of the three heat rejection mirrors were mounted inside the instrument housing. The short-wavelength rejection mirror moved up into or down out of the zero-order light path. The up or down position was controlled automatically in conjunction with the main grating position. In the raised position, it reflected the zero-order whitelight to the third (external) heat rejection mirror.

When the long-wavelength band was directed to the camera, the long-wavelength rejection mirror reflected the zero-order whitelight to the external rejection mirror.

The external heat-rejection mirror was mounted on the instrument housing, next to the aperture. It received and dumped overboard the zero-order whitelight from either of the internal rejection mirrors.

The instrument had an internal aperture door in addition to the ATM thermal shield door. Both doors operated from a single C&D console or ground command.

Although the usual operation was in the Sun-centered mode, the design provided for offset pointing up to 24 arc-minutes from Sun-center.

Camera. The camera was the only data-recording device of the instrument. The camera contained 201 strips of XUV-sensitive

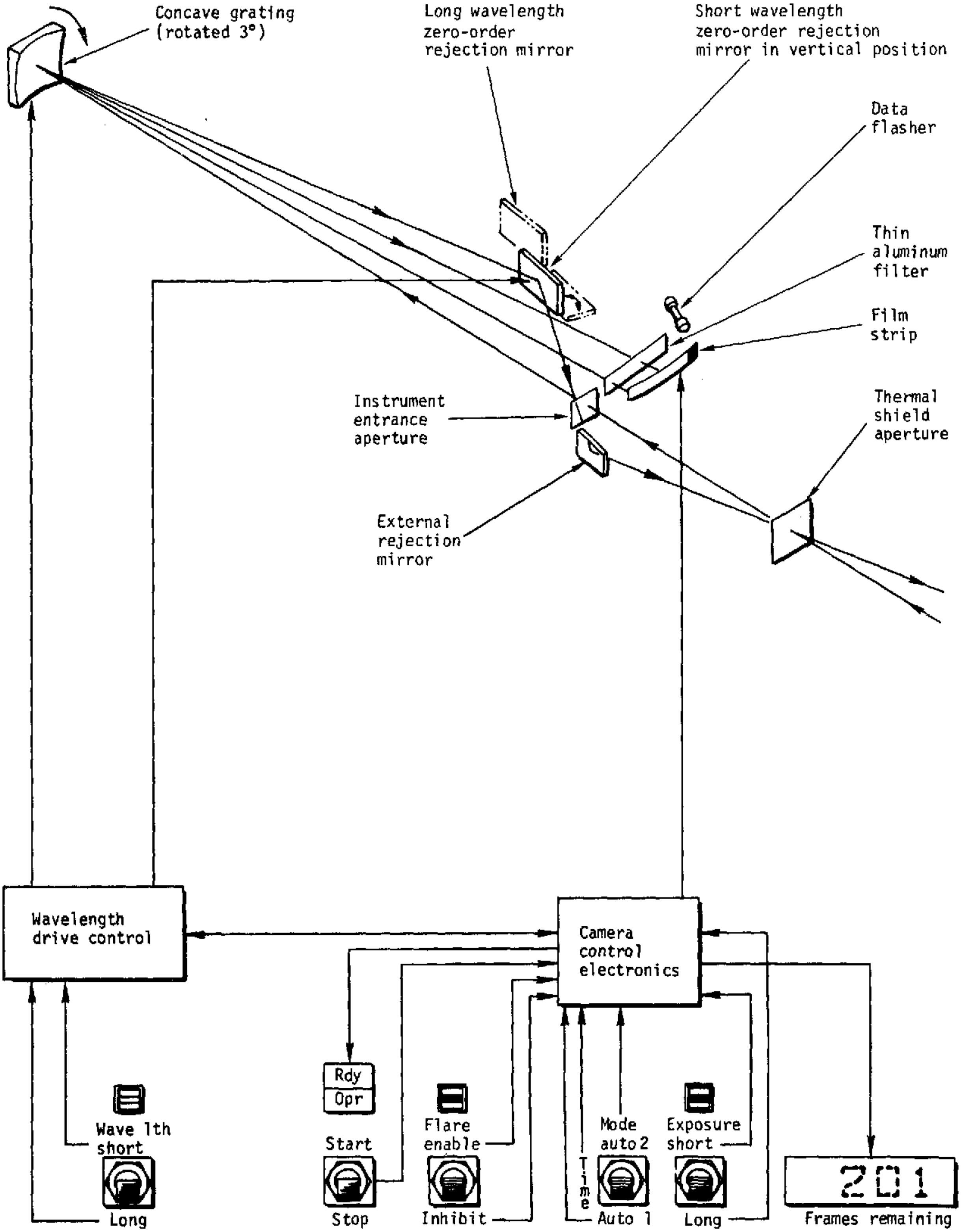


FIGURE 53. S082A OPTICAL SCHEMATIC AND CONTROLS & DISPLAYS CONCEPTIVE REPRESENTATION

film. At Skylab 1 launch, one camera (film load) was installed on the instrument. Two cameras were stored in the MDA film vaults. One camera was resupplied on Skylab 3 and two were resupplied on Skylab 4.

When all the film in a camera was exposed, the camera was manually removed, stored and replaced by the crew. The camera was attached to the Sun-end of the instrument by means of the camera latch and guide rail mechanism. The camera latch handle provided for easy installation of the camera on the instrument.

Electronics. The major elements of the instrument electronics were the power supply, reset and preset logic, mirror/grating drive controllers, camera and diode array electronics, operational mode logic, and a temperature monitoring subsystem.

Thermal Control System. The TCS consisted of an active heating system and a passive insulation system for controlling and stabilizing instrument temperature. The active heating system provided eight independent honeycomb panels with strip heaters. Each heater panel was equipped with its own independent temperature-sensing thermistors and controller circuitry. Six of the heater panels were mounted on the top surface of the instrument, and two were mounted on the right-hand (viewed from Sun-end) side wall. The passive insulation system consisted of eight insulation panels which were mounted at locations not covered by the heater panels. The insulation panels consisted of multiple layers of aluminized Mylar enclosed in thin plastic cover sheets.

The average case temperature requirements were 21.1 $\pm$ 4.4°C (70 $\pm$ 8°F) while operating. An additional requirement was necessary to control image smear. Allowable dynamic temperature gradients across the instrument case were specified at 0.12°C (0.2°F) in a five-minute period of time. Temperature changes greater than this value would degrade image resolution by smearing.

Operation. The controls for operation of the instrument were located on the ATM C&D console. The instrument required the use of the XUV Monitor (reference Section IX) and/or one of the H-alpha telescopes (reference Section X) to identify solar features of interest, the manual pointing control system for positioning the canister and instruments, and the event timer for use during manual operation of the camera.

Spectroheliograms were obtained by any of four modes; a manual (time) mode and three automatic modes (auto 1, auto 2, and flare). In addition to mode selection, the crew selected either of two wavelength bands (long and short) and three ranges of exposure times; short (1/4X), normal (1X), and long (4X).

In the time mode, individual spectroheliograms were taken with manually controlled exposure times. For automatic timing, the panel event timer was operated to terminate the exposure at the completion of the preset elapsed time. The time mode was used when none of the automatic sequences was appropriate, or to conserve film.

The auto 1 mode provided an automatic sequence of three exposures of predetermined duration. The exposure times could be increased as a group to 4 times normal, or decreased to 1/4 normal. An auto 1 mode was completed in either the short or long wavelength grating position. The desired wavelength was selected before beginning the sequence. This mode was used to study features of interest in emissions covered by one position of the grating.

The auto 2 mode provided an automatic sequence of six predetermined exposures, three in each wavelength. The grating position was automatically changed after each exposure. The first exposure was made at either wavelength. All exposure times within a sequence were prescaled up or down by a common factor with the exposure switch. This mode was used to study features in emissions covering both spectral bands.

The flare mode provided an automatic series of 24 exposures, 15 at the short wavelength and 9 at the long wavelength. The flare mode could be entered from any power-on condition of the instrument. If it was entered during another mode, that mode was immediately terminated to allow the flare mode to begin. The flare mode provided automatic coverage of a flare without continuous crew attention.

Mission Performance

General. The XUV Spectroheliograph, supported by the ATM systems, demonstrated excellent performance during the Skylab mission. The film cameras obtained 1,024 high-resolution photographs. Although the instrument was designed for a life requirement of 56 days, it remained fully operable throughout the 270 day mission.

Instrument Performance. The primary objective of the instrument, to photographically record images of the solar chromosphere and corona to 1.5 solar radii from Sun-center in wavelengths between 150 and 625 angstroms, was successfully accomplished.

Six film cameras were used during the Skylab mission (2 cameras during each manned phase). The first film camera failed after obtaining 19 exposures and was replaced by the crew during an unscheduled EVA on DOY 158. All subsequent film cameras operated properly and obtained their full complement of exposures (201 frames each). Details of the failure of the first film camera are discussed on page 121.

Evaluation of the developed film from Skylab 2 and 3 revealed that some of the exposures had streaks which corresponded to the ribs in the stainless steel film holders. Flat aluminum film holders, like those used in S082B film cameras, were loaded into the Skylab 4 cameras and the streaking did not recur. Refer to page 120 for a discussion of the camera film streak anomaly.

The S082A TCS performance was acceptable throughout the Skylab mission. At no time did thermal expansion of the instrument exceed allowable limits affecting image focus on the film. Rates of change of differential temperatures, across the S082A instrument case, also never exceeded allowable levels related to image smear due to thermal bending. All temperature measuring circuits functioned normally and indicated correct functioning of the eight thermal control panels.

Thermal and structural analytical models were computerized during S082A design and closely matched the flight configuration. Analytical predictions from these models were compared to data obtained from the flight unit tests during final ATM thermal vacuum testing. Adjustments were made and the final thermal distortion program was then used during the mission.

During Skylab 2, the average case temperatures and the rate of change of differential temperatures across the case were held within the allowable limits by the instrument TCS. Lateral movements of images amounted to less than 5 arc-seconds in a 5 minute period. The instrument case temperatures were consistently 0.5° to 1.1°C (1° to 2°F) colder than the alignment temperature. The instrument was defocused by 20 to 25 percent of the allowable focus tolerance, by the colder case temperature. The colder instrument case temperatures were attributed to the colder environmental temperature, particularly during the early mission period before the S054 instrument was powered up (reference Section V).

During Skylab 3, the average case temperatures were consistently warmer than during Skylab 2 and ranged from 0.3° to 0.7°C (0.5° to 1.3°F) colder than the alignment temperature of 21.1°C (70°F). The higher instrument case temperatures during Skylab 3 were caused by higher ATM canister Sun-end temperatures which ranged from 1.0°C (1.8°F) to 3.0°C (5.4°F) higher than during Skylab 2. The Sun-end temperature rise was attributed to degradation of the S-13G white thermal control paint on the canister Sun-end.

During Skylab 4, the average case-temperature range observed was 20.3°C (68.6°F) to 21.6°C (70.7°F). There was a period during which successive full-sunlight orbits occurred. Average temperatures were at the maximum upper excursion of 0.4°C (0.7°F) above the alignment temperature.

The following thermal distortion data was obtained from a review of the S082A thermal distortion computer program results. The maximum image defocus computed was 12 percent of the allowable defocus of 0.008 of an inch. Horizontal image smear, due to dynamic side-to-side temperature gradients across the instrument case, was always less than one percent of that allowable. The maximum vertical image smear was about one-half of the horizontal smear. The allowable horizontal or vertical image smear was 0.002 inch in 5 minutes. The maximum long-term image smear experienced was 0.0002 inch in a 55 minute period. Therefore, it was concluded that thermal distortion of the S082A instrument case caused negligible degradation of the solar images on the film.

The S082A electronics performed as designed throughout the mission. No instrument malfunctions were reported by the crew and none were apparent from telemetry indications.

The instrument mechanical systems consisting of the instrument aperture door, the grating changer and the short-wavelength heat-rejection mirror, functioned as designed. The manually-operated film-camera latching mechanism also functioned as designed.

All S082A telemetry voltage measurements and status monitors performed correctly throughout all three Skylab missions. The S082A electronic voltages, shown in Table 19, indicated that flight voltages were nominally the same as those observed during ground test. All telemetry measurements were within specification limits.

TABLE 19. S082A TYPICAL VOLTAGES

Measurement	Specification (1) (Vdc)	Mission Excursions (Vdc)
+28 V Panel	28.0 ± 2.0	28.0 to 28.4
+28 V Primary	28.0 + 2.5,-2.0	27.5 to 28.2
+28 V Actuator	28.0 + 2.5,-2.0	27.5 to 27.9
+10 V Temperature	10.0 ± 0.2	9.8 to 10.0
-10 V Temperature	-10.0 ± 0.2	-10.0 to -10.1
+ 5 V Logic	5.0 ± 0.5	5.0 to 5.1
+ 5 V Digital	5.0 ± 0.5	5.0 to 5.1
+ 5 V Analog	5.0 ± 0.5	4.8 to 4.9
+ 5 V Computer	5.0 ± 0.5	5.0 to 5.1
+ 5 V Sync	5.0 ± 0.5	5.2 to 5.3

(1) 50M02425

ATM Interface. Generally, the ATM provided satisfactory support to the S082A instrument. Although the ATM canister thermal system activation was delayed due to early Skylab problems, the experiment thermal limits were not exceeded, and there were no detrimental effects on the instrument attributable to this condition. No film sensitivity degradation occurred as a result of storage in the MDA film vaults.

During Skylab 2, when S082A was in the flare-enable state, the S082A operate light remained on at the completion of a film exposure mode. This was a result of a feedback from the flare-enable indicator on the C&D console which held the relay contacts closed after the operate signal was removed. Consequently, crew operating procedures were revised to eliminate commanding the flare-enable state until just prior to initiating a flare sequence.

The ATM thermal shield door failed to close on DOY 231 and again on DOY 236 during EVA. The ramp latch was removed and normal operation resumed until DOY 254. Two-motor operation was adopted, but on DOY 344 and 345 the condition repeated. The crew, during EVA on DOY 359, latched the door open. No loss of scientific data occurred and the instrument thermal distortion parameters were maintained within allowable tolerance even though the thermal shield door was latched open.

Ground telemetry data processing was not entirely reliable. Data noise or synchronization problems occurred which caused a measurement to read erroneously for one or more update periods. For discrete signals the noise indicated changes of state which did not occur. The most common result was that extra exposures were indicated, making troubleshooting and data reduction more difficult. Another result of the erroneous data was that all triggering functions, such as instrument aperture open and close times, had to be manually input into the S082A thermal distortion computer analysis programs.

Man/Machine Interface. Significant crew accomplishments relating to S082A were the replacement of a failed film camera during an unscheduled EVA on Skylab 2, and latching open the failed thermal shield door during Skylab 4.

Crew operation of S082A was commendable, considering the multitude of switches and displays existant on Skylab. The only reported errors were those associated with the similarity and proximity of the S082A and S082B control panels on the C&D console. According to crew comments, this similarity and proximity resulted in occasional switch operations on one panel which should have been performed on the other.

Scientific Data Quantity and Quality. Six S082A film cameras were used during the mission and 1,024 exposures were obtained. The quantity of exposures was greater than the 804 exposures originally planned. The additional exposures were the result of a decision to resupply 2 cameras. Table 20 illustrates film load usage for each mission. The low number of frames exposed on film load 1 was the result of camera failure. Film loads 1 through 5 contained type 104 film which was used exclusively for solar observation. Film load 6 contained 5 frames of type 101 film for use in Comet Kohoutek observation (the remaining 96 frames were type 104 film).

TABLE 20. S082A FILM LOAD USAGE

Film Load	Skylab Mission	Frames Available	Frames Exposed	Installed (DOY) (1)	Removed (DOY)
1	2	201	19	Prior to Skylab 1 Launch	158
2	2	201	201	158	170
3	3	201	201	218	236
4	3	201	201	236	265
5	4	201	201	326	359
6	4	201	201	359	034

(1) Unmanned mission phases did not require S082A operations.

However, the high number of exposures obtained denoted successful camera performance.

TABLE 22. S082B FILM USAGE

Film Load	Skylab Mission	Frames Available	Frames Exposed	Installed (DOY)	Removed (DOY)
1	2	1608	1608	Prior to Skylab 1 Launch	170
2	3	1608	1602	218	236
3	3	1608	1593	236	265
4	4	1608	1608	265	034

The quality of data from the exposed film was excellent. No objectionable image smear occurred due to temperature gradients or jitter. Spectral resolution was well within the design goal of 0.06 angstroms and 0.12 angstroms for short and long-wavelength exposures, respectively, and was consistent with ground test results.

Figure 61 is a spectrogram which illustrates a comparison of emission spectra obtained by the S082B camera during the Skylab 2 mission. The spectra shown represents 12 arc seconds from the limb on the solar disk exposed for 1.25 seconds and 4 arc-seconds off the disk (corona) exposed for 2.5 seconds in the 2300 to 2440 angstrom wavelength band.

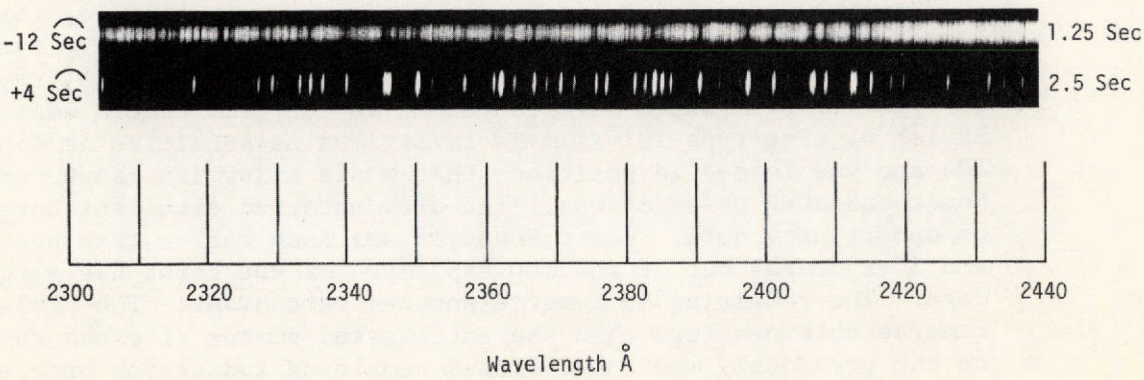


FIGURE 61. S082B COMPARISON OF PHOTOSPHERIC FRAUNHOFER AND CHROMOSPHERIC EMISSION SPECTRA

Figure 62 is a collection of S082B exposures taken through the Earth's atmosphere. In the left column (from top to bottom), light of the solar Lyman-alpha line of hydrogen is absorbed by molecular oxygen in the atmosphere, first cutting off the short wavelength side of the line. In the second column (from left), atomic oxygen in the Earth's atmosphere causes absorption in the core of solar emission lines, and molecular oxygen causes the disappearance of the entire line, as the altitude decreases. The third column (from left) shows that at 1550 angstroms the absorption of molecular oxygen is strongest, causing this line pair to be totally absorbed at 150 kilometers. In the column at the very right, absorption by bands of molecular oxygen is much weaker at 1900 - 1925 angstroms and allows the Sun's emission to penetrate much deeper into the Earth's atmosphere, even to altitudes that can be reached by high altitude balloons.

Figures 63 through 65 illustrate examples of XUV Monitor data. The photographs show a comparison between Skylab 2 and Skylab 4 data. The integration times were approximately 1, 2, and 4 seconds as shown in figures 63, 64, and 65, respectively.

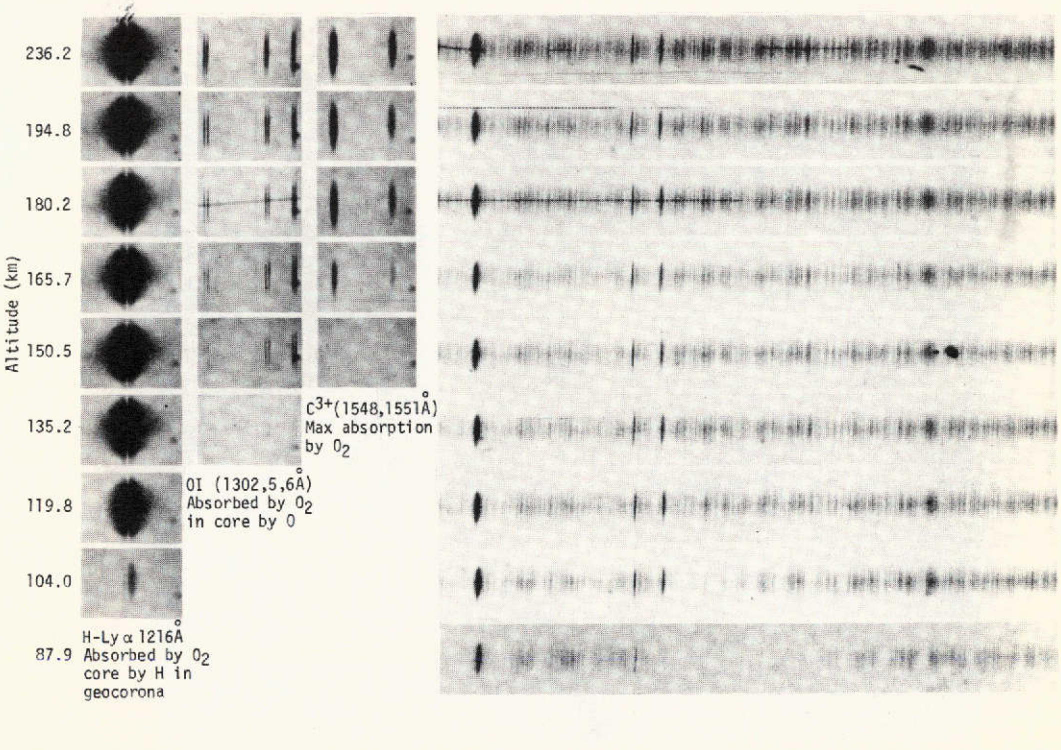
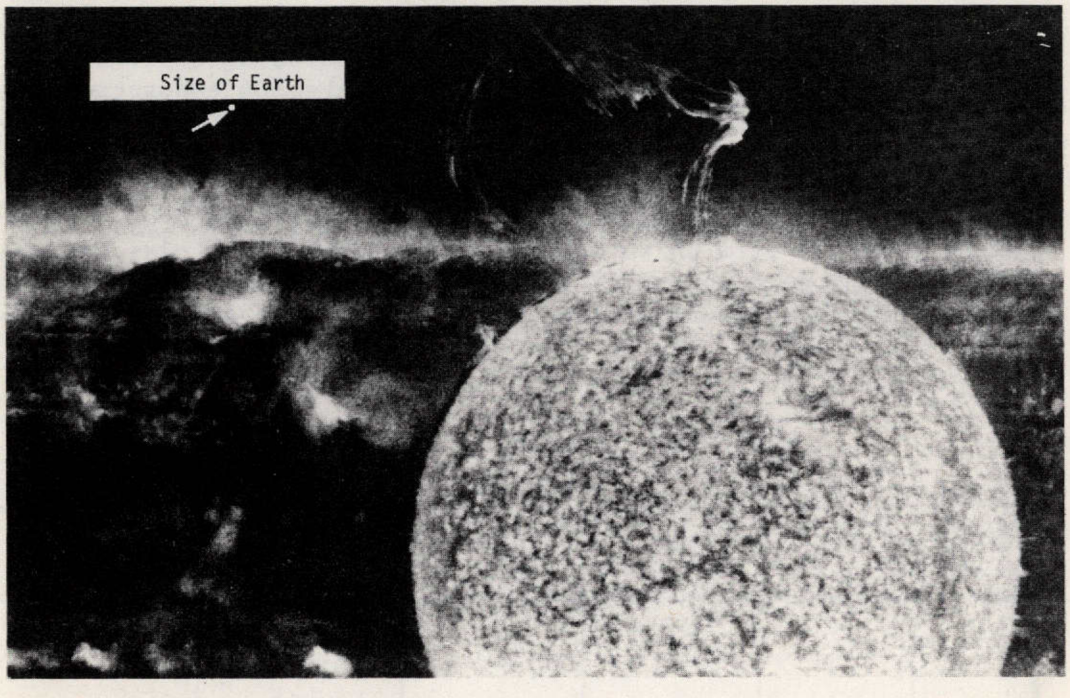


FIGURE 62. S082B UV ABSORPTION IN THE EARTH'S ATMOSPHERE

All scientific objectives were accomplished, and the spectroheliograms obtained from the film cameras indicated proper functioning of the instrument optics. Spatial resolution of 2 to 5 arc-seconds was attained, which compared favorably with the design requirement of 5 arc-seconds. Spectral resolution was well within the design goal of 0.13 angstroms for features 10 arc-seconds in diameter, and was consistent with ground test results. Some streaks were observed on the Skylab 2 and 3 film but did not significantly degrade scientific data (the previously mentioned streak problem is discussed on page 120).

Figure 54 is a photograph taken by the S082A film camera during the Skylab 3 mission and reveals for the first time that helium erupting from the sun can stay together to altitudes up to 300,000 kilometers. After being ejected from the Sun, the gas clouds seem to have come to a standstill, as though blocked by an unseen wall, and some material appears to have been directed back toward the Sun as a rain, distinguished by fine threads.



Iron^{+14} (284 Å) Helium^{+} (304 Å) and huge eruption

FIGURE 54. S082A FILM CAMERA PHOTOGRAPH

Figure 55 is a photograph taken by the S082A camera. An eruption on the limb (at the top, in the image at the left) is in progress, shooting out 60,000 kilometer-long jets of helium, emitting its characteristic extreme UV radiation at 304 angstroms. The jets seem to be following the loops characteristic of the magnetic fields above active regions.

In the corona (image at the right) the eruption is entirely different. There is a great diffuse mass of million-degree glowing iron ions; but still they show effects of the magnetic field.

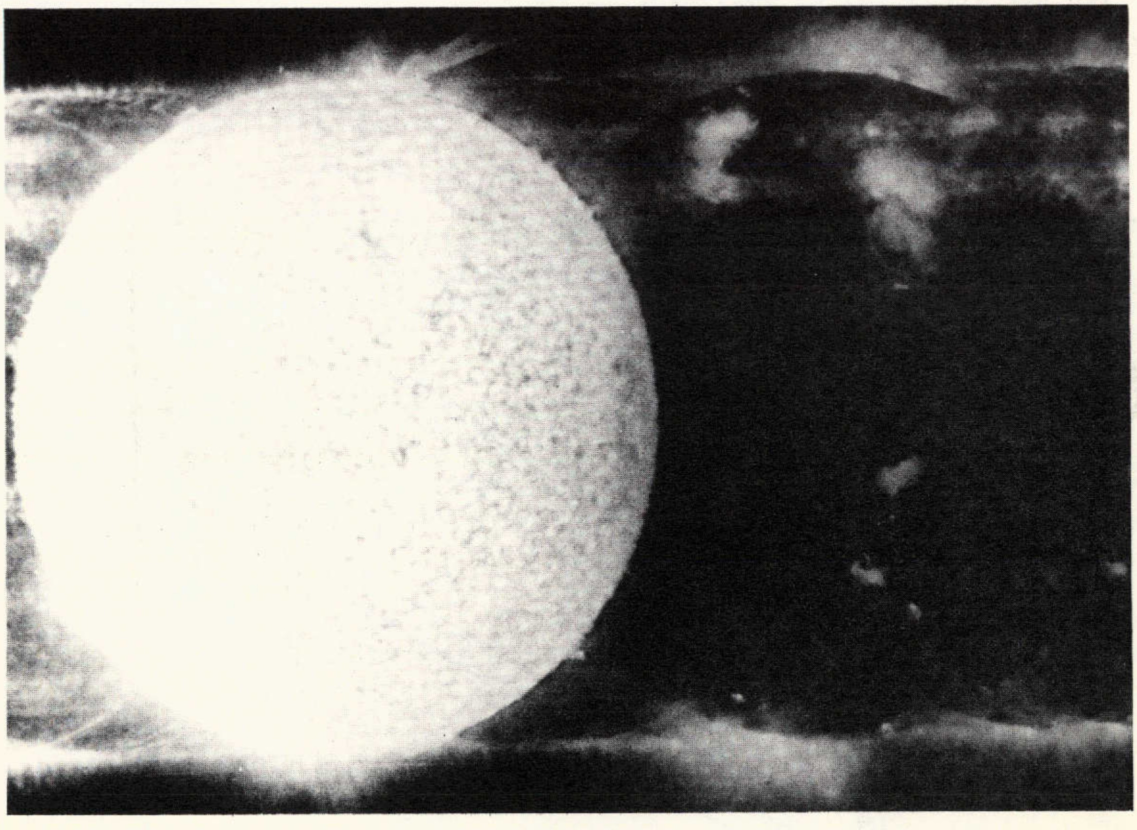


FIGURE 55. S082A FILM CAMERA PHOTOGRAPH

Anomalies

General. The S082A instrument experienced only three anomalies during the entire Skylab mission. Only one had an impact on the scientific data obtained. Streaks observed on the film from Skylab 2 and 3 slightly degraded the images on a very small percent of the data. This condition was corrected during Skylab 4 by using different type film holders. Details of the S082A anomalies are presented in the following paragraphs.

Film Streaks. On DOY 278, following development and evaluation of the Skylab 3 film, parallel horizontal pairs of streaks were observed on the film. The streaks were also present on the Skylab 2 film, but to a lesser extent. The streaks corresponded to the stiffening ribs in the film holder as shown in figure 56. Not all of the wavelength images were affected and only a small part of the images that were affected were degraded. The images contained acceptable scientific data; however a technical evaluation was conducted to determine if the S082B non-ribbed aluminum

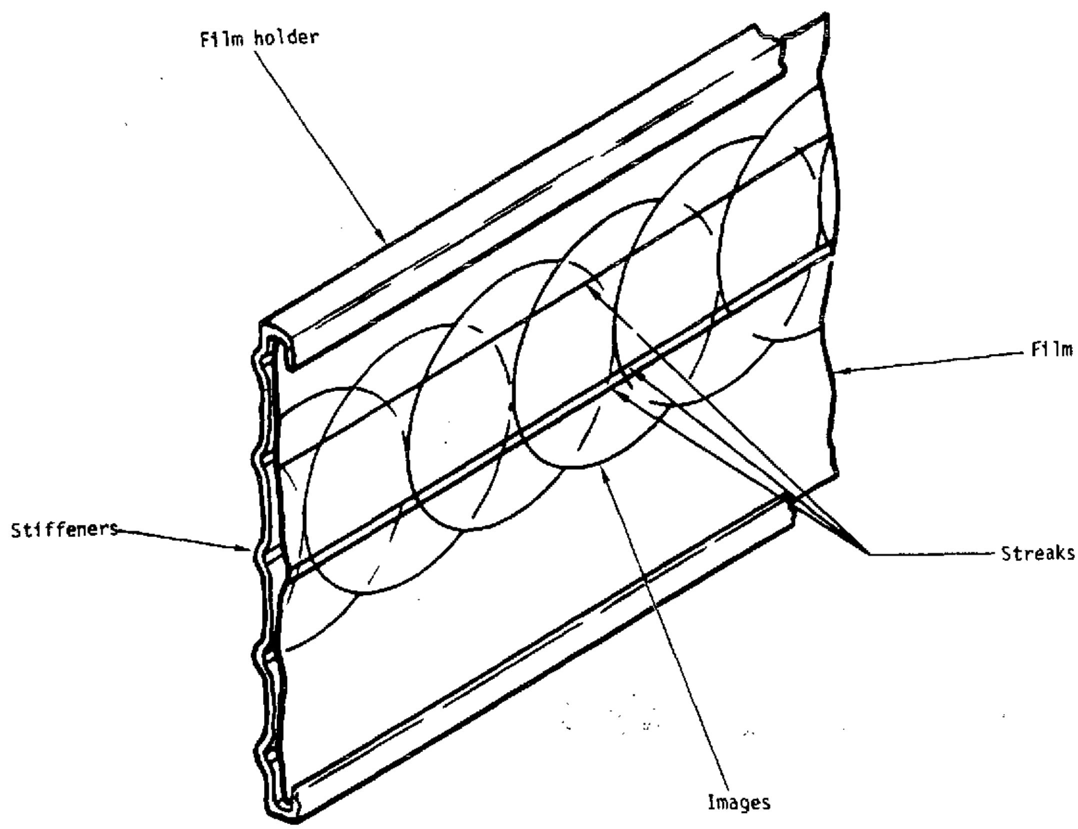


FIGURE 56. S082A FILM STREAKS

film holders could be used in the S082A camera. This approach was selected since the S082B exposures had no streaks. Evaluation of the Skylab 4 film data confirmed that the non-ribbed aluminum S082B film holders eliminated the streaks found when the ribbed stainless steel holders had been used.

S082A Camera Jam. On DOY 150 the crew indicated that the FRC failed to decrement. Telemetry verified the failure by absence of the film transport signal and by measurement of the film transport drive times. The cause of the failure was determined to be a camera jam.

The camera was exchanged during EVA on DOY 158. The replacement camera was cycled and the FRC and ground telemetry indicated proper operation. This was an unscheduled EVA and the S082A camera installed had been intended for Skylab 3. Therefore, the quantity of data obtained during Skylab 2 actually exceeded the original plan. The first camera obtained 19 exposures prior to the failure, and the entire load in the second film camera was exposed. Additional cameras were launched on Skylab 3 and 4.

The failed camera was evaluated and found to have jammed during film transport after 19 exposures. Although the failure mode was identified it could not be repeated and the cause was not determined. The problem did not recur with the other five cameras used during the remainder of the mission.

Erroneous Operate Light Indication. On DOY 153 the operate light remained on after a mode was completed when the S082A instrument was in flare-enable and operating in either auto 1, auto 2, or time mode. The operate light should have gone off at the completion of any mode. Because of this problem, the crew was unable to use the operate light as an indication of mode termination when the instrument was operated in a flare-enable. Figure 57 is an abbreviated schematic diagram of the S082A ready/operate circuit from the C&D console to the C&D logic distributor.

The problem was isolated to a sneak circuit path between the C&D console and the ATM C&D logic distributor. When the flare mode was enabled, the flare-enable talkback voltage was fed back to the operate relay in the ATM. This voltage was high enough to hold the operate relay energized.

Although the crew was inconvenienced, S082A operation was not affected. Correction of the problem was achieved through a change in operating procedure. The flare-enable was not commanded until just prior to initiating a flare sequence. Flare-initiate then

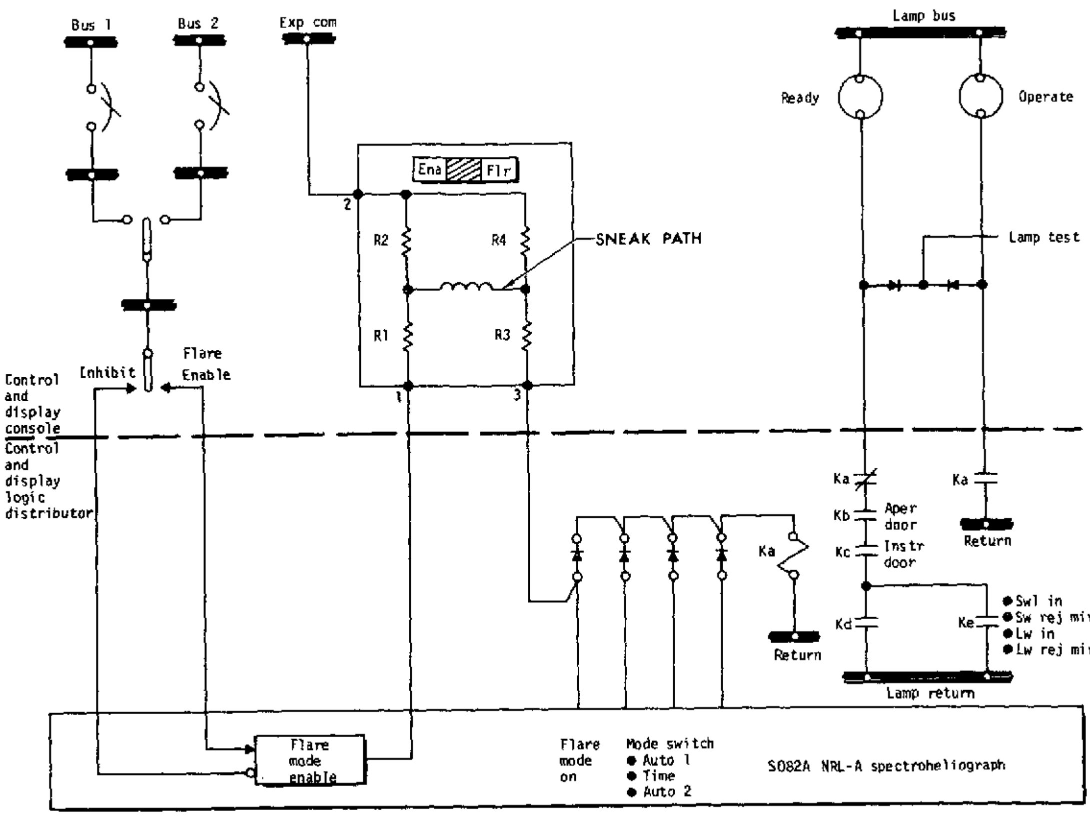


FIGURE 57. S082A READY/OPERATE CIRCUIT

removed the flare-enable command. No other problems were encountered with the S082A operate light using the new procedure.

Conclusions

The S082A instrument performed as designed. The one significant problem was corrected by crew action when the first film camera was replaced during EVA. Data returned in S082A film cameras were high in quality and demonstrated that all design goals had been met. Scientific value of the data was greatly enhanced by crew participation and by coordination between the crew and the PI. The high level of activity involved in operating the ATM instruments simultaneously, in addition to the many Skylab systems and experiments, was simplified through the use of the JOPs.

SECTION IX. SPECTROGRAPH AND EXTREME ULTRAVIOLET MONITOR (S082B)

Description

General. The Spectrograph and Extreme Ultraviolet (XUV) Monitor consisted of two different, but rigidly attached, telescopes. The spectrograph was the larger of these telescopes and contained both a TV imaging system and a spectrograph. The smaller telescope was the XUV Monitor. Both telescopes were designed for operation from the ATM C&D console.

The spectrograph was used to photograph line spectra of small selected areas on and off the solar disk and across the limb in two wavelength bands; 970 to 1970 angstroms or 1940 to 3940 angstroms. The XUV Monitor was used for observing a video image of the full solar disk in the wavelength band from 170 to 550 angstroms and to identify solar features of interest.

The S082B instrument is illustrated in figure 58. The main housing consisted of two attached aluminum cases and two removable covers. The spectrograph optical system and the pointing reference system were both enclosed by the main case and cover. A removable film-strip camera was attached by a hand-operated latch. The XUV Monitor was enclosed by the secondary case and cover. The instrument weighed 192.7 kilograms and was 304.8 by 88.9 by 49.5 centimeters in length, width, and height, respectively.

Spectrograph. The spectrograph had an internal aperture door in addition to the ATM thermal shield door. When both doors were opened, a concave mirror focused the solar image on a slit plate. The slit allowed a protion of the solar image, approximately 2 by 60 arc-seconds, to be photographed by the film strip camera. A predisperser grating, a waveband aperture, and the main grating functioned together to disperse the light passing through the slit into spectral lines which were focused onto the film strip by the main grating. The predisperser grating was changed by command from the C&D console, or automatically during an exposure sequence, to select either of two wavelength bands (970 to 1970 angstroms or 1940 to 3940 angstroms) to be photographed. Figure 59 is an optical schematic of the spectrograph.

Film Camera. Prior to Skylab 1 launch the film strip cameras were loaded with film (1,608 exposures per camera). One camera was mounted on the instrument, and two cameras were stored in the MDA film vault. One camera was resupplied on Skylab 4. Cameras

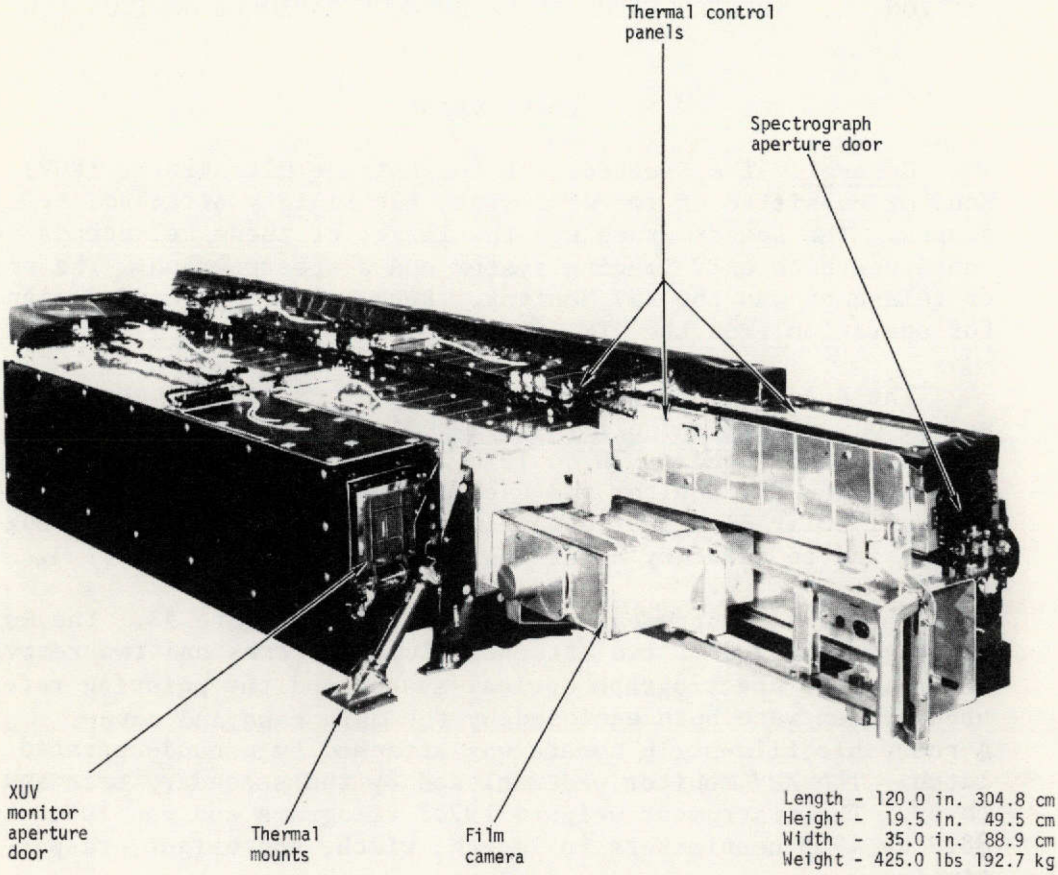


FIGURE 58. S082B SPECTROGRAPH AND XUV MONITOR

were retrieved and replaced on the instrument during EVA. Cameras containing exposed film were returned in the Skylab 2, 3, and 4 CSMs.

Pointing Reference System. The PRS basically consisted of an optical system (separate from the spectrograph optics), an image dissector tube video camera, and electronics to control experiment pointing to within 1 arc-second. The optical system, shown in figure 59, consisted of a neutral-density filter, a relay lens, and two folding mirrors. The function of the optical system was to re-image the slit plate, including slit, fiducial lines, and solar image, onto the face plate of the image dissector tube with a 15 to 1 magnification. The slit plate had a polished optical surface broken by the spectrograph slit and the darkened fiducial lines. The neutral-density filter reduced the light intensity from the solar image to an acceptable level for the image dissector tube.

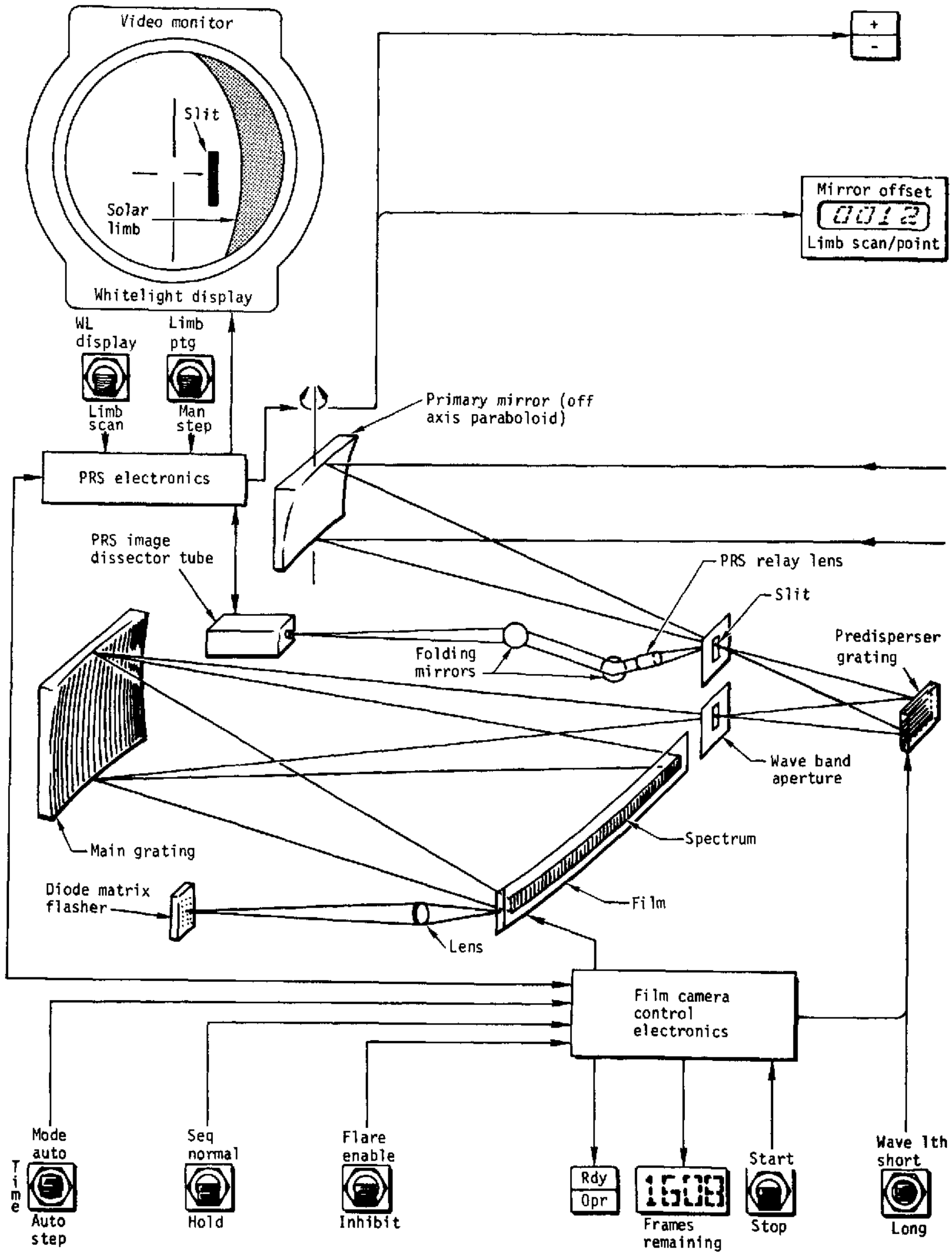


FIGURE 59. S082B OPTICAL SCHEMATIC AND CONTROLS & DISPLAYS CONCEPTIVE REPRESENTATION

The image dissector tube and electronics generated either a standard TV image of the area of the Sun presented to the slit plate, or an electrical signal representing the distance between the solar limb and the slit. The TV image was displayed on a monitor, and the limb offset in arc-seconds, on a digital indicator on the ATM C&D console.

XUV Monitor. The XUV Monitor operated independently of the spectrograph to provide a real-time image of the solar disk in the XUV waveband between 170 and 550 angstroms. The XUV Monitor optical schematic is shown in figure 60. The XUV Monitor consisted of a mirror, three thin aluminum filters, and a low-light-level TV camera. The XUV Monitor had a separate, independently operated aperture door in addition to an ATM thermal shield door that admitted light to its compartment.

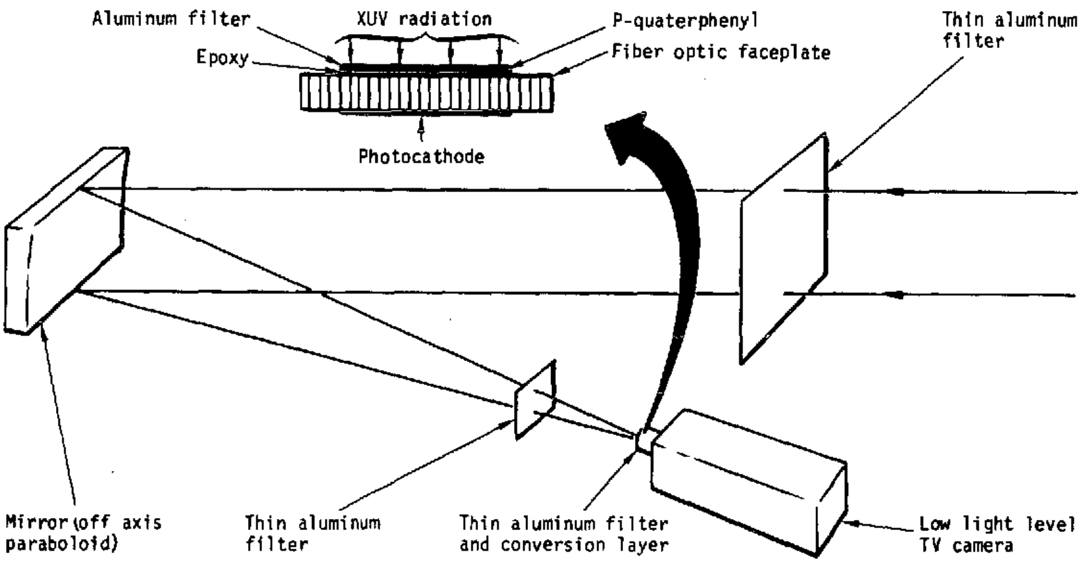


FIGURE 60. XUV MONITOR OPTICAL SCHEMATIC

The mirror had a concave reflecting surface, and was rigidly mounted to the rear wall of the XUV Monitor case.

The filters were aluminum films approximately 1500 angstroms thick. One filter was located inside the XUV Monitor instrument aperture door, one was in front of the TV camera, and one was deposited on the face plate of the TV camera.

The TV camera contained a secondary-electron-conduction vidicon with an aluminum filter and a thin layer of conversion material bonded to the face plate of the tube. The conversion material converted the filtered XUV wavelengths to visible light in the 4000 to 4500 angstrom range which the camera transmitted to the ATM C&D console and to the CSM transmitter for transmission to ground stations. The TV camera was mounted at the Sun-end of the XUV Monitor case.

Thermal Control System. An active TCS was required, because of the critical alignment and focus requirements of the S082B instrument. The TCS consisted of low-thermal-capacity standoff heater panels and passive insulation panels. The system was designed to operate in the controlled environment of the ATM canister at 8.3° to 14.4°C (47° to 58°F) and maintain the instrument average case temperatures at 21.0 $\pm$ 0.67°C (69.8 $\pm$ 1.2°F). The most critical thermal control requirements were rates of change of instrument side-to-side differential temperatures since these affected image smear. The rate of change of side-to-side differential temperatures was specified to be no more than $\pm$0.18°C per 15 minutes time. The heating system had 14 independent honeycomb panels with strip heaters. Each heater panel was equipped with its own temperature-sensing thermistors and controller circuitry. An analog telemetry monitoring subchannel for heater panel and instrument reference temperatures was provided for each heater panel. Nine of the heater panels were mounted on the top surface of the instrument. The remaining five were installed on the side walls.

Operation. The controls necessary to operate the S082B instrument were located on the ATM C&D console. The S082B instrument required the use of the H-alpha telescope for pointing to solar features of interest (reference Section X), the manual pointing control system for pointing the canister, and the event timer for use during manual operation of the spectrograph camera.

The PRS had 3 operating states; whitelight display, limb scan, and limb pointing. In whitelight display, a 3-arc-minute portion of the solar image was displayed on the TV monitor showing the relative position of the slit to the limb. In limb scan, a numerical display in arc-seconds was provided to aid positioning of the slit with reference to the solar limb. In limb pointing, the primary mirror position was maintained automatically within 1 arc-second of the selected limb offset. In limb scan or limb pointing, no video display was provided.

The S082B instrument functioned in four operating modes to provide spectrograms; the time mode, the three automatic modes (auto, flare, and auto step). An additional hold mode was provided to stop and retain automatic mode logic for continuation of a mode on the next orbit. The crew, in addition to selecting the mode of operation, selected either of two wavelength bands (long or short) on the C&D console.

The time mode provided the capability to take manual exposures. The time mode was used when the automatic modes did not fit the situation, or to conserve film.

The auto mode was used normally for monitoring features of interest which are characterized by slow temporal variations. The auto mode was preprogrammed to photograph the two wavelength bands alternately by positioning one and then the other of the two pre-disperser gratings into the optical path. The two wavelength bands were photographed with different exposure times for a total of eight exposures. Exposure times were automatically prescaled in the programmer electronics by a zone signal from the PRS when operating in limb point or limb scan mode. The three prescaling zones were:

Zone 1. On the disk, or within 1 arc-second off the limb,

Zone 2. +2 to +9 arc-seconds off the limb, and

Zone 3. +10 arc-seconds or greater off the limb.

The auto step mode was used to record temperature inversion phenomena in the vicinity of the limb. With the PRS in limb pointing, the instrument automatically pointed to ten different positions in the vicinity of the limb, and took eight exposures at each position. Exposure times were prescaled by the PRS as in the auto mode.

The flare mode was preprogrammed to take a series of 48 exposures to record the rise and early stages of a flare.

The hold mode was a nonoperational mode which was necessary for S082B because the auto step mode required more than one orbit for completion. The hold mode was used during the dark-side passes. When hold mode was activated, any automatic mode in progress was stopped and held for later resumption.

Mission Performance

General. The Spectrograph and XUV Monitor, well supported by the ATM systems and crew, performed satisfactorily throughout the Skylab mission. The film cameras obtained 6,411 high-resolution photographs. The XUV Monitor was used to observe the video image of the full solar disk and to identify solar features of interest. The instrument significantly exceeded its designed 56-day orbital life period and remained operable throughout the 270 day mission.

Instrument Performance. Four film cameras were used on the S082B instrument during the Skylab mission, and all cameras functioned satisfactorily. However, two cameras did not obtain the full number of 1,608 frames. The first Skylab 3 camera obtained 1,602 exposures. The onboard FRC had indicated that all frames had been exposed. Camera investigation revealed that a noisy microswitch in the film camera caused erroneous pulses to the FRC. See page 141 for a discussion of this problem. The second Skylab 3 camera obtained only 1,593 exposures because of a premature end-of-film condition in the camera. This anomaly is discussed on page 141.

A review of the Skylab 2 film data by the PI revealed that exposures taken with the grating in the long-wavelength position were being overexposed when the preselected auto mode exposure times were used. Daily flight plans were altered during Skylab 3 to take fewer long-wavelength exposures, and to take exposures of very short duration in the long-wavelength band. This procedure resulted in obtaining more desirable data with less expenditure of film, but required substitution of manual exposures for the auto mode. An auxiliary timer supplied for Skylab 4 provided an automatic mode with shorter exposure times without a change of predisperser position, thus alleviating the requirement for excessive manual exposures.

During the latter portion of Skylab 4, the PRS sensitivity degraded to the extent that the limb-scan and limb-pointing modes became nonoperational. The crew implemented a backup procedure which used the ATM pointing control system with the whitelight-display mode to locate the S082B slit on targets under study. Therefore, successful operation of the instrument was maintained through the end of the mission with the impact of additional crew participation. PRS anomalies are discussed on page 141.

The XUV Monitor performed satisfactorily; however, sensitivity was too low so that the video display on the C&D console TV monitor presented only the brightest XUV solar features. XUV video data were available for full solar disk by use of the video integration capability.

The Skylab 3 and 4 crews were supplied with an image persistence scope which increased the period of visibility of the XUV Monitor integrate image from 1/30 of a second to 1 second. By using repeated integrations adequate image persistence was available for viewing and photographing. These photographs constituted a daily log of XUV Monitor pictures.

When the crew recorded XUV Monitor video for downlink transmission, a series of integration times were used. These were standardized at 1/2, 1, 2, and 4 seconds. This had the effect of greatly extending the contrast range of the XUV Monitor camera tube. In the short integrations, very few Sun features had reached saturation. In the long integrations, most Sun features had reached saturation, but some dim features contained detail not yet detected in the shorter integrations. Ground analysis utilized these schemes to extend XUV Monitor usefulness. PI and crew coordination conferences were held using the XUV Monitor data as a point of reference for solar activity. By combining these techniques, the usefulness of the XUV Monitor steadily improved during the mission. Although the XUV Monitor had been of minimum value to the crew during Skylab 2, it was an important factor in the planning of daily ATM data taking schedules. On Skylab 3 and 4 the XUV Monitor was used extensively by the crew.

Two blemishes were noted on the XUV Monitor image. The blemish areas did not show substantial change and did not significantly degrade the data. See page 142 for a discussion of this anomaly.

The S082B TCS performance was acceptable throughout the Skylab mission. During Skylab 2, slightly colder average case temperatures were observed than those experienced during thermal vacuum test of the flight unit. During Skylab 3, case temperatures were slightly warmer than on Skylab 2, but were always within the prescribed limits. The higher case temperatures were attributed to higher canister Sun-end temperatures caused by degradation of the thermal control paint on the canister, and a greater percent of time in full sunlight.

Dynamic temperature gradients across the instrument case were held within the specified $\pm 0.18°C$ ($\pm 0.3°F$) per 15 minutes time which maintained slit image movement at the film plane within 0.00254 cm (0.001 inch) per 15 minutes. These values were not exceeded during Skylab 2 or 3.

A relatively high horizontal image smear rate of 0.01016 cm (.0004 inch) per 15 minutes was noted for the S082B instrument for one orbit during Skylab 3. During the first 15 minutes after aperture opening, the rate of change of horizontal position slit image on film was 43.7 percent of the allowable 0.00254 cm (0.001 inch) per 15 minute rate.

As anticipated, there were out-of-tolerance thermal conditions during Comet Kohoutek observations and during the full sunlight orbit periods of Skylab 4. The out-of-tolerance conditions observed during Comet Kohoutek observations consisted of excessive horizontal smear of the slit image on the film. Horizontal image-smear rates of the slit image on the film were from 150 to 200 percent of the maximum allowable value on DOY 357, 358, and 365 during the comet observations. However, the total image smear was still within the allowable limits for short exposures, since the allowable value is based upon a 15 minute duration exposure.

During periods of successive full sunlight orbits, the focus limit requirements for the slit image on film were exceeded by as much as 13.3 percent (DOY 017). However, all other distortion parameters were within the allowable limits during these periods as verified by a computerized thermal distortion analysis program. Usable data were obtainable with the slit image slightly wider and less sharp.

All S082B telemetry voltage measurements and status monitors performed correctly throughout all three Skylab missions. The S082B electronic voltages, shown in Table 21, indicated that flight voltages were nominally the same as those observed during ground test. All telemetry measurements functioned correctly and were within specification limits.

The mechanical systems functioned as required with only one exception. As expected from prelaunch test data, the predisperser did not complete its rotation cycle on a few occasions during Skylab 2 and 3. This occurred only once during Skylab 4, and was noticed and corrected by the crew.

The instrument power supply operated as required. Table 21 illustrates typical output voltages monitored by telemetry.

TABLE 21. S082B TYPICAL VOLTAGES AND LIMITS

Measurement Identity	Specification (Vdc)	Actual (Vdc)
28V Panel	28 ± 2.0	28
28V Primary	28 + 2.5,-2.0	28
28V Actuator	28 + 2.5,-2.0	28
5V Computer	5 ± 0.5	4.09
5V Sync	5 ± 0.5	5.1
+15V Analog	+15 ± 0.5	+15.2
-15V Analog	-15 ± 0.5	-14.9
2V Temp	2 ± 0.1	1.99
5V Analog	4.9 + 0.2,-0.5	4.5
±15V PRS	30 ± 0.6	30.0
5V Logic	5 ± 0.5	4.8
+10V TCS	+10 ± 0.3	+10.05
-10V TCS	-10 ± 0.3	-9.95
5V Digital	5 ± 0.5	5.05

ATM Interface. Generally, the ATM provided satisfactory support to the S082B instrument. Although the ATM canister thermal system activation was delayed due to early Skylab problems, the experiment thermal limits were not exceeded, and there were no detrimental effects on the instrument attributable to this condition. No film sensitivity degradation occurred as a result of storage in the MDA film vaults.

The S082B ATM film retrieval door was difficult to open during EVA on DOY 265, and again on DOY 034. On DOY 034 the crew experienced significant difficulty in opening the door. The door appeared to be warped and numerous attempts to open the door were unsuccessful. The canister was rotated to facilitate better leverage and after 15 minutes into the day cycle, with additional solar heating, the door was opened without difficulty.

ATM thermal shield door operational problems were experienced during Skylab 4 but resulted in the loss of only 3 frames of data. When the door failed to close on DOY 363, a ground command was issued which resulted in door closure. Because of the general failure history associated with the thermal shield doors, a strong possibility existed for this door to fail in the closed position. If this occurred, an unscheduled EVA would have been necessary to pin open the failed door. To preclude this event, both the spectrograph and XUV monitor doors were electrically driven to the full open position using maximum power of both motors. The door motors were subsequently disabled. The added risk of instrument thermal distortion, and contamination increase was recognized; however, engineering evaluation using computerized thermal models, and analysis of contamination management procedures showed the risk to be acceptable. As a result, no further door operation anomalies occurred, and post mission data analysis indicated no degradation of photographic data.

The only anomalous behavior associated with the telemetry was that of ground telemetry data reduction. Data noise or synchronization problems occurred that caused erroneous measurement readings for one or more update periods. For discrete signals, the noise indicated changes of state which did not occur. The most common result was that extra exposures were indicated, making troubleshooting and data reduction more difficult. Another result of the erroneous data was that all triggering functions, such as instrument aperture open and close items, had to be manually input to the S082B thermal distortion computer analysis programs.

Man/Machine Interface. Crew operation of the S082B instrument was commendable. The crew indicated that a few errors were made because of the similarity and proximity of S082A and S082B control panels on the C&D console: switch operations on one panel were commanded by mistake when operations on the other panel were intended.

Significant crew accomplishments relating to S082B were the use of auxiliary equipment and PI conferences which resulted in the XUV Monitor reaching its full potential as a solar activity planning and coordinating tool, and the installation of an auxiliary timer to automatically control S082B exposure times.

Scientific Data Quantity and Quality. Four film cameras were used during the mission and 6,411 exposures were obtained. Table 22 illustrates film load usage per mission. All four film cameras used type 104 UV sensitive film with the exception of 400 frames of type 101 film which were contained in the film camera used for Skylab 4. The type 101 film is five times as sensitive as type 104 and was loaded in positions that would allow its usage for Comet Kohoutek observations. The crew obtained excellent targets of opportunity data. Comet Kohoutek was much weaker than predicted and 5 exposures out of the 100 exposures of the comet had marginal data. The remaining 95 comet exposures were blank. The Skylab 3 cameras obtained less than the anticipated number of exposures due to the previously mentioned frames-remaining indication problem.

However, the high number of exposures obtained denoted successful camera performance.

TABLE 22. S082B FILM USAGE

Film Load	Skylab Mission	Frames Available	Frames Exposed	Installed (DOY)	Removed (DOY)
1	2	1608	1608	Prior to Skylab 1 Launch	170
2	3	1608	1602	218	236
3	3	1608	1593	236	265
4	4	1608	1608	265	034

The quality of data from the exposed film was excellent. No objectionable image smear occurred due to temperature gradients or jitter. Spectral resolution was well within the design goal of 0.06 angstroms and 0.12 angstroms for short and long-wavelength exposures, respectively, and was consistent with ground test results.

Figure 61 is a spectrogram which illustrates a comparison of emission spectra obtained by the S082B camera during the Skylab 2 mission. The spectra shown represents 12 arc seconds from the limb on the solar disk exposed for 1.25 seconds and 4 arc-seconds off the disk (corona) exposed for 2.5 seconds in the 2300 to 2440 angstrom wavelength band.

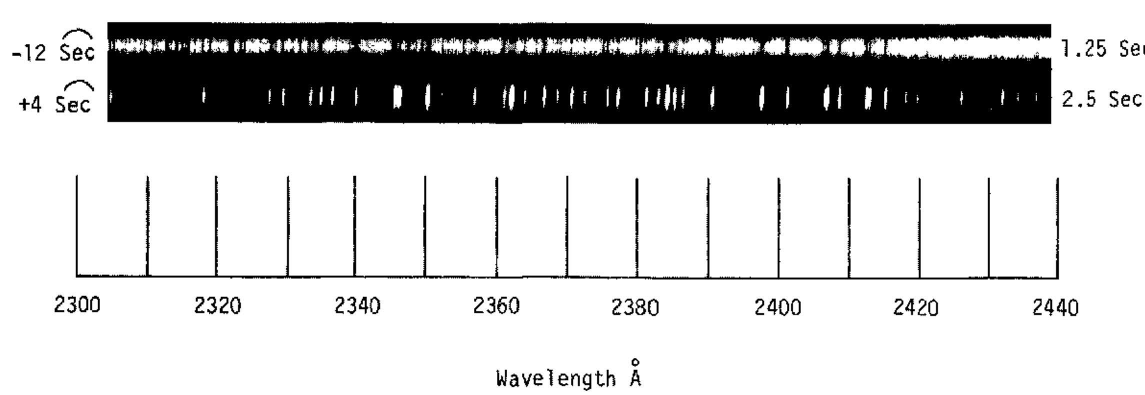


FIGURE 61. S082B COMPARISON OF PHOTOSPHERIC FRAUNHOFER AND CHROMOSPHERIC EMISSION SPECTRA

Figure 62 is a collection of S082B exposures taken through the Earth's atmosphere. In the left column (from top to bottom), light of the solar Lyman-alpha line of hydrogen is absorbed by molecular oxygen in the atmosphere, first cutting off the short wavelength side of the line. In the second column (from left), atomic oxygen in the Earth's atmosphere causes absorption in the core of solar emission lines, and molecular oxygen causes the disappearance of the entire line, as the altitude decreases. The third column (from left) shows that at 1550 angstroms the absorption of molecular oxygen is strongest, causing this line pair to be totally absorbed at 150 kilometers. In the column at the very right, absorption by bands of molecular oxygen is much weaker at 1900 - 1925 angstroms and allows the Sun's emission to penetrate much deeper into the Earth's atmosphere, even to altitudes that can be reached by high altitude balloons.

Figures 63 through 65 illustrate examples of XUV Monitor data. The photographs show a comparison between Skylab 2 and Skylab 4 data. The integration times were approximately 1, 2, and 4 seconds as shown in figures 63, 64, and 65, respectively.

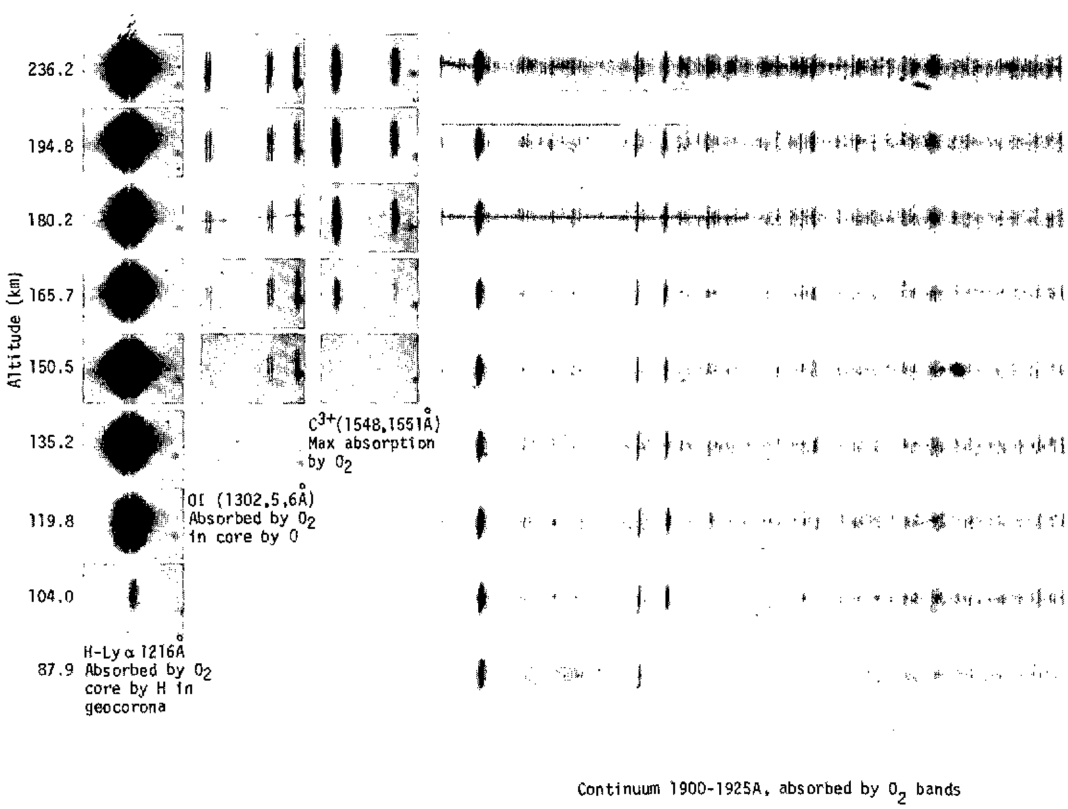
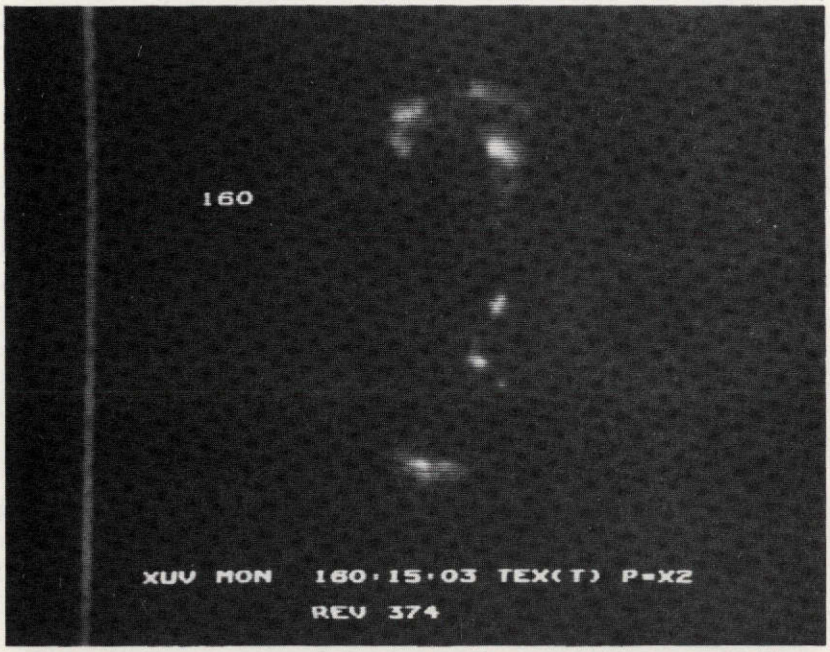


FIGURE 62. S082B UV ABSORPTION IN THE EARTH'S ATMOSPHERE

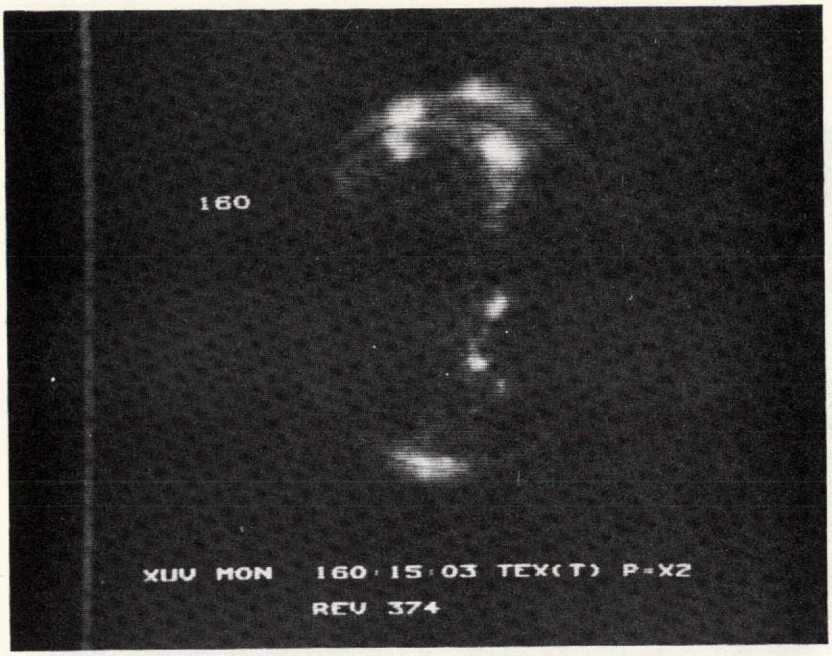
Skylab 2



Skylab 4

FIGURE 63. S082B XUV MONITOR 1-SECOND INTEGRATION

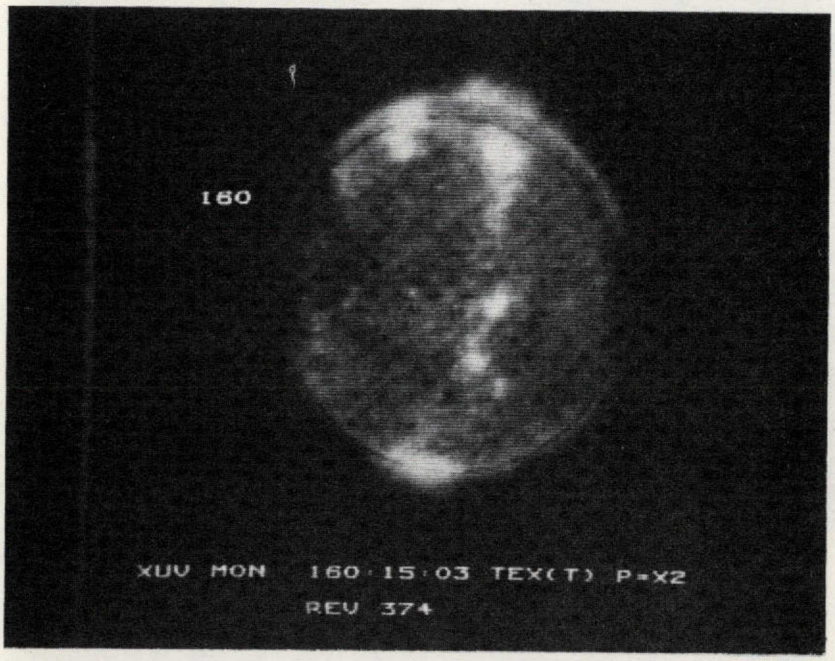
Skylab 2



Skylab 4

FIGURE 64. S082B XUV MONITOR 2-SECOND INTEGRATION

Skylab 2



Skylab 4

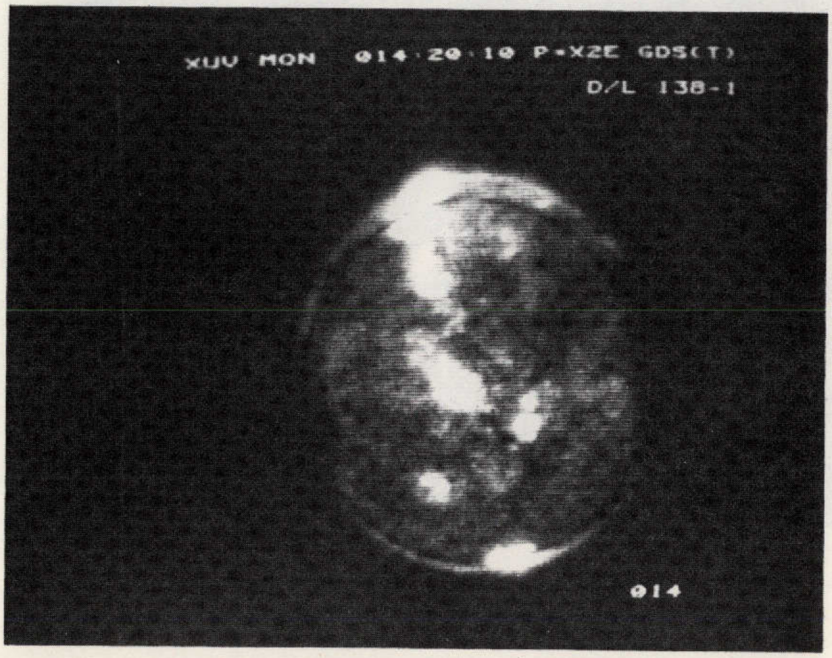


FIGURE 65. S082B XUV MONITOR 4-SECOND INTEGRATION

Solar activity was similar in all six photographs, with the quiet background having similar brightness in both 4-second integration pictures shown in figure 65. All six photographs were taken with identical ground TV monitor and camera lens settings. Figure 66 is a photograph of the downlink video of the PRS in the whitelight display mode.

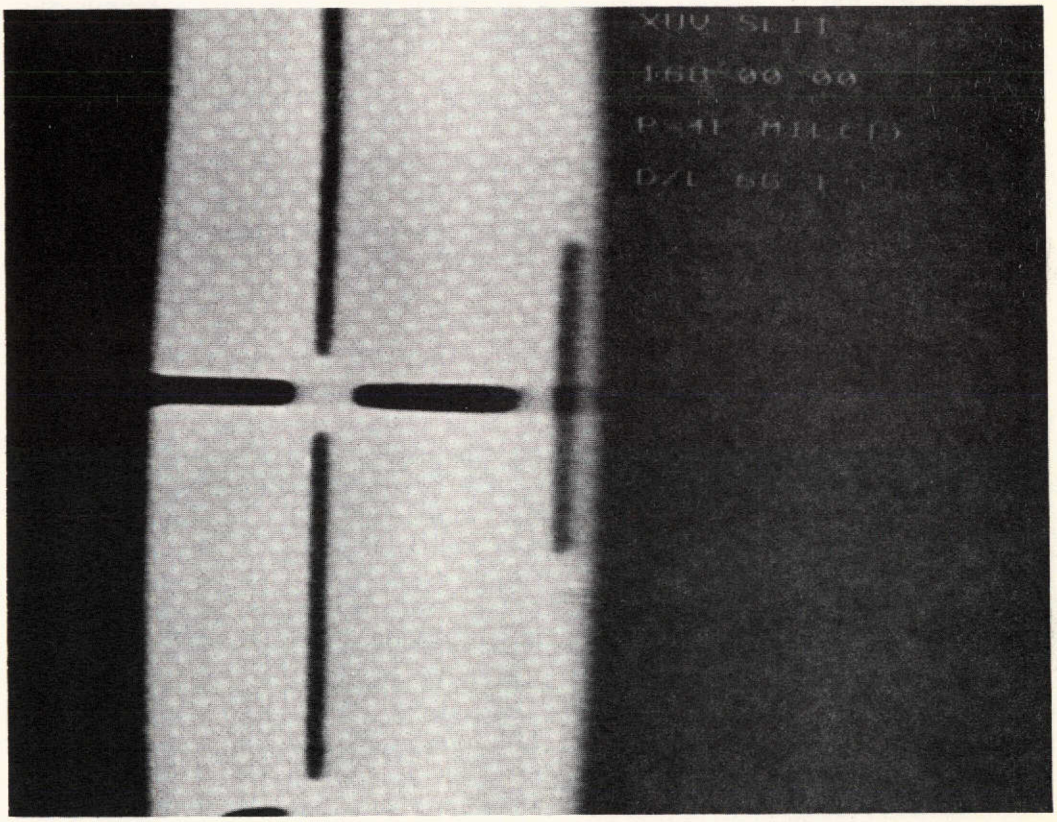


FIGURE 66. S082B DOWNLINKED VIDEO OF PRS IN WHITE LIGHT DISPLAY MODE

Anomalies

General. The S082B instrument experienced few anomalies during the mission. In each case workaround negated the problem. Review of Skylab 2 film revealed that exposures taken in the long-wavelength were overexposed. This was corrected by manually timing the exposures taken during Skylab 3, and the addition of an auxiliary timer on Skylab 4. A malfunction in the S082B PRS late in Skylab 4 was overcome by using the ATM experiment pointing control system in conjunction with the S082B whitelight display. An occasional extra frame count resulted in the loss of 21 frames of data. The XUV Monitor sensitivity was low, resulting in a faint image on the TV display. Use of an image persistance scope and Polaroid camera launched with the Skylab 3 crew alleviated this condition. A bright spot on the XUV Monitor TV display, during Skylab 4, was not a major problem for the crew. Off pointing necessitated by Comet Kohoutek observations during Skylab 4 caused minor, anticipated thermal distortion. Details of these anomalies are in the following paragraphs.

S082B Overexposures. Review of the Skylab 2 film data by the PI determined that exposures taken with the grating in the long-wavelength position were overexposed when the longer exposure times were used. The affected modes were the auto and auto-step modes in which a series of eight exposures was taken, alternating between long and short wavelengths. Five of the eight exposures were overexposed.

During Skylab 3, the daily flight plans were altered to take fewer and very short duration long-wavelength exposures. This resulted in a schedule containing very few auto or auto step modes. A new procedure called a mini-limb scan was developed. This procedure contained very short time duration long-wavelength exposures, and involved the use of the time mode in which the crew manually selected the time for the exposures. The procedure was very time consuming for the crew, but more desirable data were obtained and film was conserved. The Skylab 3 crew requested that an auxiliary timer be developed and installed on the ATM C&D console to allow automatic exposure sequencing. The auxiliary timer and associated cabling were designed, developed, qualified, launched, and installed for Skylab 4. Crew procedures were revised to incorporate the change. The timer was used for the majority of the Skylab 4 exposures. No problem was encountered with the use of the auxiliary timer. The newly developed timer automatically controlled three exposures of 10, 40, and 160 seconds in the short wavelength. Six additional exposure times were obtainable, since switch selections provided multiply and divide-by-four capability. Due to using five times more sensitive film on Skylab 4 for Comet Kohoutek, the Comet Kohoutek exposures were made with the switch in the normal position. Skylab 4 solar observations required the divide-by-four (1/4) switch setting.

S082B Pointing Reference System Malfunction. On DOY 347 the crew noticed limb offset indication fluctuations when pointing the S082B slit on the solar limb. Similar fluctuations occurred on DOY 350, 362, and 003. These malfunctions had limb-offset fluctuations of from +2 to +6 arc-seconds when scanning the solar limb. When limb pointing was selected, the limb-offset fluctuations increased. If the pointing was near 0 arc-seconds, the fluctuations in limb pointing were +50 to -50 arc-seconds. On DOY 003 the crew reported oscillations of the solar image on the TV display when whitelight display was acquired immediately after limb pointing. Ground analysis and test indicated that the oscillations on the TV monitor image were caused by primary mirror oscillations. The mirror oscillations were caused by the video signal level from the S082B electronics being below the level required for electronic detection of the reference points. This conclusion was verified by a test performed by the crew on DOY 009. The test used limb darkening to provide an increasing video level as pointing was changed from off-disk to on-disk. The PRS was operated in limb scan and limb point at +40, +20, 0, -20, and -40 arc-seconds. The system malfunctioned at +40, +20, and 0 arc-seconds and operated properly at -20 and -40 arc-seconds. Limb offset is positive when the slit is off the solar disk, negative when the slit is on the solar disk. Since the planned solar observations were within the PRS failure region, use of the PRS for limb pointing was discontinued on DOY 009 for the remainder of the mission.

An ATM stability test performed during Skylab 2 using the whitelight display of the S082B PRS had shown that the ATM stability normal to the solar limb was approximately +0.4 arc-seconds for about 3 minutes. The ATM experiment pointing control, in conjunction with the S082B whitelight display, was used for S082B limb pointing, permitting continued operation of the S082B instrument.

Film Camera Anomalies. Anomalies which occurred in the two Skylab 3 film cameras resulted in the loss of 21 exposures. The first camera stopped transporting film 16 frames early. The cameras had a lockout device to prevent recycling the film when all of the film had been exposed. The lockout device in the first Skylab 3 camera actuated early, preventing use of 16 frames of film.

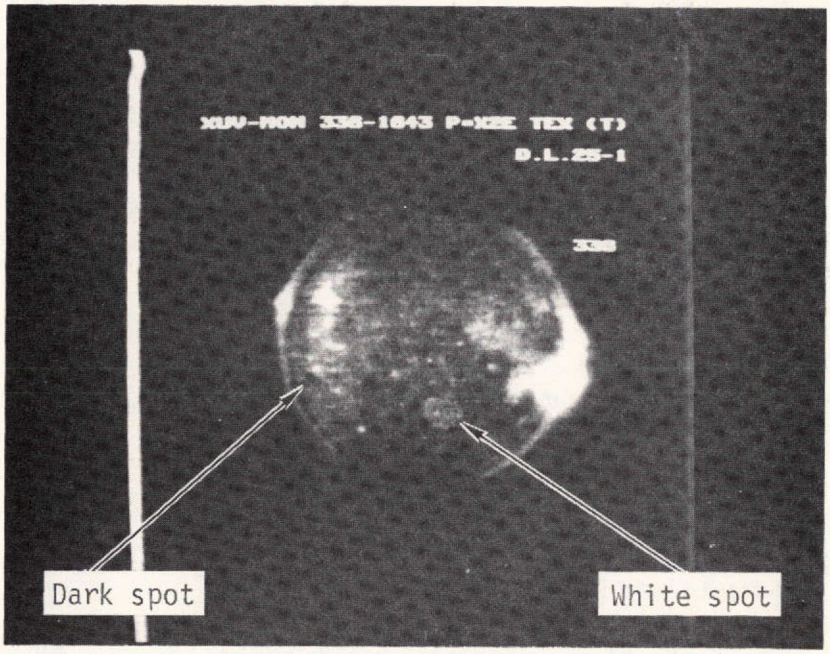
The second Skylab 3 film camera skipped one of the eight exposure positions on one film strip, and also produced extra frames-remaining pulses. This caused the C&D console frames-remaining indication to reach 0, four frames early. The extra pulses were due to a noisy film transport switch. Instrument operation was discontinued when the frames remaining indication reached 0 and the four frames were never used. The loss of 21 frames accounts for 0.3 percent frame loss for the mission which produced 6,411 of 6,432 possible exposures.

XUV Monitor Low Sensitivity. Following initial ATM experiment operation, the Skylab 2 crew reported the XUV Monitor video display on the C&D console was very faint. The insufficient video signal level was due to low sensitivity of the monitor. This was not a malfunction, but a performance limitation. At highest gain without integration, the ATM TV monitor showed only extremely bright XUV sources. By using the video integrate switch, an image was allowed to accumulate on the XUV Monitor camera tube. When the switch was released, the accumulated image flashed on the ATM TV monitor for 1/30 of a second. The image duration was too short for viewing with the eye.

To correct the problem, an image persistence scope (a night vision pocket scope with long-persistence phosphor), and a Polaroid camera were launched with the Skylab 3 crew.

The Skylab 3 and Skylab 4 crews used the image persistence scope which lengthened the period of visibility of the integrated XUV Monitor image from 1/30 of a second to 1 second. By using repeated integrations, adequate image was available for viewing. The crew used the Polaroid camera to photograph the images. The photographs constituted a daily log of XUV Monitor pictures. The permanent record of the XUV integrated display allowed the crew to identify major changes in the solar surface. To correct a malfunction of the image persistence scope that occurred during Skylab 3, a replacement scope was launched with the Skylab 4 crew. Additional Polaroid film was also launched on Skylab 4.

XUV Monitor Image Blemishes. Early in Skylab 2 a small dark spot was noted in the XUV Monitor image. The spot did not change with time and is shown in figure 67. During the second week of Skylab 3 an enhanced or bright spot appeared in the XUV Monitor image. The spot remained constant throughout the remainder of the mission. The spot is identified on the polaroid photographs shown in figure 67. Available data were insufficient to determine the cause of the blemishes. The XUV Monitor image did not show substantial change throughout the mission, and no significant degradation occurred.



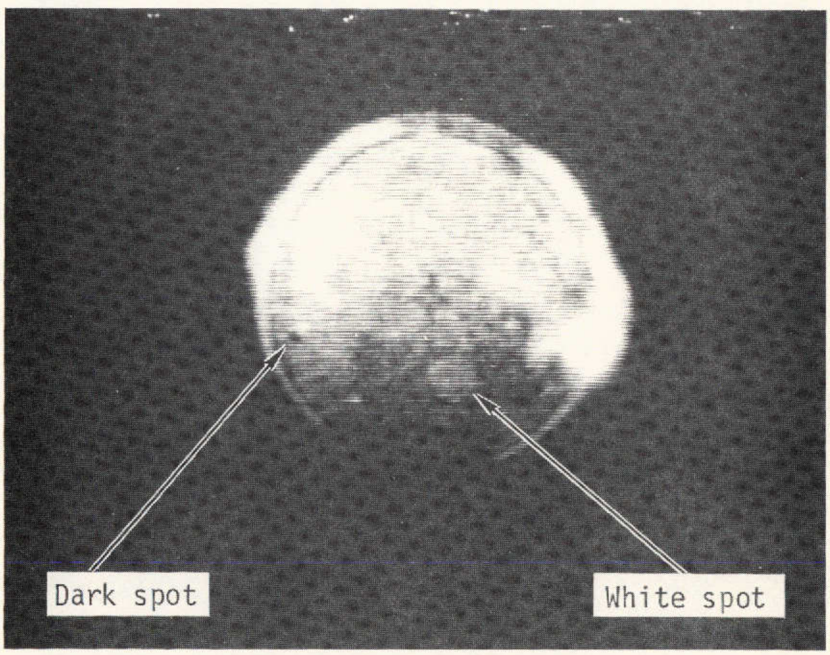


FIGURE 67.   S082B XUV MONITOR BLEMISHES

Conclusions

The S082B Spectrograph and XUV Monitor performed well within design limits and exhibited very few anomalies as identified above. Spatial and spectral resolution and focus remained at values set by design and as observed during testing. The efficiency of the instrument was constant throughout the mission.

The auxiliary timer launched and installed during Skylab 4 provided appropriate film exposure without personal attention of the crew.

The crew pointed the 2-arc-second wide slit on targets on the solar disk as well as near the limb. Near the end of the mission, when PRS operation was degraded, manual pointing provided a good workaround.

The persistent image scope and on-board Polaroid camera provided the crew with persistent and photographed images of XUV Monitor data for on-board use. ATM mission planning was enhanced by XUV Monitor data.

Comet Kohoutek intensity was insufficient in XUV to be of value.

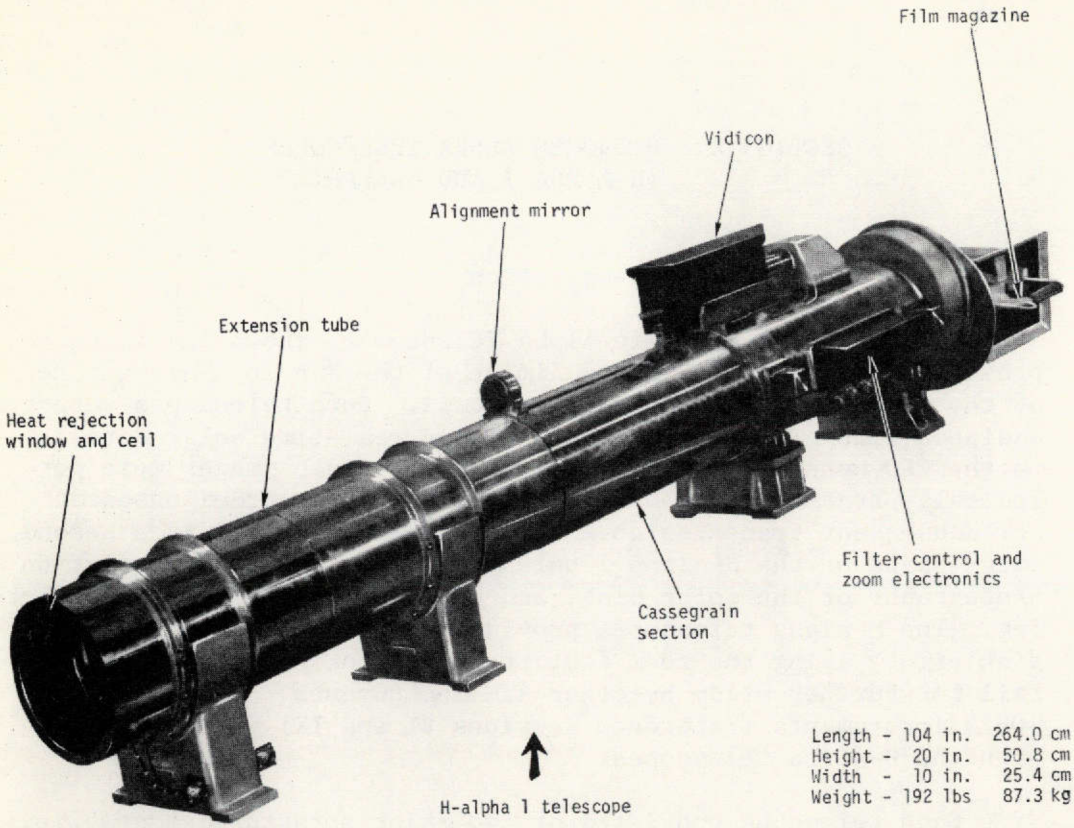
SECTION X. HYDROGEN ALPHA TELESCOPES (H-ALPHA 1 AND H-ALPHA 2)

Description

General. The Hydrogen-Alpha Telescopes, shown in figure 68, provided a diffraction-limited image of the Sun in H-alpha line of the Balmer series (6562.8 angstroms). Both telescopes were equipped with a vidicon which displayed real-time solar detail on the C&D console for crew observation. Video images were periodically transmitted real-time to ground or recorded onboard for subsequent transmission. A film camera, mounted at a second image plane on the H-alpha 1 telescope, provided high-resolution photographs of the solar disk, and permanent records of ATM pointing. The H-alpha telescopes provided a view of the entire solar disk or, by using the zoom feature, a view of specific solar detail for further study by other ATM instruments. The S055A and S082B instruments (reference Sections VI and IX) were coaligned with the H-alpha telescopes.

Each telescope consisted of two major structural assemblies: the front extension tube assembly, which contained the heat-rejection windows, and the main telescope assembly, which housed the remaining optical components. The only element in the H-alpha telescopes that required an active TCS was the temperature-critical Fabry-Perot filter assembly. Otherwise, the two telescopes were passively temperature-controlled. Insulating spacers were used between the telescope and spar. Temperature-sensing thermistors, located at various points on the telescope, provided telescope thermal performance data.

Optics. An optical schematic of the H-alpha 1 instrument is shown in figure 69. Design characteristics are listed in Table 23. Light from the Sun first contacts the two-element heat-rejection window, which covers the aperture of the telescope. The first element was primarily a UV-rejection filter, and the second was an induced-transmission filter, designed to reject visible and infrared energy, while providing high transmission in hydrogen-alpha. The light was then transmitted to the paraboloid primary mirror, reflected to the hyperboloid secondary mirror, and then transmitted through the f/28 telecentric correctors to the focal plane, which contained the mechanical, movable reticles. The light was then transmitted through the Fabry-Perot filter and onto the beam splitter, which directed 90 percent of the light through relay optics to the photographic film camera, and 10 percent of the light through the zoom lens to the vidicon TV camera.



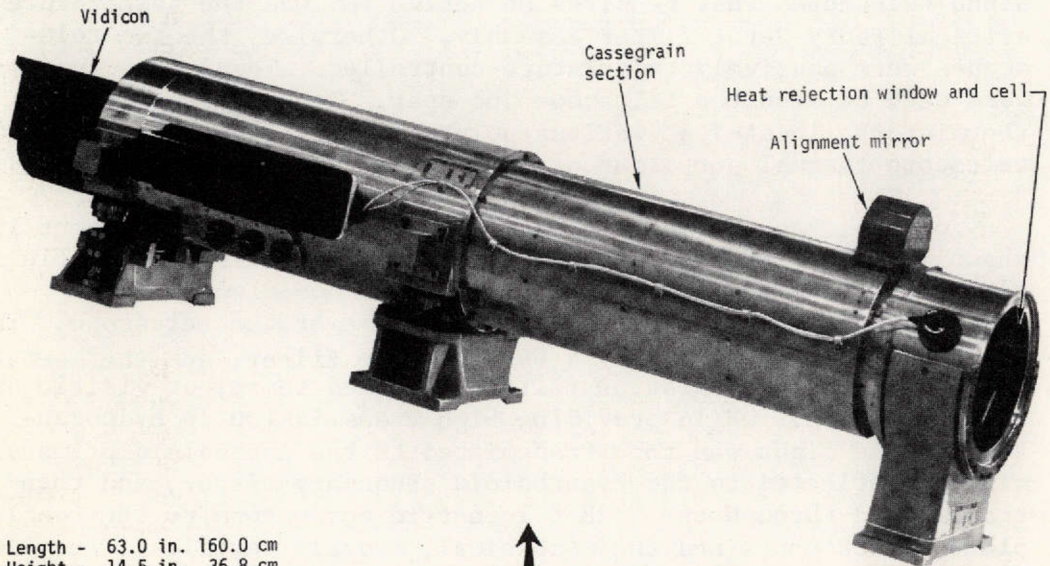


FIGURE 68. H-ALPHA TELESCOPES

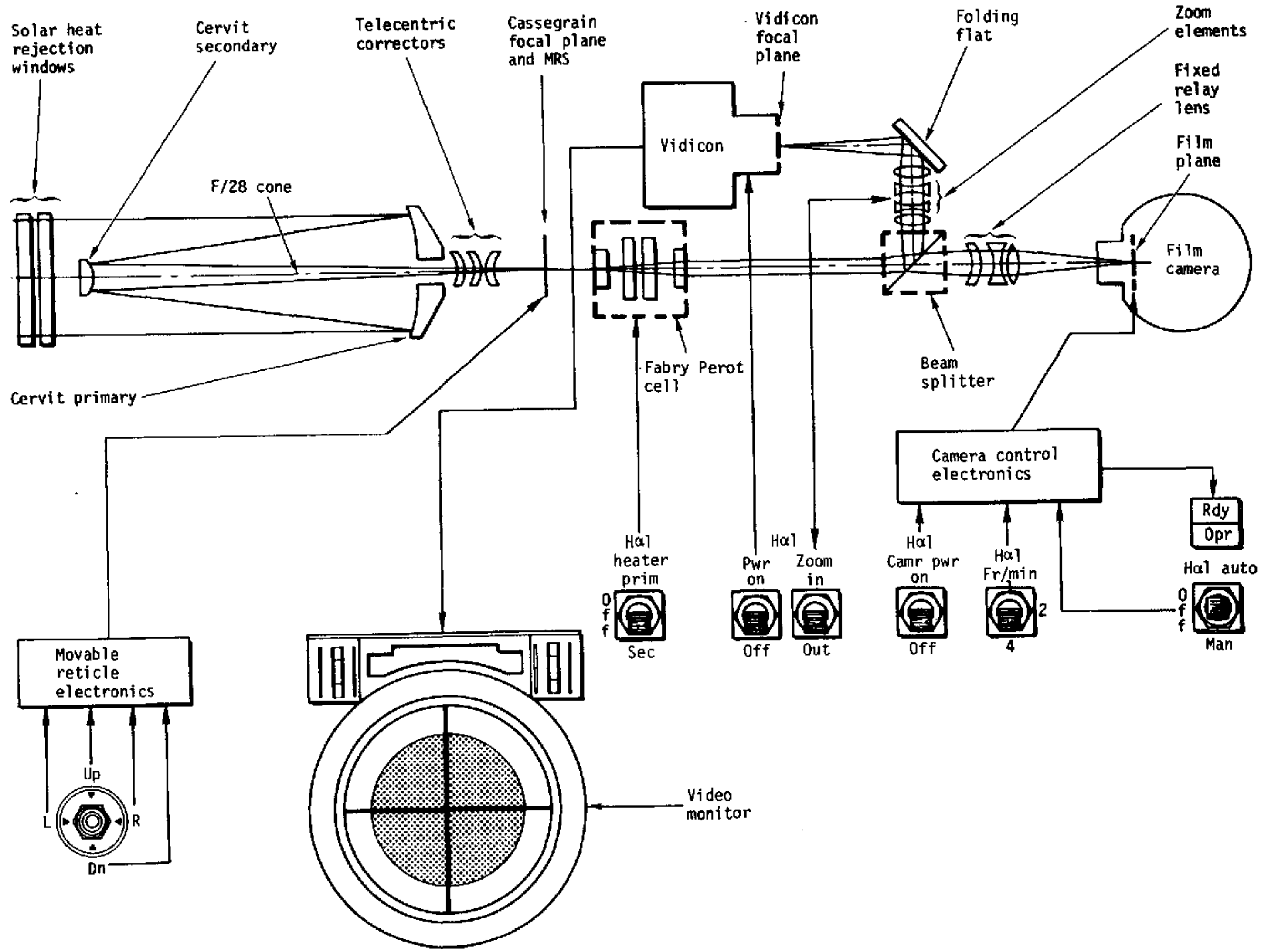


FIGURE 69. H-ALPHA 1 TELESCOPE - OPTICAL SCHEMATIC AND CONTROLS AND DISPLAYS CONCEPTIVE REPRESENTATION

TABLE 23. H-ALPHA DESIGN CHARACTERISTICS

Resolution:	
H-Alpha 1 Film Camera Focal Plane	1.0 arc-sec
H-Alpha 1 Vidicon Focal Plane	1.5 arc-sec at max zoom 5.0 arc-sec at min zoom
H-Alpha 2 Vidicon Focal Plane	1.5 arc-sec at max zoom 5.0 arc-sec at min zoom
Field of View:	
H-Alpha 1 Vidicon	4.5 to 16 arc-min
H-Alpha 1 Film Camera	35 arc-min
H-Alpha 2 Vidicon	7.0 to 35 arc-min
Zoom Ratio:	
H-Alpha 1	3.6:1
H-Alpha 2	5:1
Filter Assembly:	
Transmission at 6562.8 Å	>40 percent
Bandwidth	0.7 angstroms
Clear Aperture	6.4 cm
Telescope Aperture	16.5 cm
TCS:	
H-Alpha 1 Fabry-Perot	$36.5 \pm 0.5°C$
H-Alpha 1 Telescope	Passively controlled
H-Alpha 2 Fabry-Perot	$35.9 \pm 0.5°C$
H-Alpha 2 Telescope	Passively controlled

The zoom system was designed to provide a continuously-variable field-of-view from 4.4 to 16 arc-minutes, with a resolution of 1.5 arc-seconds to 5 arc-seconds, respectively. The zoom lens position was controlled by a three-position, center-off switch, which energized the zoom motor.

A movable reticle system (MRS) consisted of vertical and horizontal stretched-wire reticles, which were independently moved $\pm$ 3 1/2 arc-minutes about the center position, by two, 28-Vdc motors. The MRS, in combination with a set of fixed fiducial marks, oriented at 45-degree intervals around the edge of the field, was primarily used for alignment and pointing of other ATM instruments.

Fabry-Perot Filter Assembly. The Fabry-Perot assembly determined the bandpass characteristics of the H-alpha telescopes. The two primary components of the filter assembly were a solid-spaced Fabry-Perot etalon and a blocking filter. These two elements were housed in a temperature controlled cell with the other optical elements necessary to achieve the desired optical system performance.

The filter assembly spectral bandwidth of 0.7 angstrom at H-alpha (6562.8 angstroms) was obtained by placing two, interference optical filters in series. The heart of the system was a solid-spaced Fabry-Perot etalon filter which transmitted 65 percent of the energy at the H-alpha line, with a half-bandwidth of 0.7 angstrom. This filter had transmission peaks separated by 11 angstroms. These adjacent etalon peaks were suppressed by a blocking filter which had a half-bandwidth of 7 angstroms. The combined transmission was 40 percent of the H-alpha energy. The filter transmission characteristics are illustrated in figure 70.

Television System. The TV system used vidicon cameras in a standard operational mode. The TV camera voltages were controlled by the camera control unit, mounted on the rear of the ATM canister. Sync signals were provided from the system sync generator. All TV signals were transmitted to two video switches which were controlled from the ATM C&D console. The signals could be displayed on the C&D console and also recorded and/or transmitted to ground stations. The transmitted signal to ground was limited to a 2 MHz bandwidth and consequently the onboard resolution was much greater than that available at the ground station.

Film Camera. The H-Alpha 1 camera was a 35-millimeter, roll film sequential type camera. The film camera including the shutter assembly was permanently mounted on the telescope. Film-load replacement was accomplished by inserting film magazines containing

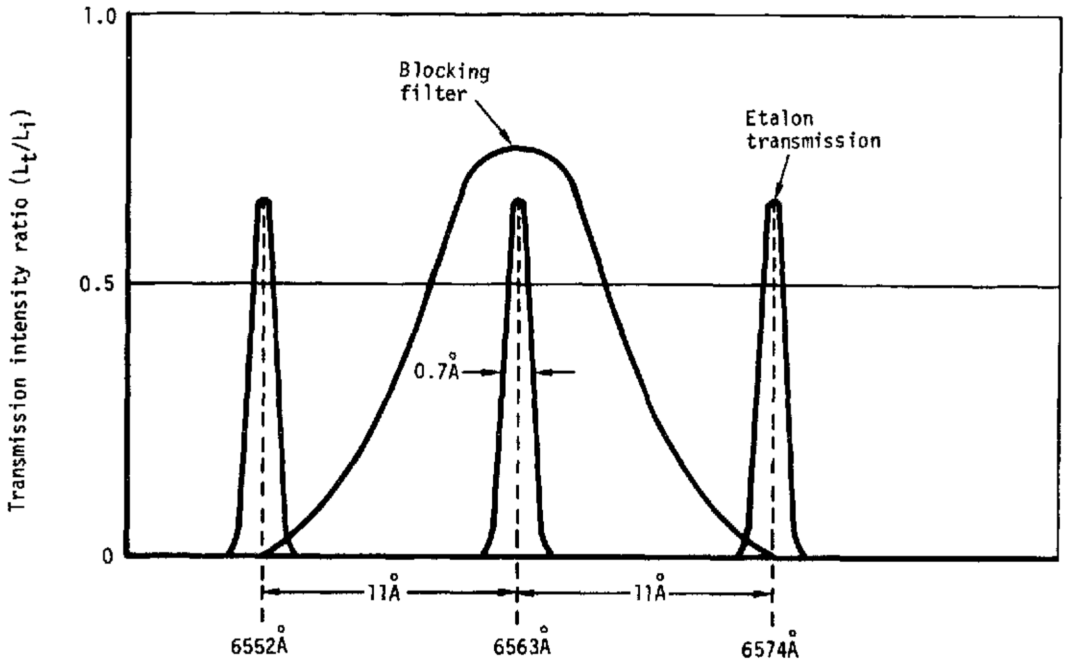


FIGURE 70. FABRY-PEROT TRANSMISSION CHARACTERISTICS

1000 feet of SO-101 film into the camera during EVA. The film camera had two modes of operation, automatic and manual. In the automatic mode, photographs were taken at 1, 2, or 4 frames per minute, as selected by the crew. In the manual mode, only one frame was exposed per command.

Thermal Control System. Because both filters in the Fabry-Perot Assembly were temperature-sensitive, they had to be maintained at a constant, preset temperature, when in operation. This was accomplished by the TCS, which consisted of a heater surrounding the Fabry-Perot cell, and the necessary electronics to maintain the cell at the desired level within 0.5°C (0.9°F). Primary and secondary heater power could be controlled by C&D console or ground command. This was the only active TCS in the H-alpha telescopes. All other parts of the telescope were temperature controlled by passive measures.

H-Alpha 2 Telescope. The H-alpha 2 telescope was designed to present the crew with a redundant H-alpha viewing system. The H-alpha 2 optical design was similar to that of H-alpha 1, with the exception of a beam splitter, film camera, and TCS ground commands. An optical schematic of the H-alpha 2 instrument is shown in figure 71. The design characteristics are listed in Table 23.

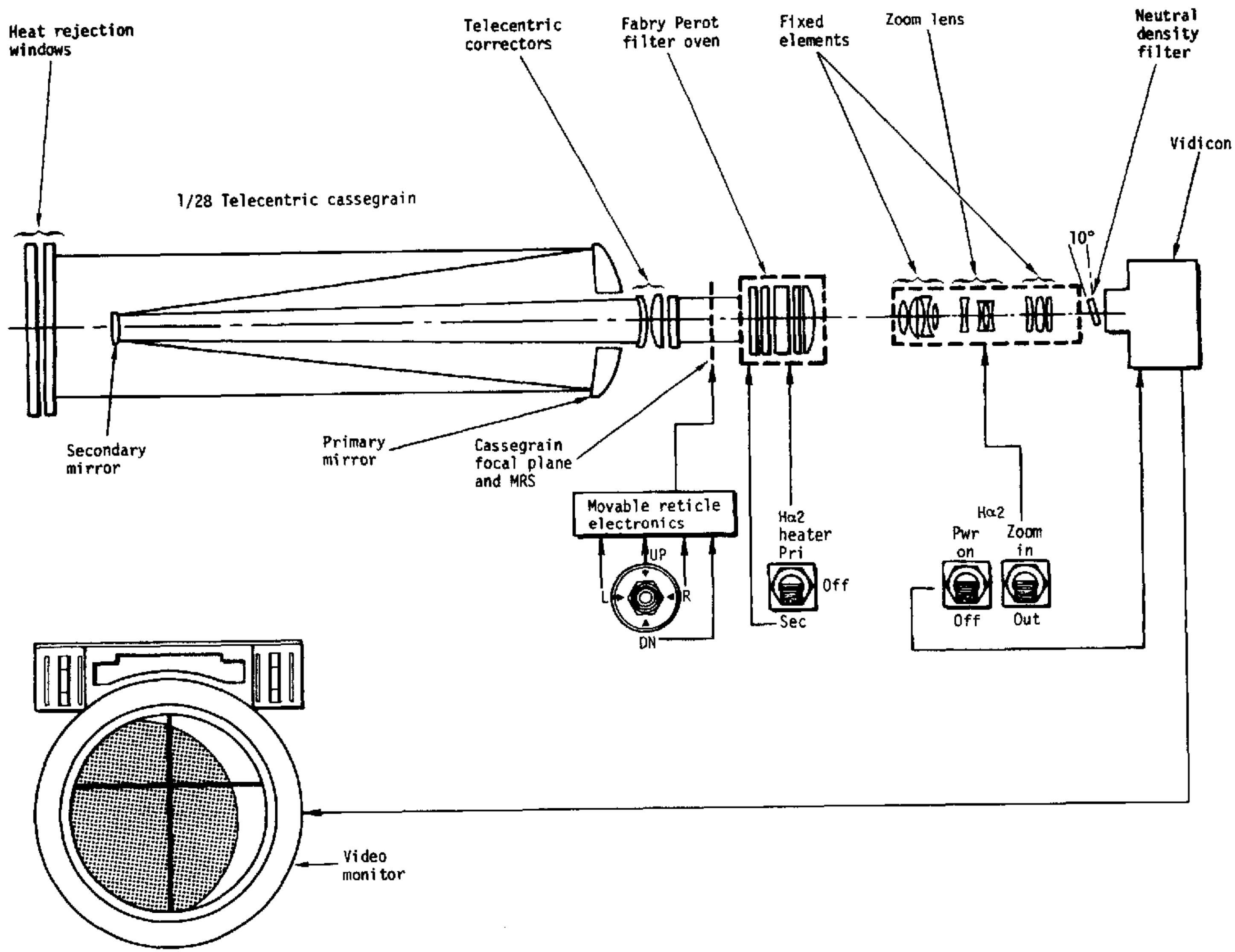


FIGURE 71. H-ALPHA 2 TELESCOPE - OPTICAL SCHEMATIC AND CONTROLS & DISPLAYS CONCEPTIVE REPRESENTATION

Mission Performance

General. The H-Alpha Telescopes successfully accomplished mission objectives by providing high-quality solar images, both photographic and video, throughout the manned Skylab mission. The H-alpha telescopes were not required to operate unmanned, but some unattended operations were performed. The three primary objectives--solar observations, pointing, and photography--were successfully accomplished. The H-alpha telescopes were used by the crew to search the Sun for regions of scientific interest, and to detect long-term changes in solar structural phenomena. Video displays permitted solar observations by both the crew, and scientists on the ground. The design of the H-alpha telescopes permitted the crew to coalign the S055A and the S082B instruments within 1 arc-second of the H-alpha reticle intersection. The H-alpha 1 photographs provided high-resolution scientific data, as well as an accurate record of ATM pointing.

Instrument Performance. The H-alpha telescopes operated within design requirements throughout the mission. The H-alpha 1, because of its small field-of-view, was used to point the ATM at specific features on the Sun. The H-alpha 2 telescope was used to monitor features of interest on the full solar disk.

The H-alpha 1 film camera was operated extensively during the mission, and obtained over 68,000 high-resolution photographs of the Sun. Five film magazines were used during the mission. Operation of the film transport mechanism in loads 4 and 5 became intermittent, causing many overlapped or multiple exposures. This anomaly is discussed in detail on page 163. During the Skylab 3 mission, the H-alpha 1 film-camera ready/operate light stopped operating when the FRC indicated 595 frames remaining. This was due to prelaunch testing using approximately 600 frames.

Each vidicon accumulated approximately 750 hours of operation during the mission. Real-time solar detail was displayed to the crew on the two C&D console video monitors and transmitted to ground. Crew comments indicated that the TV imagery was excellent until late in Skylab 4 when the H-alpha 1 image started to degrade (see page 164). Other TV anomalies included a burn-in seen on the H-alpha 2 video downlink, and blossoming of the H-alpha 2 image when the TV was first powered up. These anomalies are discussed in detail beginning on page 164.

The automatic gain control (AGC) levels of the H-alpha vidicons remained stable during the Skylab 2 and 3 missions. When the telescopes were Sun-centered, telemetry showed H-alpha 1 AGC was about 2 volts when zoomed in, and H-alpha 2 AGC was about 0.5 volts when zoomed out. During Skylab 4, the vidicon AGC voltages increased approximately 10 percent due to anticipated vidicon aging.

Video downlinked during Skylab 2 showed a slight (1 arc-second) jiggle of the H-alpha 1 image at maximum zoom magnification. The jiggle remained the same throughout the mission and did not affect viewing or pointing. For details of this anomaly refer to page 165. The H-alpha zoom systems were exercised repeatedly, and otherwise operated normally throughout the mission.

The MRSs were used to coalign the H-alpha telescopes with S055A and S082B (reference Sections VI and IX). First the crew positioned the S082B and S055A slits on the limb of the Sun, then moved the H-alpha 1 mechanical reticle until it was tangent to the limb. Coalignment data showed that the initial offset of the H-alpha 1 telescope, prior to any inflight coalignment adjustments, was within 24 and 28 arc-seconds of S082B and S055A, respectively. Following coalignment, H-alpha 1 was within 1 arc-second of S082B and S055A. On subsequent coalignments, the average adjustment required was approximately 2 arc-seconds.

The Fabry-Perot filter TCSs, in both H-alpha telescopes, maintained their specified temperatures. The pre-set temperatures of 36.5°C (97.7°F) for H-alpha 1, and 35.9°C (97.1°F) for H-alpha 2, were held within 0.5°C (0.9°F). Figure 72 shows 20-day plots depicting variations in the Fabry-Perot filter temperatures, and is representative of the mission. H-alpha 1 and 2 heater systems each operated approximately 3700 hours. Telemetered

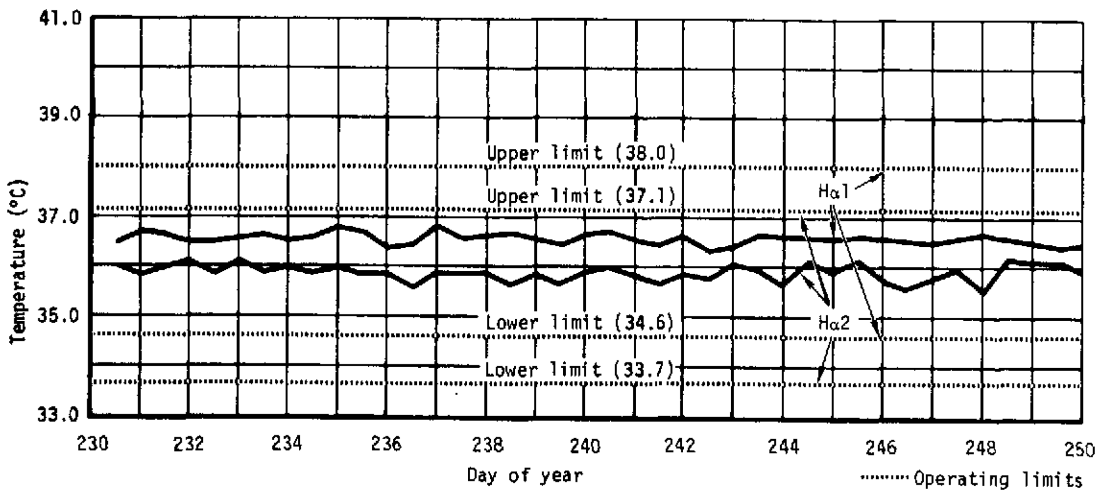


FIGURE 72. TYPICAL FABRY-PEROT FILTER TEMPERATURES

data showed no degradation of heater performance through the end of ATM operations. Use of the secondary systems was not required or verified in flight.

During normal ATM operations, the thermal profiles of the H-alpha telescopes were generally the same for each mission. Figure 73 shows typical daily temperature variations of the large optical elements of the H-alpha telescopes. The heat-rejection window temperature indicates the temperature at the front end of the telescope, the element most thermally affected by the Sun, and the primary mirror temperature is indicative of the main telescope assembly. Typical temperatures at other points on the telescopes are shown in figure 74.

The H-alpha operating temperatures were affected by the percent of time in Sun per orbit. As the percent of time increased from 70 to 100 percent, the heat rejection window temperatures increased from 31°C (87.8°F) to 37°C (98.6°F). During Comet Kohoutek observations, which required off-set pointing, the H-alpha 2 heat-rejection window temperature increased to approximately 34°C (93.2°F) due to the ATM thermal shield door being latched open and the impingement of solar energy on the surrounding structures. The temperature then returned to normal when the spacecraft was maneuvered back to solar-inertial attitude. The increased temperatures did not affect subsequent H-alpha 2 solar observations. Temperatures at other points on the telescopes did not show a significant change.

<u>ATM Interface</u>. ATM interfaces, with the exception of the thermal shield doors, adequately supported the H-alpha telescopes. The H-alpha 2 thermal shield door failed to close properly on DOY 251, 259, and 264. To preclude further problems, the H-alpha 2 door was latched open during the first EVA on Skylab 4. The H-alpha 1 thermal shield door failed to close properly on DOY 021 and 022, but the malfunction procedure cleared the problem.

Automatic thermal shield door operation was discontinued on DOY 153, due to a problem with the S054 thermal shield door (reference Section V). Several H-alpha procedural workarounds were required. The crew manually operated the H-alpha doors and the H-alpha 1 film camera. To operate the H-alpha 1 film camera without automatic door control, the night interlock switch was placed in the override position during orbital day operations. In several instances, this resulted in the camera being left operating during orbital night. Subsequent correction of the S054 thermal shield door anomaly permitted return to automatic door operation.

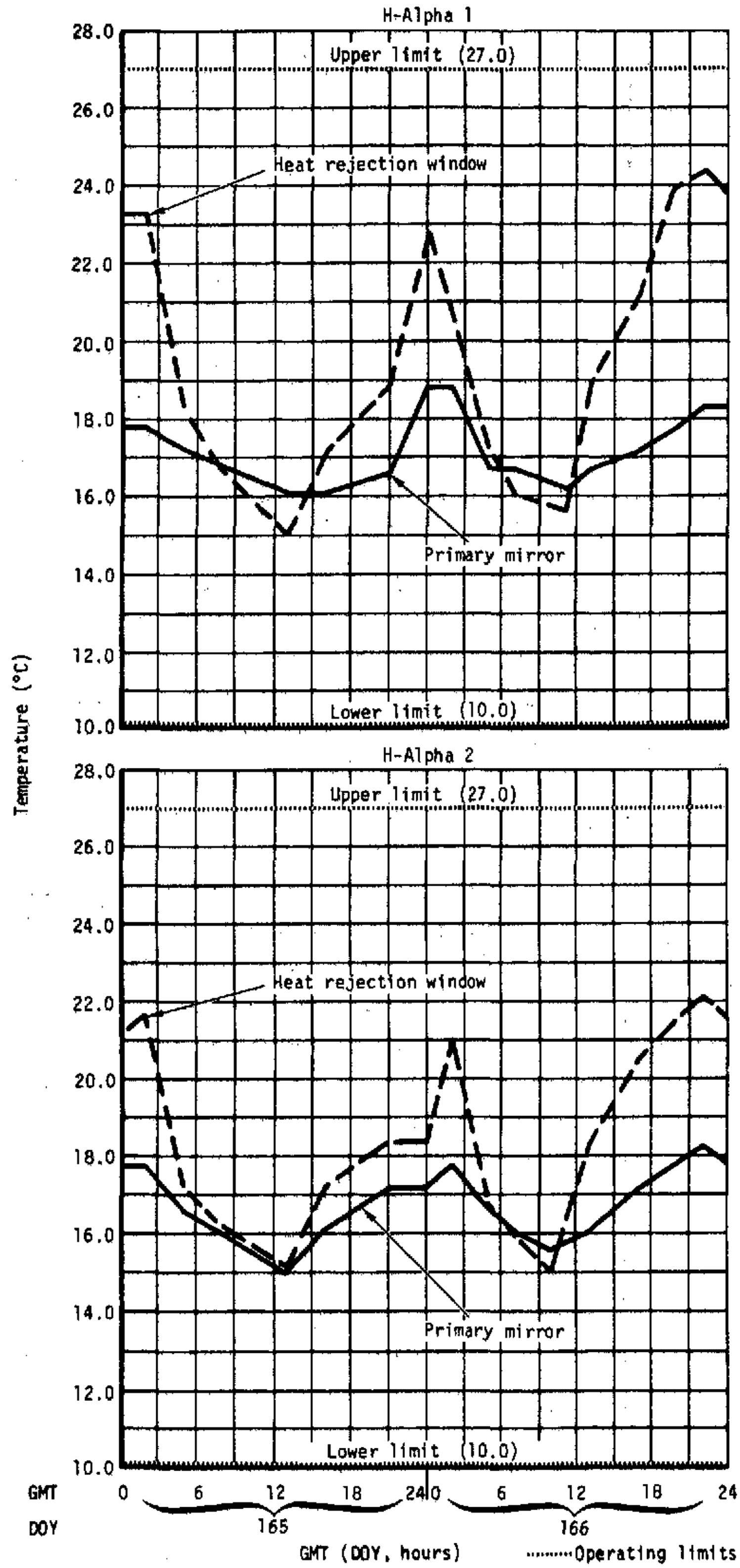


FIGURE 73. TYPICAL DAILY TEMPERATURE VARIATIONS FOR H-ALPHA 1 & 2 OPTICAL ELEMENTS

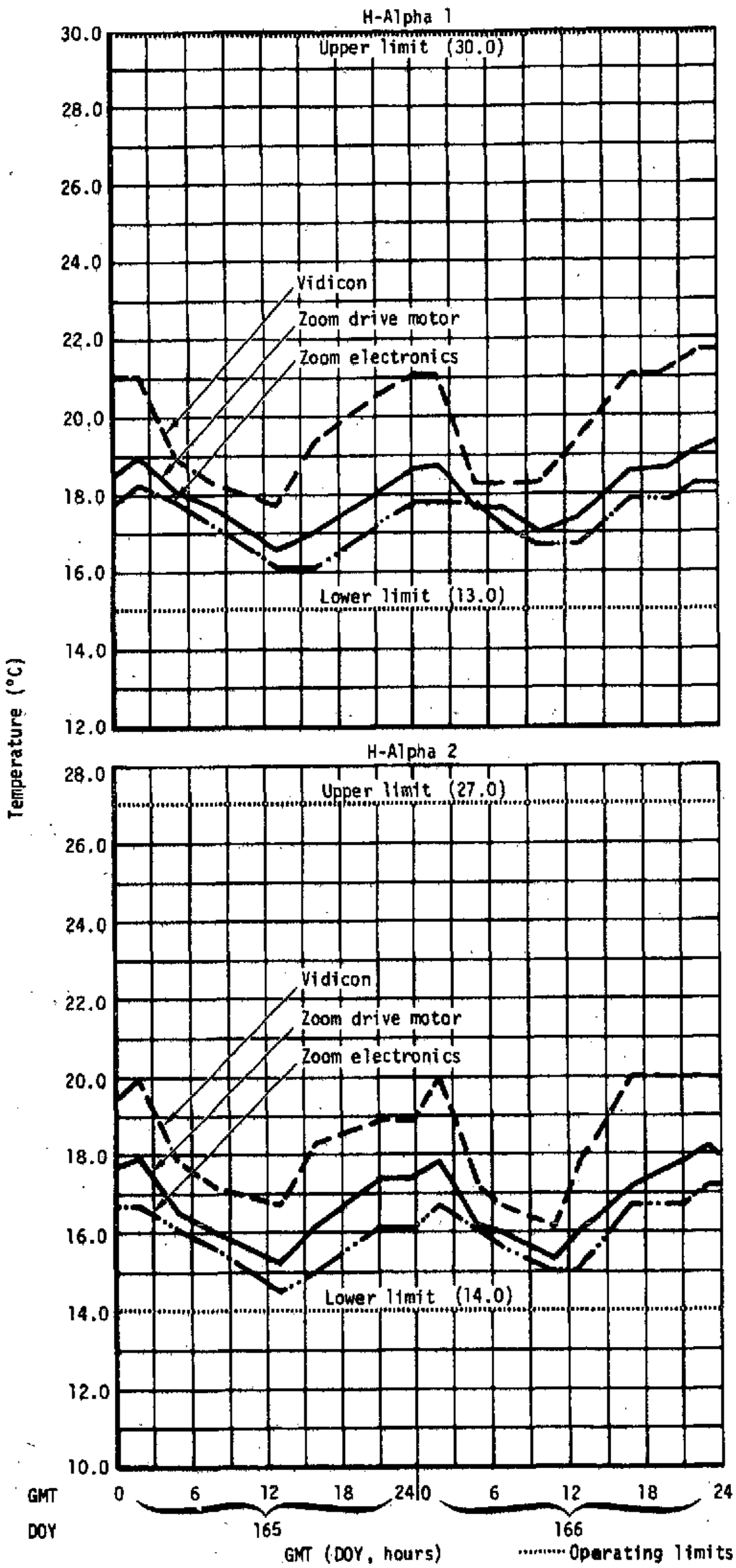


FIGURE 74. TYPICAL TELESCOPE TEMPERATURE FOR H-ALPHA 1 & 2

No contamination was noted on the H-alpha 1 telescope by the crew when removing the film magazine during the EVA activities. No particles were visible on the TV monitors when using H-alpha 1 or H-alpha 2.

H-alpha 1 film was stored in the MDA film vault. At the beginning of Skylab 2 during the period of high thermal stress, the film was exposed to 32.2°C (90°F) for approximately one week. Film analysis indicated that the film fog levels were not exceeded.

Limited ground data-processing capabilities affected real-time planning. Engineering analysis was hindered due to the delay in data retrieval.

Man/Machine Interface. Significant crew accomplishments relative to H-alpha 1 and 2 operation were efficient coordination of onboard solar observations with real-time ground observations to allow accurate planning of solar viewing time, configuring the H-alpha 1 film camera for unattended operation, thermal shield door corrective action, and reporting of irregular instrument status.

The crew observed that the H-alpha video monitors provided a flare precursor. During solar observation, it was found that a general reorienting of bright spots, coupled with a heightening of activity in the H-alpha wavelength, indicated that a solar flare was beginning.

Scientific Data Quality and Quantity. Five film loads were used during the mission and over 68,000 photographs were obtained. Table 24 illustrates film usage from each film load.

Evaluation of the flight film indicated that high-quality photographs were obtained. Spatial resolution was 1.0 arc-second. Figures 75 and 76 are examples of the developed film from Skylab 2, showing the solar disk in fine detail. Note that the reticle width is approximately 1 arc-second. These exposures were made on DOY 166.

The H-alpha 1 and 2 TV systems operated within design specifications. Both vidicon cameras displayed real-time solar detail to the crew on the C&D console video monitors, and provided downlink TV images to the PI for use in solar observation planning. Table 25 illustrates TV usage for each mission.

TV images remained stable except for some degradation evident on H-alpha 1 during the last month of the Skylab mission. This

TABLE 24. H-ALPHA 1 FILM LOAD USAGE

Film Load	Skylab Mission	Frames (1) Available	Frames Exposed	Installed (DOY)	Removed (DOY)
1	2	15,400	12,998	Prior to Launch	218
2	3	15,400	15,405	218	236
3	3	15,400	15,383	236	265
4	4	15,400	15,400	326	359
5	4	15,400	9,000(2)	359	034

(1) Frames available varied slightly with the amount of film in each load.
(2) This is an approximation due to an anomaly that occurred on Skylab 4 (see page 163).

TABLE 25. H-ALPHA TV OPERATION TIME

Skylab Mission	H-Alpha 1 (Hours)	H-Alpha 2 (Hours)
2	107	107
3	305	305
4	338	338

anomaly is discussed in detail on page 164. Figures 77 and 78 are photographs of downlink TV images. Table 26 lists the H-alpha TV resolution parameters.

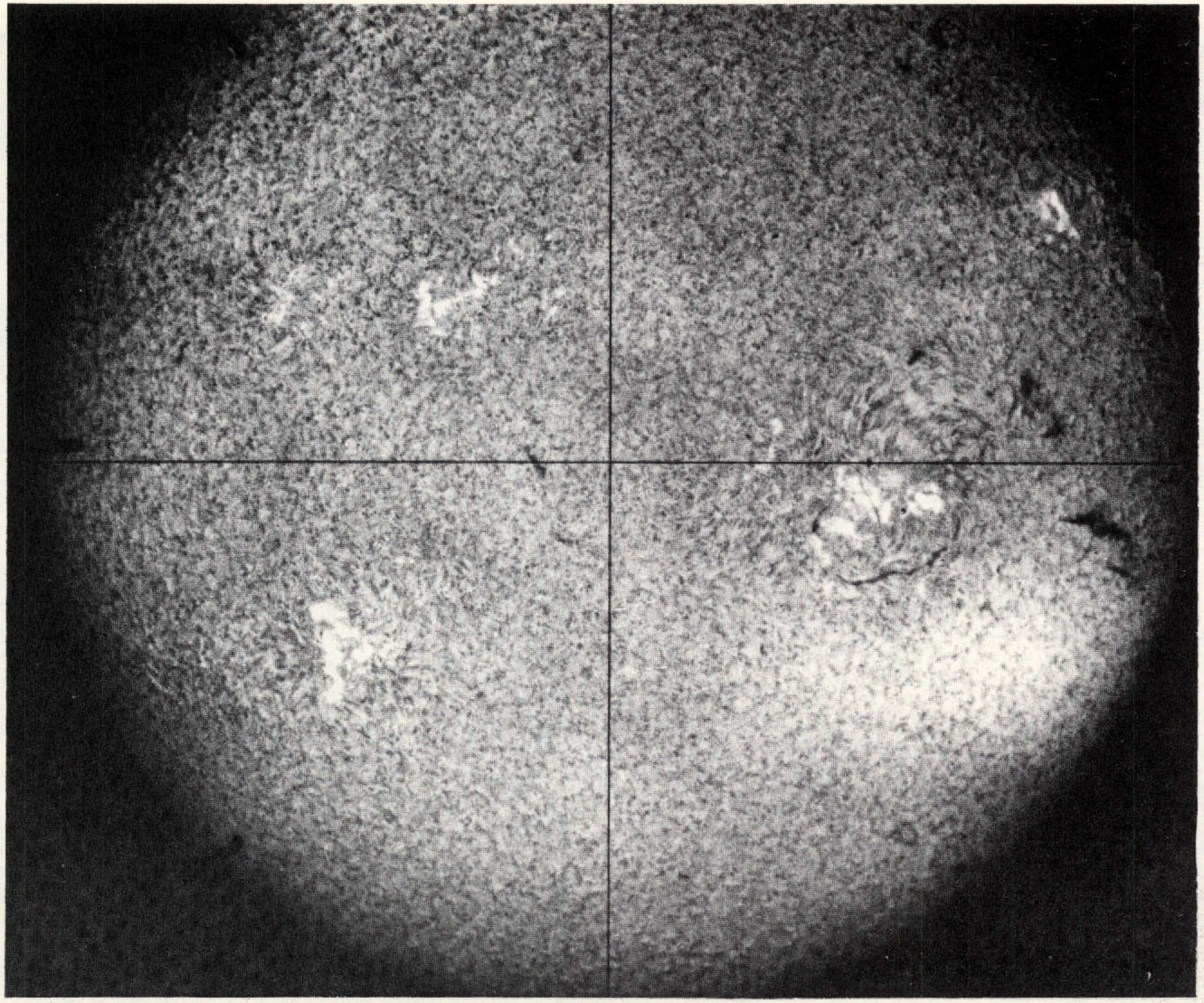


FIGURE 75. H-ALPHA FILM CAMERA PHOTOGRAPH OF FULL SOLAR DISK

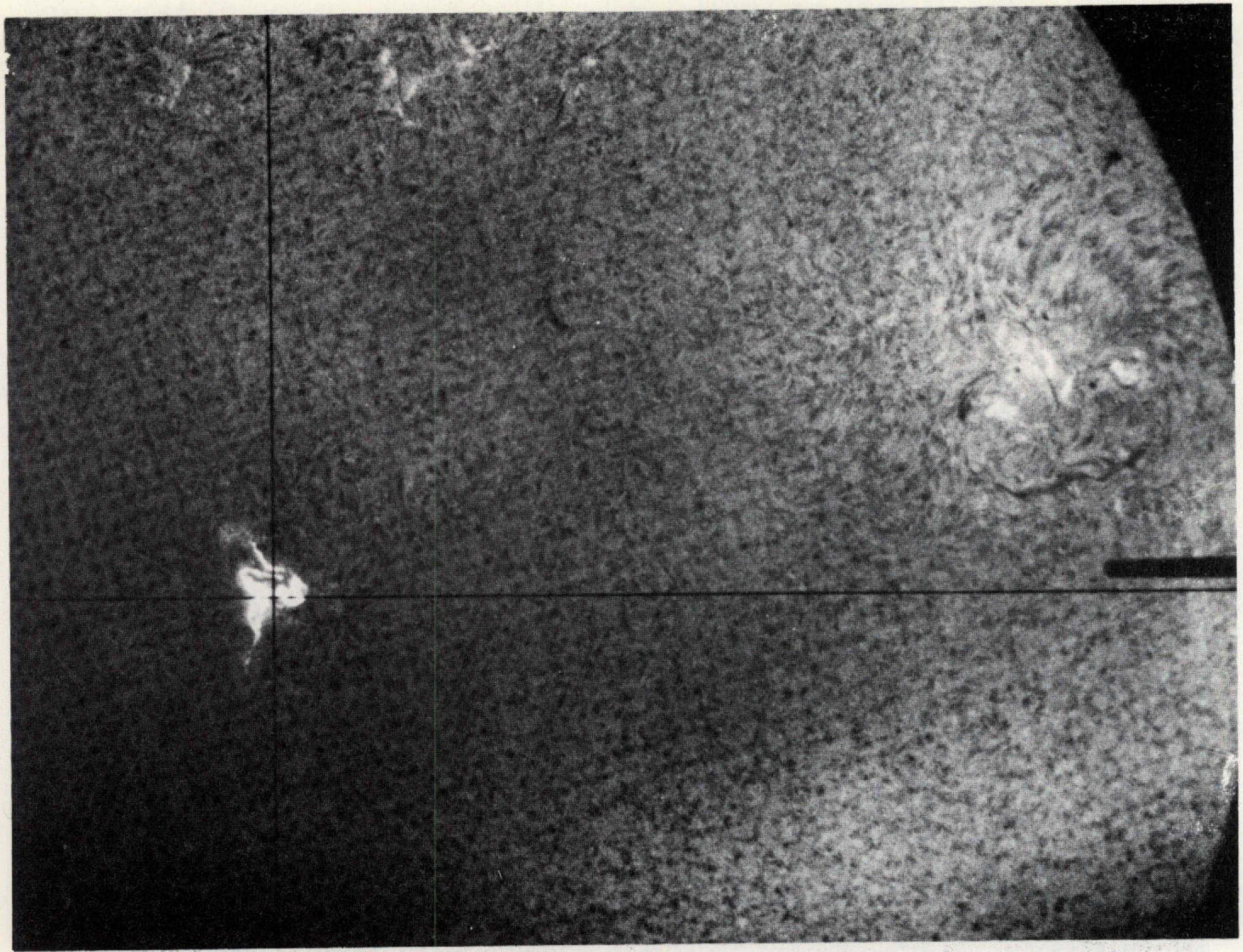


FIGURE 76. H-ALPHA FILM CAMERA PHOTOGRAPH OF SOLAR FLARE

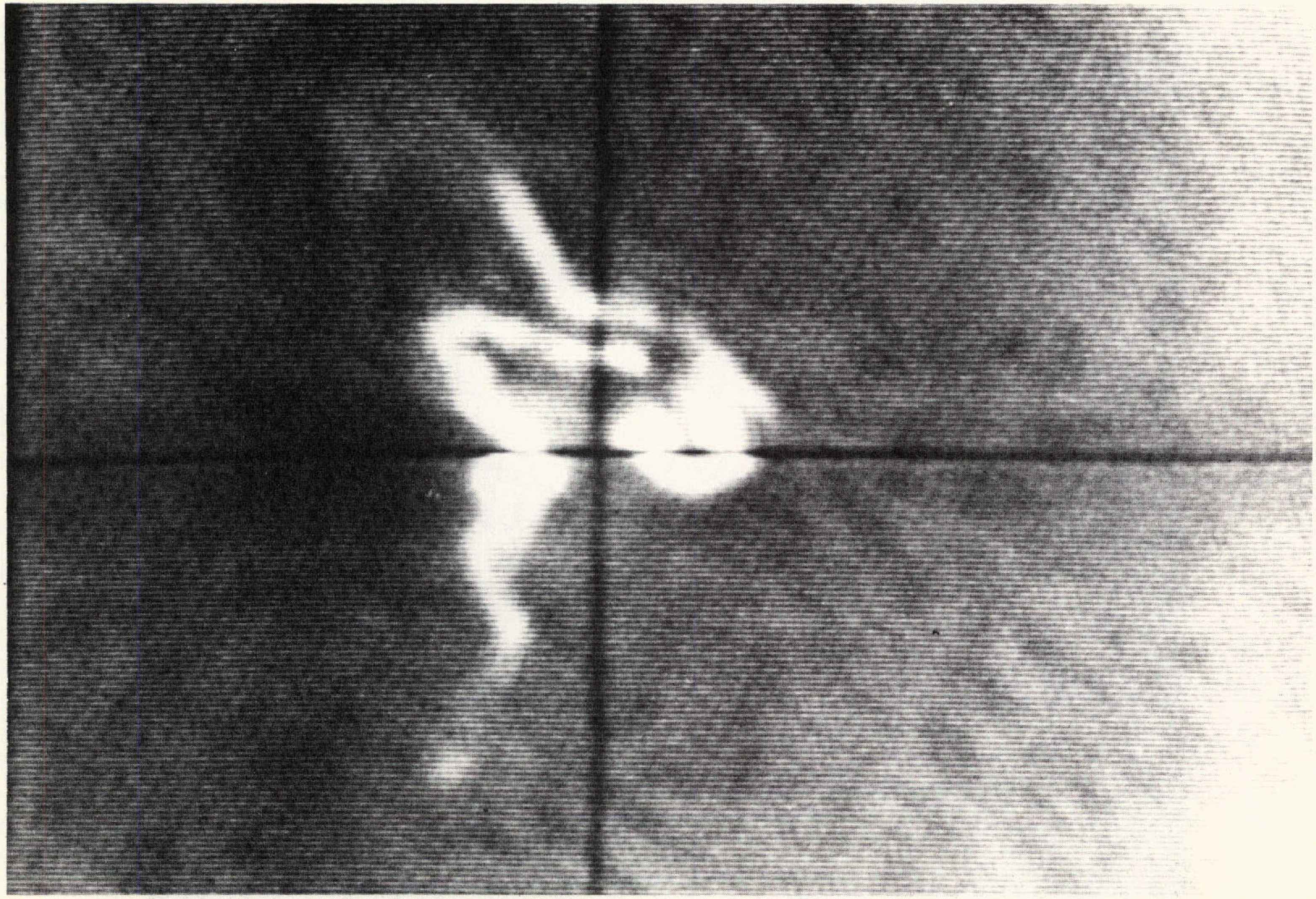


FIGURE 77. H-ALPHA 1 DOWNLINKED TV IMAGE

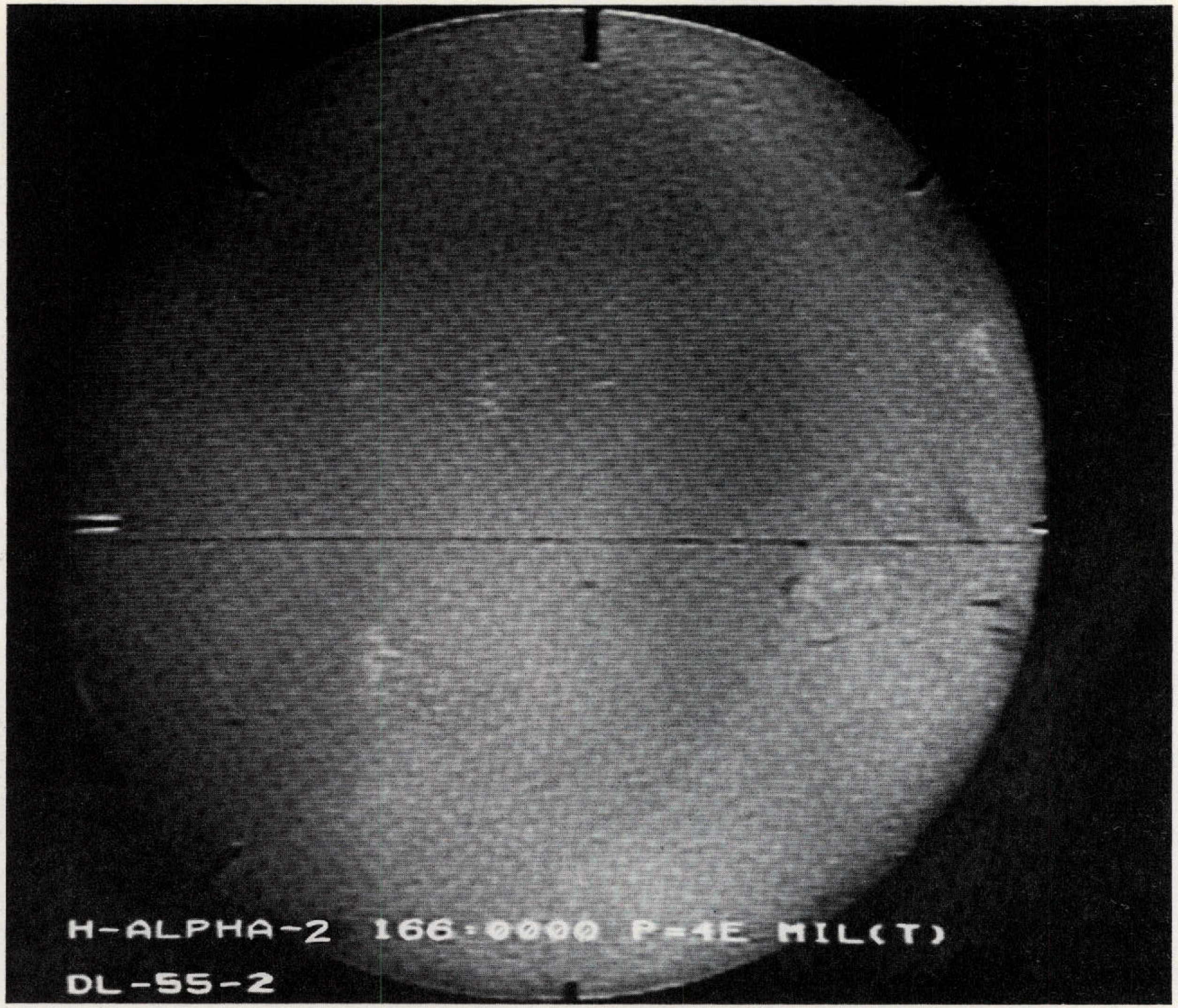


FIGURE 78. H-ALPHA 2 DOWNLINKED TV IMAGE

TABLE 26. H-ALPHA TV RESOLUTION

Display and Zoom	Field of View (Arc-minutes)	Estimated Spatial Resolution (Arc-seconds)	Estimated Spectral Resolution (Angstroms)
H-Alpha 1 Vidicon at 1X	16.0	5.0	0.7
H-Alpha 1 Vidicon at 3.6X	4.4	<1.5	0.7
H-Alpha 2 Vidicon at 1X	35.0	2.0	0.7
H-Alpha 2 Vidicon at 5X	5.0	<1.0	0.7

Anomalies

General. The H-alpha telescopes experienced one significant anomaly. The H-alpha 1 film transport operation became intermittent late in Skylab 4. The result was that approximately 25 percent of the Skylab 4 film was not exposed, and approximately 20 percent of the exposed film contained overlapped or multiple exposures. Toward the end of Skylab 4 the H-alpha 1 image appeared to be out of focus following the first 15 to 30 minutes of operation each day. To minimize degradation, the crew was requested to turn the H-alpha 1 TV camera off when not in use. Other minor anomalies were: a 1.0 arc-second jiggle on the H-alpha 1 TV image, image burn-in on the H-alpha 2 TV downlink, and blossoming of the H-alpha 2 image on the C&D console TV monitor. Details of each anomaly are discussed below.

H-Alpha 1 Film Transport Failure. On DOY 016 the crew reported that the film camera was inoperative. Reinitializing the system cleared the problem. On DOY 017 the crew reported the FRC failed to decrement. The camera appeared to be operating, based on shutter telemetry and the crew's statement that the C&D console camera operate light was performing properly. A daily comparison of the onboard FRC indication and the ground estimate of frames remaining, indicated an inconsistancy. Operation continued until the scheduled removal of film load 5. When the film magazine was removed on DOY 034, ground personnel estimated 15,191 exposures had been taken while the FRC indicated 9,000 frames had advanced. Approximately 50 percent of the recovered film was not exposed. Approximately 20 percent of the exposed film contained overlapped images (reference report number FI: SE-QUAL-AF-74.1). Evaluation of the film from load 4 revealed that it, too, had unexposed frames and overlapped images, but only on 20 percent of the film.

H-Alpha 1 TV Image Degradation. During the Skylab 4 crew debriefing, the crew reported that the H-alpha 1 TV image was very good until approximately one month before the end of Skylab. At that time, the video started to degrade gradually, but, because it was slight, the crew did not become aware of it until it became noticeable on DOY 015. The image appeared to be out of focus. From then on, the video was good for only the first 15 to 30 minutes after powering up each day, and then it degraded. The imagery would not improve until the TV was turned off for at least 8 hours. The video downlink TV recordings confirmed the degraded imagery. Investigation results are contained in Perkin-Elmer engineering report number 11947.

H-Alpha 2 Blossoming. On DOY 222 the crew reported that the H-alpha 2 vidicon blossomed (change in intensity and contrast) occasionally, at about one second intervals when it was powered up in the full field-of-view position. The vidicon washed out, and then returned to normal contrast. This condition was eliminated by zooming in for a few seconds which reduced the amount of H-alpha energy impinging on the vidicon surface. The problem was caused by the AGC circuit being shocked into oscillation when initially powered up with a bright (1X) solar image on the vidicon. This occurred when the TV was turned on and before the camera had time to warm up. The Skylab 3 and 4 crews avoided the problem by operating the TV initially in a slightly zoomed-in position.

H-Alpha 2 Vidicon Burn-In. On DOY 238, during the Skylab 3 mission, H-alpha 2 vidicon burn-in was observed on real-time downlink. The H-alpha 2 vidicon burn-in was verified during review of video tapes recorded DOY 238. Vidicon burn-in appeared as a negative image of a previous picture. It occurred when the camera scene was changed after having viewed the same scene for a long period of time. When the scene was changed, the former image was retained by the vidicon target in the negative sense, and therefore appeared in the new scene as a shadowing effect. The burn-in on the H-alpha 2 vidicon was a 32 arc-minute image of the solar disk. The burn-in appeared darker on Skylab 4, and tended to wash out solar detail when observing the Sun, zoomed in. During debriefing both the Skylab 3 and Skylab 4 crews stated that they did not notice burn-in on the TV monitors.

H-Alpha 1 Video Image Jiggle. On DOY 150, during Skylab 2, the crew reported that the H-alpha 1 solar image jiggled on the TV monitors. While zoomed in, the solar image and the H-alpha crosshairs jiggled in unison. Video downlink from DOY 150 verified that the H-alpha 1 picture jiggled with an amplitude of approximately 1 arc-second, when zoomed in. The jiggle did not create ATM pointing problems. Computer analysis and special bench tests of spare zoom assemblies were conducted. The results of these investigations indicated that the motion could have been due to the radial clearances between sliding components within the zoom assemblies. The jiggle continued during Skylab 3 and 4. A slight jiggle, less than 1 arc-second, was also seen on the H-alpha 2 image while zoomed in. There was no effect on ATM observations or pointing.

Conclusions

The H-alpha 1 and 2 telescopes satisfied their mission objectives; the crew was able to identify solar features, point the ATM at those features, and record the solar features on film for post-mission data analysis and coalignment records. The H-alpha telescopes enabled the Skylab crews to go beyond premission objectives. The crew was able to detect solar flares early and to observe limb prominences and fluctuating points in plage. The 0.7 angstrom-bandpass H-alpha filter proved a good selection in performing the prescribed telescope tasks. The H-alpha telescope system proved to be indispensable in performing the solar JOPs during the Skylab mission.

SECTION XI. CONCLUSIONS AND RECOMMENDATIONS

General

The ATM experiment module and its man/machine interface have served as a pioneering adventure in solar physics. Numerous technological advancements in hardware development and significant achievements in solar research have resulted. This report represents an engineering evaluation of ATM instrument performance during the mission; therefore, only those items related to experiment hardware and interfaces are addressed.

Conclusions

The following list of conclusions was obtained from various sources. Although many aspects of the mission are mentioned, the list cannot be considered complete.

The ATM mission provided the most intensive and extensive scientific coverage of solar events ever obtained.

Manned operation significantly enhanced the ATM mission in solar observation detection, mission planning, utilization of instrument versatility, maintaining instrumentation, incorporating work-arounds due to anomalies, and coordinating instrument status.

The JOP concept provided a flexible, workable system for fulfilling the requirements of the multi-objective observatory program.

The instruments accomplished their respective mission objectives and there were no failures which significantly restricted scientific data gathering capability.

The basic design of the experiment hardware was more than adequate. Each instrument exceeded its design life requirement.

Thermal control of the ATM and the MDA film vaults was sufficient to maintain experiment hardware within the limits necessary for optical alignment stability and for film preservation.

Pointing stability was generally commensurate with instrument resolution, except during periods of excessive mechanical perturbations.

Alignment of the instruments to each other and to the fine sun sensor remained stable through launch and mission phases and was within the JOP requirements.

Contamination from the manned orbiting vehicle was controlled sufficiently to preclude significant optics degradation and to assure an unobscured field of view.

The use of TV displays was an essential aide to the crew for searching for and pointing at solar features.

Preselected photographic exposure times and mode integration were, in most cases, adequate. Where necessary, suitable work-arounds were incorporated to adjust exposure times and mode durations.

Most of the switch functions were exercised and verified to operate. The built-in redundant systems assured mission success and were used on a limited basis.

Thermal shield door operation was not optimum but use of contingency procedures and backup design features assured continued mission success.

Data acquisition and retrieval was satisfactory, but its use for real-time mission planning was limited due to the restricted number of high-speed data lines and processing capability.

Recommendations

The following recommendations are made pursuant to improvements to the ATM instruments and supportive systems. These recommendations should be considered for other space missions with hardware and mission requirements similar to those of the Skylab mission. Although the list cannot be considered complete, the information was obtained from various sources responsible for ATM systems and covers many aspects of the mission.

Provide capacity for additional telemetry measurements. Additional instrument and C&D console switch position telemetry monitors would aid in ground data analysis and troubleshooting.

Provide continuous telemetry and communication coverage.

Provide additional ground command capability. This would allow operation of all instruments during unattended or unmanned periods and permit ground personnel to perform malfunction procedures, releasing the crew for other tasks.

Provide a continuous voice channel for crew-scientist use to coordinate solar observation for optimum data collection.

Increase the capacity of ground data handling, analysis and retrieval system.

Provide for convenient methods of maintainability in flight. A study should be initiated to evaluate the use of plug-in unit replacement techniques at readily accessible locations. This feature could possibly reduce the cost of manufacture of high-reliability hardware.

Optimize the number of switches on the C&D console. Seldom-used switch functions could be available by keyboard or ground command. The remaining switches should have a wider throw to enable crewmen to readily recognize switch positions.

Provide for computer operated JOPs which could be interrupted, if necessary, by the crew. The computer program should be readily changeable and have the capability to vary mode operational events such as camera exposure times.

Provide for inflight alignment-adjustment capability between instruments and reference axis.

Redesign thermal shield door mechanism to increase reliability. Additionally, door open and close indications should be a function of actual door position rather than relay position controlled by commands.

Initiate analysis to determine the feasibility of replacing film-strip cameras with roll-film cameras or using film-strip cassettes to avoid film limitations.

Supply DOY/GMT information on all TV downlink data trains.

Improve the scientific data return from S054 by supplementing the grating with high-resolution X-ray crystal spectroscopy.

Provide sufficient shielding to the S054 flare detection system to preclude false flare alert signals triggered by the SAA.

Incorporate a reversible grating drive mechanism for the S055A instrument operation. This would permit faster selection of grating positions.

Provide the capability to vary the size and alter start and stop points of the S055A mirror raster pattern.

Provide a spectroheliogram display of photoelectric detector outputs to aid in pointing to and identifying solar features.

Increase S082A grating dispersion and make multi-positional to provide greater resolution and decrease overlapping of spectral images.

Provide a secondary data acquisition system consisting of a vidicon camera and video display capability for each instrument.

Increase the range of TV sensitivity so that data can be obtained from both very dim and bright targets.

Provide tunable hydrogen-alpha Fabry-Perot filters to allow additional monochromatic wavelength studies.

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APPROVAL TM X-64821

MSFC SKYLAB
APOLLO TELESCOPE MOUNT
EXPERIMENT SYSTEMS
MISSION EVALUATION

BY

A. F. White, Jr.

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission porgrams 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.

A. F. White, Jr.
Skylab ATM Experiments
Technical Manager

Rein Ise JUN
Manager, Skylab Program Office