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Catalog of Lunar Mission Data

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Catalog of Lunar Mission Data

Technical Coordinator
WINIFRED SAWTELL CAMERON

Editors
ELLEN J. MANTEL
ELIZABETH R. MILLER

July 1977

II

PREFACE

We acknowledge with thanks those persons, too numerous to name, of the National Space Science Data Center (NSSDC) who have contributed to the production of this *Catalog*. Appreciation of the contributions of the experimenters is also hereby acknowledged. Their data submission and explanatory documentation form the base of this *Catalog*. The NSSDC personnel activity included data and information handling, verification, data description, inventory, illustrations, and photography, as well as document production, and involved both the acquisition scientists and the Data Center's onsite contractor, General Telephone and Electronics/ Information Systems, PMI Facilities Management Corporation personnel.

The Data Center strives to serve the scientific community in a useful manner so that the scientific data deposited there can be disseminated for continued and further analysis. Scientists are invited to submit comments or recommendations regarding the format of this *Catalog*, the data announced herein, and the services provided by NSSDC. Recipients are urged to inform other potential data users of its availability.

Winifred Sawtell Cameron

Elizabeth R. Miller

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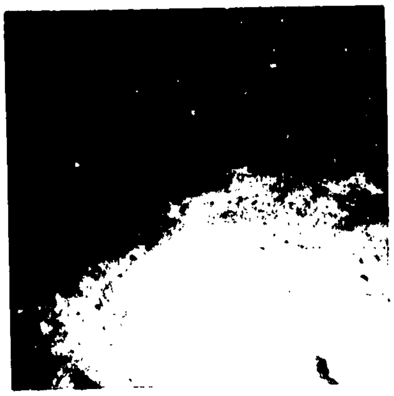
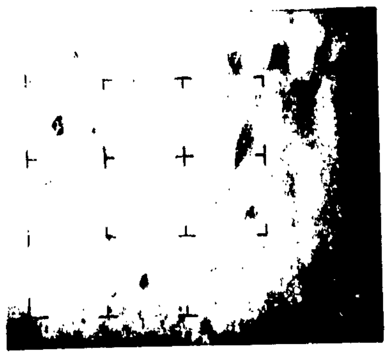
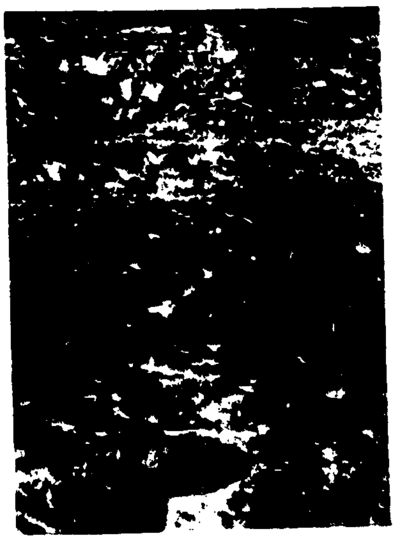
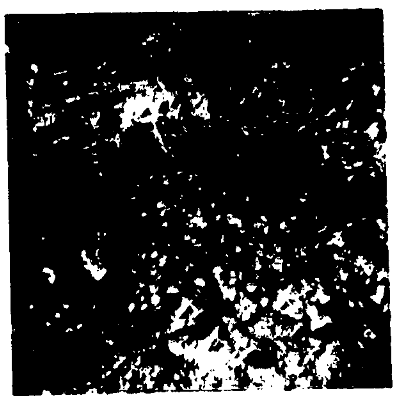
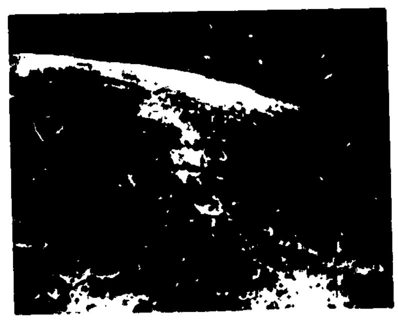
INTRODUCTION











INTRODUCTION

THE U.S. LUNAR PROGRAM

The decision to go to the Moon with manned spacecraft resulted in a carefully planned program of lunar exploration designed to determine if and where on the Moon safe, manned landings could be made, and subsequently to achieve manned landings. To accomplish this objective, several series of spacecraft were designed, developed, built, and launched to determine different characteristics of the lunar surface and environment. The premanned series were, in chronological order, Ranger, Surveyor, and Lunar Orbiter. The manned missions comprised the Apollo series, which achieved six landing missions.

The largest volume of data from these missions was photographic, beginning with the Ranger series on July 31, 1964, and ending with Apollo 17 on December 19, 1972. The Ranger series spacecraft were designed to impact the lunar surface after transmitting photographs during the final minutes of approach. They were also equipped with other instruments to study the cislunar and lunar environments. The Surveyor series soft-landed on the lunar surface and surveyed the local area photographically. Other Surveyor instruments were used to determine soil mechanics and composition and thermal and mechanical properties. Lunar Orbiter spacecraft obtained both high- and low-resolution photographs from lunar orbit for selection of manned landing sites. Radiation dosimeters and meteor detectors also returned data. The Apollo manned series was a broad scientific assault on the geophysical nature of the Moon and its environment. In addition to the photography obtained, experiments were performed by the astronauts from orbit and on the lunar surface and some instruments placed on the surface continue to return data.

The lunar missions resulted in a broad scientific instrumental exploration of the geological, geophysical, and physical properties of the Moon and its environs, augmented by man himself with his capacity to judge, select, adapt, correct, and improvise in his explorations.

CATALOG ORGANIZATION

The National Space Science Data Center (NSSDC) publishes catalogs of data for the disciplines described on the inside front cover. The purpose of this *Catalog* is to announce the availability of all scientific data acquired by the specified lunar missions and available at NSSDC. Table 1-1 summarizes all the experiments carried on U.S. lunar missions. The coding indicates whether or not NSSDC has data from these experiments and identifies failed or aborted experiments, thus providing the scope of the U.S. lunar program.

INTRODUCTION

This *Catalog* discusses only those experiments for which NSSDC can provide data. In addition to the U.S. data, limited amounts of U.S.S.R. lunar data from several Luna and Zond missions are also available from NSSDC and are announced in this *Catalog*. Data requested from NSSDC may be in the form of film, photographic paper prints, magnetic tape, hardcopy, microfilm, or microfiche as indicated in data descriptions.

The *Catalog* has been divided by programs: Ranger, Surveyor, Lunar Orbiter, Apollo, and Luna and Zond. A brief description of the mission of each program and the spacecraft flown is given, followed by experiment descriptions. The data obtained by the experiments and stored at NSSDC are described, and information such as the form and quantity of data is provided. References and sources of information are provided at the end of each program section.

In addition, some nonsatellite data that may be pertinent to scientific studies of lunar mission data are described in Appendix 1. These data are available from NSSDC and other sources as indicated. The principal investigators of the U.S. experiments described in this *Catalog* are given in Appendix 2, which is listed by program and alphabetically by experiment. The Index to Principal Investigators provides their affiliations, all lunar experiments with which they are associated, and the location of descriptions of their experiments in this *Catalog*. Appendix 3 provides a list of acronyms and abbreviations used throughout the text.

Refer to Appendix 4, NSSDC Facilities and Ordering Procedures, to order or request data from this *Catalog*. A discussion of ordering procedures is given, and an order form is provided. Refer to the Index to Available Data to obtain the NSSDC ID number for the specific data required. To obtain photography from most missions, it will be necessary first to request documentation and photographic catalogs described herein from which individual pictures may then be selected and ordered.

NSSDC MISSION

The raison d'être of the National Space Science Data Center is to be the repository of space science data and the distributor of these data to the scientific community, as described in Appendix 4. To organize and systematize the great volume of data received, NSSDC has a computerized file that maintains information on spacecraft, experiments flown on the spacecraft, and data stored at NSSDC from those experiments. For filing purposes, these records are each given NSSDC identification (ID) numbers utilizing a spacecraft/experiment/data hierarchy. Data are ordered from NSSDC by these numbers.

The Data Center has reproduction services, data viewing resources, and personnel to assist scientists in procuring the desired data products. In order to acquaint the user public with the data products stored at NSSDC, the Data Center publishes catalogs and documents such as this.

Table 1-1. U.S. Lunar Mission Data

LEGEND

- ● All or partial data at NSSDC
- X No data at NSSDC
- ◊ Experiment failed
- □ Experiment aborted

		PHOTOGRAPHY																									
	Television	Hasselblad	Multispectral	Maurer	Closeup Stereoscopic	Hycon	Nikon	Contamination	TV Kinescope	Panoramic	Mapping Camera System (Mapping and Stellar)	Gegenschein	Far UV Camera/ Spectrograph	Geologic Samples	Soil Mechanics	Alpha Particle Measurements	Radiation	Selenodesy	Meteoroids	Laser Altimeter	S-Band Transponder	Bistatic Radar	Gamma-Ray Spectrometer	X-Ray Fluorescence	Mass Spectrometer	Far UV Spectr…	Lu…
Ranger 7	●																										
Ranger 8	●																										
Ranger 9	●																										
Surveyor 1	●*														X												
Surveyor 3	●*														●												
Surveyor 5	●*														X	●											
Surveyor 6	●*														X	●											
Surveyor 7	●*														●	●											
Lunar Orbiter 1	●																X	●	●								
Lunar Orbiter 2	●																X	●	●								
Lunar Orbiter 3	●																X	●	●								
Lunar Orbiter 4	●																X	●	●								
Lunar Orbiter 5	●																X	●	●								
Apollo 9		●		●																							
Apollo 10		●		●																							
Apollo 11		●		●	●									●	●				X								
Apollo 12		●	●†	●	●									●	●				X		●						
Apollo 13		●		●	□	□								□	□				□								
Apollo 14		●*		●	●	●						X		●	●						●	●					
Apollo 15		●*		●			●		●	●	●	◊		●	●	●		●		●	●	●	●	●	●		
Apollo 16		●		●			●	●	●	●	●	●§	●	●	●	●		●		●	●	●	X	●	●		●
Apollo 17		●		●			●		●	●	●	X		●	●			●	X	●	●					●	

*Mosaics also available.

†Included with Hasselblad data.

§Included with Maurer and Nikon data.

FOLDOUT FRAME 2

...eteroids	Laser Altimeter	S-Band Transponder	Bistatic Radar	Gamma-Ray Spectrometer	X-Ray Fluorescence	Mass Spectrometer	Far UV Spectrometer	Lunar Sounder	IR Scanning Radiometer	Seismic Experiments	Laser Ranging Retroreflector	Magnetic Fields	Heat Flow	Traverse Gravimeter	Lunar Surface Gravimeter	Electrical Properties	Neutron Probe	Suprathermal Ions	Cold Cathode Ion Gage	Charged Particles	Atmospheric Composition	Solar Wind Experiments	Cosmic-Ray Experiments	Lunar Dust Detector	Particle Shadows/ Boundary Layer	Biaxial Fluxgate Magnetometer
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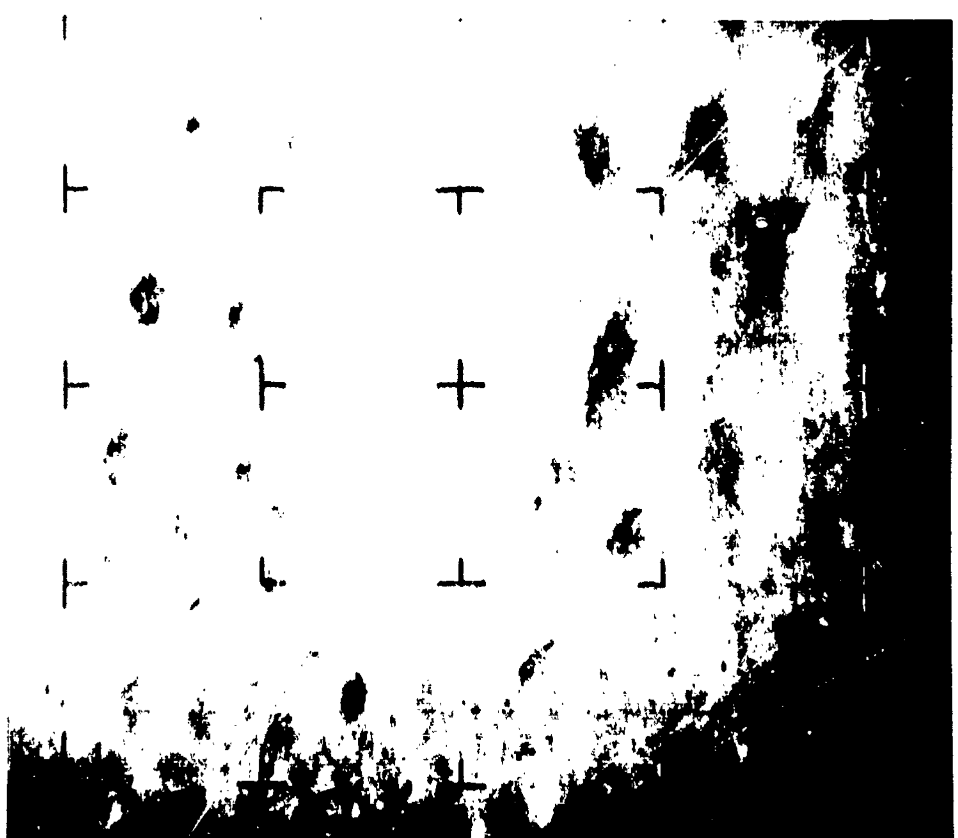
2
THE RANGER PROGRAM



Ranger 7 last full-scan A-camera frame taken before surface impact and not completely read-out; the noise at the right-hand edge is due to impact. Note the smooth surface and that only one crater (800-m diameter) in upper left contains anything. Spacecraft altitude was 5 km (3 mi) and resolution is 30 m (100 ft).

THE RANGER PROGRAM

The Ranger program consisted of nine spacecraft missions with the ultimate objective of obtaining high-resolution photographs of the lunar surface.

Ranger 1 and 2 made up Block I of the program and were test missions. They were launched in 1961 for nonlunar-oriented engineering development. Block II missions (Ranger 3, 4, and 5) were launched during 1962 to achieve rough lunar landings, to obtain some science data, and to test approach television camera operations. These Ranger spacecraft experienced satisfactory vehicle performance but either missed the Moon (Ranger 3) or failed before impacting the lunar surface (Ranger 4 and 5).

The experiences of these earlier phases of the program led to the Block III missions in 1964 and 1965: Ranger 6, 7, 8, and 9. These spacecraft were designed to achieve lunar impact trajectories and to transmit high-resolution photographs of the lunar surface during the final minutes of flight. The Ranger spacecraft is shown in Figure 2-1.

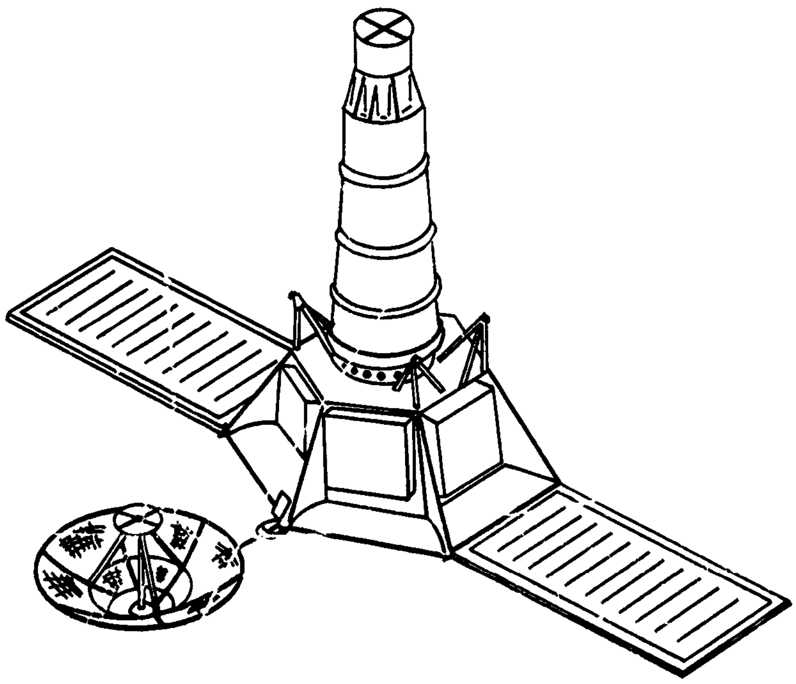


Figure 2-1. The Ranger spacecraft.

RANGER

Ranger 6 performed satisfactorily, but the cameras failed to operate before lunar impact. However, Ranger 7, 8, and 9 fulfilled the mission objectives and provided over 17,000 photographs at resolutions not previously obtainable. It is these missions and the resulting photography that are discussed here.

The Ranger 7 and 8 missions provided coverage of the two types of mare terrain in which they impacted. The first type is modified by crater rays, and the second is crossed by a complex system of ridges. Image motion limited terminal resolutions on these missions. Ranger 9 provided coverage of a highland region, impacting in the large central highland Crater Alphonsus. During the picture-taking sequence, lighting was excellent, image motion was negligible, and terminal resolution was 0.3 m. Comparative information for these successful Ranger missions can be found in Table 2.1.

The Ranger photographs, which are available from NSSDC, provided valuable information for lunar surface interpretation (*Heacock et al.*, 1965 and 1966), future landing site selection for Surveyor and Apollo missions, and feature designation of surface detail not heretofore visible to Earth-based observations. The impact on lunar mapping was considerable (*Ranger Program*, 1961).

TELEVISION EXPERIMENT

Each Ranger spacecraft approached the Moon in direct motion along hyperbolic trajectories and encountered the surface with incoming asymptotic direction angles with respect to the lunar equator. During the final minutes of flight, the spacecraft television camera system began operations and continued until impact on the lunar surface.

The Ranger spacecraft television equipment had the same basic construction and operational capability for all missions (*Kirhofer*, 1966). Included in the system were six cameras.

The six cameras were fundamentally the same with differences in exposure times, fields of view, lenses, and scan rates. The camera fields of view were arranged to provide overlapping coverage so that a nested sequence of photographs was obtained.

The camera system was divided into two completely separate channels designated P (partial) and F (full). Each channel was self-contained with separate power supplies, timers, and transmitters.

Table 2-1. Successful Ranger Missions

Parameters	Mission Name: Ranger 7	Ranger 8	Ranger 9
SPACECRAFT			
Hours of Flight	68.6	64.9	64.5
Inclination	26.84°	16.5°	15.6°
Trajectory Asymptotic Angle	-5.57°	-13.6°	-5.6°
Impact Coordinates	20.7°W 10.7°S	24.8°E 2.7°N	2.4°W 13.1°S
Impact Location	Mare Cognitum	Mare Tranquillitatis	Alphonsus
Impact Date	July 31, 1964	Feb. 20, 1965	Mar. 24, 1965
PHOTOGRAPHY			
Transmission Time (UT)	1308 to 1325	0934 to 0957	1349 to 1408
Sequence Duration (min)	17.2	23	19
Quantity	4308	7137	5814
Quality	Excellent	Good	Good Contrast
Highest Resolution (m)	0.5	1.5	0.3

The F-channel had two cameras. The A-camera was wide angle, and the B-camera was narrow angle. Both cameras had a large dynamic range from approximately 35 to 50 cd/m^2 (10 to 15 fL). The two cameras operated in sequence so that only one camera exposure scanned at a time, with 5-s intervals between consecutive pictures on a particular camera.

The P-channel contained four cameras designated P_1 through P_4, and they had the same combination of lenses as the cameras in the F-channel. P_1 and P_2 cameras were narrow angle, and the P_3 and P_4 cameras were wide angle. The primary difference between the two channels was in the camera scan rate and portion of the photoconductive target used. See Table 2-2 for camera characteristics.

Table 2-2. Ranger Television Camera Characteristics

Characteristics	Ranger Cameras					
	F-Channel		P-Channel			
	A	B	P_1	P_2	P_3	P_4
Focal Length (mm)	25	76	76	76	25	25
f Number	1.0	2.0	2.0	2.0	1.0	1.0
Frame Time (s)	2.56	2.56	0.2	0.2	0.2	0.2
Horizontal Frequency (cps)	450	450	1500	1500	1500	1500
Exposure Time (ms)	5	5	2	2	2	2
Field of View	25°	8.4°	2.1°	2.1°	6.3°	6.3°
Target Size	11°	11°	2.8°	2.8°	2.8°	2.8°
Scan Lines	1150	1150	300	300	300	300
Time Between Frames (s)	5.12	5.12	0.84	0.84	0.84	0.84

The last F-channel picture was taken between 2.5 and 5 s before impact (altitude about 5 km), and the last P-channel picture was taken between 0.2 and 0.4 s (altitude about 600 m) from which the highest resolutions were obtained. The resolution achieved by Ranger 9 (0.3 m) was a factor of 1000 better than any Earth-based views of the Moon.

Vidicons with 2.54-cm (1-in.) diameters were used for image sensing, and electromagnetically driven slit-type shutters exposed the vidicons. Images were focused on the vidicon target, which was made up of a layer of photoconductive material initially charged by scanning with an electron beam. The charge pattern formed by the image on the photoconductor remained much longer than in commercial systems. An electron beam then scanned the surface and recharged the photoconductor. The video signal was amplified several thousand times, sent to the transmitter where amplitude variations were converted to frequency variations, and were then transmitted to Earth. At the end of the active scan, the camera entered an erase cycle to prepare it for the next exposure. Twelve P-channel pictures were exposed between each F-channel picture.

The television signals were received on 25.9-m (85-ft) antennas at Goldstone, California, were amplified and mixed to reduce the signal center frequency to 30 MHz, and were sent to a television receiver.

Another mixing operation reduced the frequency to 4.5 and 5.5 MHz, respectively, for the two channels. The signals were then reconverted to amplitude variations in two demodulators. The output was the same as the original video generated in the cameras. These video signals were used to control the intensity of an electron beam in a cathode-ray tube that was scanned in unison with the electron beam in the cameras. This reconstructed the original image, which then was photographed on 35-mm film.

In addition to the film recorders, another means of recording was used. The 4.5- and 5.5-MHz signals were sent from the demodulator to another mixer that reduced the center frequency further to 500 kHz. They were then recorded on magnetic tape. To obtain film records from these magnetic tapes, they were played through a demodulator, and the video signal was applied to the film recorder as discussed above (*Billingsley*, 1966 and 1970).

The film used was Eastman Kodak television recording film type 5374. The negatives were developed by a commercial film processor to a 1.4 gamma.

Television Experiment Data

The photographs from the Ranger missions are stored at NSSDC and are available as described below. Table 2-3 summarizes the NSSDC data holdings. See the Index to Available Data to obtain the NSSDC ID numbers necessary for ordering these data.

Table 2-3. Ranger Television Experiment Data at NSSDC

Mission	Lunar Photographs	Atlas Photographs		
		F-Channel		P-Channel
		A(wide)	B(narrow)	
Ranger 7	4308	199	200	758
Ranger 8	7137	60	90	79
Ranger 9	5814	70	88	46

In addition to the data listed here, there are supporting data available on microfiche that present photographic parameters for each mission.

To aid in selecting and using Ranger data, NSSDC published a *Data Users Note* (DUN), *Ranger 7, 8, and 9 TV Cameras* (NSSDC 68-06). The DUN briefly describes the instrumentation and measurements, the telemetry, and the operational experience of the Ranger television cameras. A reference list and bibliography are also provided. It is recommended that this DUN be obtained before ordering Ranger data (see order form).

Lunar Photographs

These photographs are duplicate negatives made from the master positive prints that were matched very closely to the density distribution of the originals. The original negative was obtained from tape playback as described.

The total full-scan and partial-scan data transmitted by the Ranger experiments are contained on these 35-mm black and white films of Eastman Kodak type 5285. They provide lunar views and information on topographic features of the lunar surface.

Atlases of Lunar Photographs

These atlases contain selected photographs from the television experiments flown on the last three Ranger missions. The photography from the various cameras is found in three volumes for Ranger 7 and one volume each for Ranger 8 and 9. Included are mission and camera system descriptions as well as tables of values for each published photograph. The atlases were reproduced photographically to preserve the rich image of the originals. Shown in Table 2-3 are the quantities of photographs for the cameras and missions. These atlases are available from NSSDC on microfiche.

REFERENCES/SOURCES

The following citations are annotated with A- and N-numbers where applicable. An A-number indicates those documents available from:

Technical Information Service
American Institute of Aeronautics
and Astronautics
750 Third Avenue
New York, NY 10017

N-numbers refer to documents available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

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Heacock, R. L., G. P. Kuiper, E. M. Shoemaker, H. C. Urey, and E. A. Whitaker, "Ranger 7 Part 2, Experimenters' Analyses and Interpretations," JPL-TR-32-700 Part 2, Pasadena, California, February 1965. (N65-22162)

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Hess, W. N., D. H. Menzel, and J. A. O'Keefe, *Nature of the Lunar Surface*, Johns Hopkins University Press, Baltimore, Maryland, 1966.

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Kirhofer, W. E., "Ranger 8 Photographic Parameters," JPL-TR-32-965, November 1966. (N67-11818)

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Schurmeier, H. M., "Ranger 8 and 9 Part 1, Mission Description and Performance," JPL-TR-32-800, Part 1, Pasadena, California, January 1966. (N66-16149)

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3 THE SURVEYOR PROGRAM

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Surveyor 7 mosaic of the northern flank of Crater Tycho. The large block is approximately 0.3 m (1 ft) in diameter, and the horizon is approximately 3 km (2 mi) away. Resolution is approximately 1 mm along the lower edge of the photograph. (7SE31)

N77-32131

THE SURVEYOR PROGRAM

The Surveyor program consisted of seven unmanned lunar missions that were launched between May 1966 and January 1968. Five of these spacecraft, Surveyor 1, 3, 5, 6, and 7, successfully soft-landed on the lunar surface. It is these missions and the resulting data that are discussed in this *Catalog*.

In addition to demonstrating the feasibility of lunar surface landings, the Surveyor missions obtained lunar and cislunar photographs and both scientific and technological information needed for the Apollo manned landing program. Four spacecraft, Surveyor 1, 3, 5, and 6, returned data from selected mare sites for Apollo program support, and Surveyor 7 provided data from a contrasting rugged highland region.

Each spacecraft weighed 100 kg at launch, was 3.3 m high, and had a 4.5-m diameter. The tripod structure of aluminum tubing provided mounting surfaces for scientific and engineering equipment. (See Figure 3-1.) Onboard equipment consisted of a 3-m^2 solar panel that provided approximately 85-W output, a main battery and a 24-V nonrechargeable battery that together yielded a 4090-W total output, a planar array antenna, two omnidirectional antennas, and a radar altimeter. The soft landing was achieved by the spacecraft free falling to the lunar surface after the engines were turned off at a 3.5-m altitude. Operations began shortly after landing.

Each Surveyor spacecraft carried a television camera, and over 86,000 70-mm pictures were obtained at very high resolutions (to 1 mm). This photography provided information on the nature of the surface terrain in the immediate vicinity of the spacecraft as well as the numbers, distribution, and sizes of the craters and boulders in the area. In addition to lunar terrain studies, the photography supported investigations of soil mechanics, magnetic properties, and composition of the surface material (*Phinney et al.*, 1970; *Gold*, 1970; *Gault et al.*, 1970; and *Le Croissette*, 1969). Table 3-1 provides comparative information for the Surveyor missions.

Surveyor 3 and 7 carried a soil mechanics surface sampler (*Christensen et al.*, 1967). Photographs of trenching operations performed with the scoop provided soil mechanics information. Bearing and impact tests were also photographed, and these photographs provide similar information.

Surveyor 5, 6, and 7 had a magnet attached to one of the spacecraft footpads to determine magnetic properties and composition of the soil (*De Wys*, 1967). Surveyor 7 had additional magnets on a second footpad and the surface sampler. Photographs showing the amount of dust adhering to the

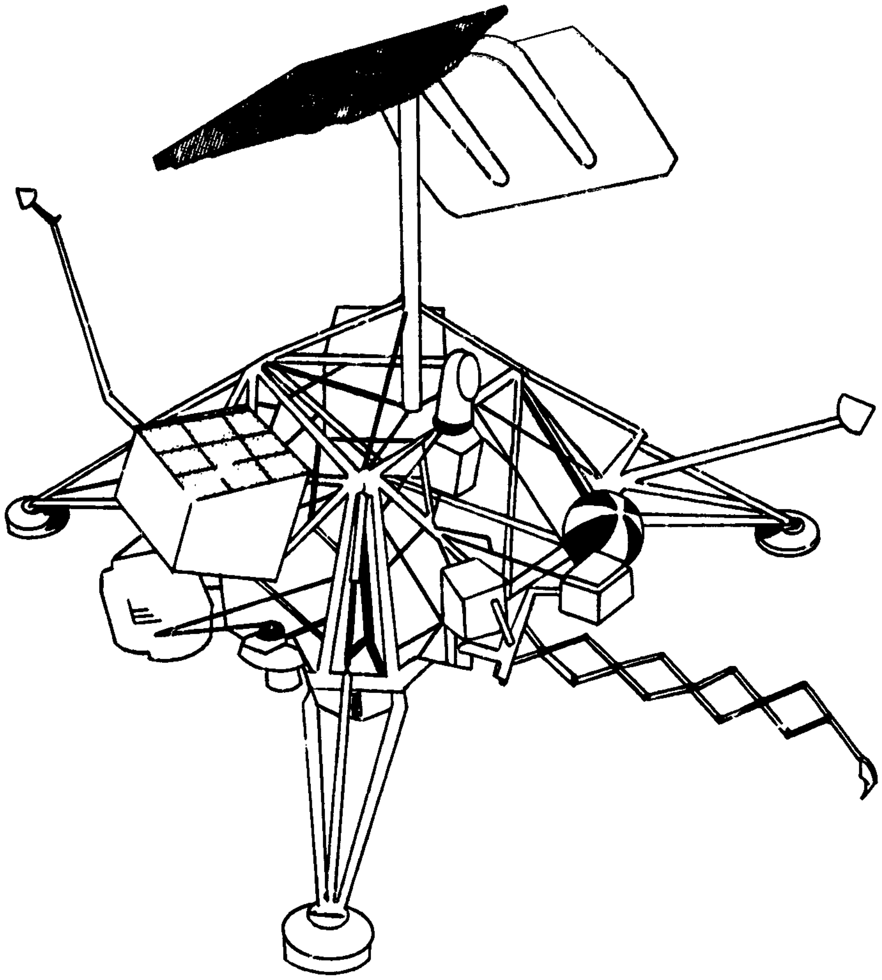

Figure 3-1. The Surveyor spacecraft.

magnets indicated the amount of magnetic particles (principally iron) in the soil and allowed estimates of the lunar soil composition when compared with premission experiment photographs of magnets in terrestrial soils of various compositions with varying iron content.

Composition of surface material was also determined from data obtained by the alpha-scattering instrument (*Turkevich*, 1970). This instrument was carried by Surveyor 5, 6, and 7 to allow chemical analysis of the lunar surface material.

Touchdown dynamics data from engineering sensors provided soil mechanics information, and erosion data were obtained from vernier engine activity. The Surveyor 6 spacecraft performed a "hop" maneuver moving 2.5 m away from its original landing area. Photography obtained after the hop contributed to the soil mechanics investigations.

Table 3-1. Surveyor Spacecraft and Experiment Information

Parameters	Mission Name				
	Surveyor 1	Surveyor 3	Surveyor 5	Surveyor 6	Surveyor 7
SPACECRAFT					
Launch Date	May 30, 1966	Apr. 17, 1967	Sept. 8, 1967	Nov. 7, 1967	Jan. 7, 1968
Landing Date*	June 2, 1966	Apr. 20, 1967	Sept. 11, 1967	Nov. 10, 1967†	Jan. 10, 1968
Last Usable Data	July 13, 1966	May 4, 1967	Sept. 24, 1967	Nov. 24, 1967	Feb. 14, 1968
Landing Coordinates	2.46°S, 43.22°W	2.99°S, 23.34°W	1.42°N, 23.20°E	0.51°N, 1.39°W	40.88°S, 11.45°W
Landing Location	Flamsteed P	Oceanus Procellarum	Mare Tranquillitatis	Sinus Medii	Tycho North Rim
EXPERIMENTS					
Television (photos)	11,000§	6,315	18,006	29,914	20,961
Soil Mechanics Surface Sampler**		Texture, Structure,†† Bearing strength			Soil properties, Bearing strength
Alpha-Scattering Surface Analyzer			Chemical composition	Chemical composition†	Chemical composition
Strain Gage	Texture, Structure, Bearing strength	Texture, Structure, Bearing strength	Bearing strength	Touchdown dynamics†	
Magnets**					
Bar			Magnetic particles, Chemical composition	Magnetic particles, Chemical composition	Magnetic particles, Chemical composition
Horseshoe					Magnetic particles, Chemical composition
Vernier Engine Erosion			Bearing strength	Touchdown dynamics†	

*Data acquisition began.
†Spacecraft moved 2.5 m away on Nov. 17, 1967; therefore, there are two data recordings.
§Estimate.
**Data included with the 70-mm photography data.
††Data included with Surveyor 3 animated field sequence.

NSSDC holdings include all the Surveyor photography, partial soil mechanics surface sampler data, and the best alpha-scattering data obtained. These experiments and their data are described in the following sections.

TELEVISION EXPERIMENT

The television (TV) carried on the Surveyor spacecraft was a slow scan vidicon camera (*Smokler*, 1969; *Wolfe and Montgomery*, 1966). It was operated by ground command and demonstrated great flexibility. Preplanned tapes commanded the camera to take panoramic surveys, and manual commanding was performed when individual visual observations were required.

The six major assemblies of the camera were the mirror head, filter wheel, variable focal-length lens and iris assembly, shutter, vidicon tube, and the TV auxiliary electronics. The camera accommodated scene luminescence levels from approximately 0.00027 to 8900 cd/m^2 (0.00008 to 2600 fL). It provided a 1-mm resolution at 4 m, and the lens was able to focus from 1.23 m to infinity. On level surfaces, the lunar horizon was approximately 2 km distant.

The mirror head rotated 360° horizontally, allowing panoramic views around the spacecraft. Azimuth motion was obtained by rotating the mirror-head assembly about the optical axis of the lens (+31° to -67° above and below the plane normal to the camera Z-axis). The mirror reflected the lunar surface images through the filter wheel and the other camera assemblies to the vidicon faceplate.

The filter wheel was mounted above the lens and had four sections. On Surveyor 1, 3, and 5, the four sections were clear, red, green, and blue. On Surveyor 6 and 7, three polarizing filters were used in place of the color filters to investigate the polarization of light reflected both from the lunar surface and from the Earth.

The variable focal-length lens and iris assembly was adaptable to 25-mm and 100-mm focal lengths. The extreme stops only were used and allowed wide- and narrow-angle views of the lunar scene. The shutter, below the lens and iris assembly, was designed to give an exposure of 150 ms. This was considered to be optimum for the lunar light conditions. The vidicon-tube assembly included a 2.54-cm (1-in.) diameter vidicon tube positioned 0.5 cm (0.2 in.) behind the shutter. Upon receiving the reflected image, a video signal was produced from the photoconductive target layer for analog transmission of the image to Earth.

The Surveyor camera had three modes of operation. The normal mode provided one 600-line TV frame every 3.6 s and required 1 s to be read from the vidicon. To transmit lens and mirror position, temperature, calibration level, and identifying information required 200 ms using a 220-kHz video bandwidth over a directional antenna. The vidicon was erased in 2.4 s for the next exposure. The 200-line mode required 61.8 s per frame and 1.2 s to complete video transmission at a 1.2-kHz bandwidth over an omnidirectional antenna. The third mode was referred to as an integrating mode and provided both 600- and 200-line scans. In this mode, the scanning beam of the vidicon was cut off, and the shutter remained open allowing a continual charge build up on the vidicon proportional to the received photon energy.

The integrating mode was used for stellar observations and views of the lunar surface under earthshine conditions. The 200-line mode was used immediately after touchdown and under special conditions. The normal 600-line mode was used at all other times and obtained more than 99 percent of the pictures taken during the Surveyor missions.

The picture information was processed by a central command decoder with further processing performed by the TV subsystem decoder. The analog identification signals from the camera were commutated by the television auxiliary. Analog-to-digital conversion was performed by the central signal processor. The pulse-code-modulated identification data were mixed in a proper time relationship with the video signal and transmitted to Earth.

Most TV data transmissions were received at Goldstone, California, and relayed to the Space Flight Operations Facility at Pasadena for data processing. Overseas Deep Space Network stations also participated in television operations.

The TV images were displayed on Earth on a slow scan monitor coated with a long persistency phosphor that optimally matched the nominal maximum frame rate. One frame of TV identification was received for each incoming frame and was displayed in real time at a rate compatible with that of the incoming image. These data were recorded on a video tape recorder.

For photograph reconstruction, there were two photometric/colorimetric reference charts on the spacecraft, within view of the camera. These charts contained a series of precalibrated wedges; 13 were gray and 3 were color. Photographs of these charts, taken at the beginning of each mission, allowed comparison with corresponding wedges on Earth for photographic reconstruction. Radial lines on the charts provided a gross estimate of camera resolution. The mounting post for these charts aided in determining solar angles from shadow information.

Television Experiment Data

The television performance was generally good, and the quality of the pictures was excellent on each mission when favorable lighting conditions existed. The 600-line, high-resolution pictures show details as small as 0.5 mm (0.02 in.). The photographic subjects for each mission are shown in Table 3-2. The time periods of usable data acquisition are from the landing date to the date of last usable data (see Table 3-1).

Table 3-2. Surveyor Photographic Subjects

Subjects	Surveyor 1	Surveyor 3	Surveyor 5	Surveyor 6	Surveyor 7
PANORAMAS					
Wide Angle	X	X	X	X	X
Narrow Angle	X	X	X	X	X
SURVEYS					
Focus Ranging	X	X	X	X	X
Photometric	X		X	X	X
Stereo Mirror					X
Color	X	X	X		
Polarimetric				X	X
OBJECTS					
Celestial	X	X	X	X	X
Earth					X
INSTRUMENTS					
Surface Sampler		X			X
Alpha Scatterer			X	X	X
Bar Magnet			X	X	X
Horseshoe Magnet					X
SPECIAL AREAS	X	X	X	X	X

The TV experiment data held at NSSDC include 70-mm film generated from the original video transmissions, mosaics, and digitally processed photographs. Catalogs are also available for some missions, and photographic identification information is available for all missions. Tables 3-3 and 3-4 summarize the NSSDC data holdings that are also described individually in the following sections. In addition to data listed in Table 3-3, NSSDC has available an animated sunset sequence from Surveyor 3 and 173 selected mosaics from Surveyor 5. See the Index to Available Data to obtain the NSSDC ID numbers necessary for ordering these data.

Table 3-3. Quantity of Surveyor Television Photography at NSSDC

Mission	70-mm Photography	Digitally Processed 35-mm Photography		Mosaic Negatives	Regenerated 70-mm Photography
		D&R	SWRF		
Surveyor 1	11,000*	88	90	334	
Surveyor 3	6,315	28	98	60	6,315
Surveyor 5	18,006	8	49	237	18,006
Surveyor 6	29,914	325		358	29,914
Surveyor 7	20,961	17	56	244	20,961

*Estimated.

Table 3-4. Surveyor Television Experiment Identification Information at NSSDC

Mission	Catalogs	Magnetic Tape	16-mm Microfilm
Surveyor 1	NSSDC 68-10*		3
Surveyor 3		1	1 } same reel
Surveyor 5	NASA SP-341*	1	1 } same reel
Surveyor 6		1	1 } same reel
Surveyor 7		1	1 } same reel

*Series number for document.

To aid in selecting and using Surveyor 1 data, NSSDC published a *Data Users Note* (DUN), *Surveyor 1 (1966-45A) Lunar Television Data* (NSSDC 67-30, June 1967). This DUN briefly describes the instrumentation, measurements, and operations of the Surveyor 1 TV camera. Data reduction and format are also described, and a bibliography is included. Much of this information is applicable to all Surveyor missions.

Detailed descriptions of the experiment and samples of the photography for all Surveyor missions are contained in the Jet Propulsion Laboratory series of technical reports cited at the end of this section. It is recommended that the supporting or selection information be obtained before ordering Surveyor television data.

70-mm Photography

These third generation film negatives are on 70-mm film rolls and were reproduced from the original negatives with a master positive. These data are available for all Surveyor spacecraft.

The types of photographs available for each Surveyor spacecraft, as well as objects photographed, were shown in Table 3-2.

Digitally Processed 35-mm Photography

The Surveyor digitally processed photography is available for all Surveyor spacecraft. The photographs are 35-mm first generation selected negatives produced after analog-to-digital conversion of data transmitted by the satellite. Negatives were produced by the Deblock and Register (D&R) program and by the Sine Wave Response Filter (SWRF) program and are on one reel of 35-mm microfilm. See Table 3-3 for the number of photographs processed for each mission.

The D&R program adjusted the analog-to-digital conversion output to a form more easily adaptable to processing operations. The data consist of 600 digital records written on magnetic tape representing 600 picture lines. Each record normally contains 684 characters corresponding to the picture elements in a line. This image was digitized only to produce the negatives.

The SWRF program was applied to the raw image and restored high-frequency data (fine detail in picture) in the horizontal direction along the camera scan lines and in the vertical direction. Pictures produced by the SWRF program are much sharper and show more detail, but are somewhat noisier than the original pictures.

The photographs include views of lunar surface rocks, craters, slopes, the horizon, and surface instruments.

Mosaic Negatives

These mosaic photographs are on 10.2- x 12.7-cm (4- x 5-in.) black and white negative film sheets. The mosaics were compiled from the 70-mm photographs and are available for all Surveyor missions. The number of mosaics available for each mission is found in Table 3-3.

Included in these data are analytical, improved, rectified, and spherical mosaics. Analytical mosaics were made by placing the pictures at their correct nominal location on a prepared grid without attempting to match images. Improved mosaics present a more coherent view of small areas of the panorama because their images were carefully matched. Rectified mosaics were made by transforming the image plane of the individual pictures to a plane other than that perpendicular to the line of sight of the camera. Spherical, semi-improved, and semi-enhanced mosaics were made on the inside of large hemispheres and appear similar to the improved mosaics. This process does not distort the panoramas, as does flat processing.

Regenerated 70-mm Photography

These regenerated photographs are available for Surveyor 3, 5, 6, and 7. They were enhanced by computer programs to reduce noise, streaks, and other distortions. This process generates film with a sharper image than that distinguishable from nonregenerated film. A masking process also makes these pictures more uniform than the original photographs. Correct TV identification is included on each frame. The data are on first generation 70-mm negative film.

Catalogs of TV Photographs

Catalogs of television photographs for Surveyor 1 and 5 contain most of the pictures transmitted by the spacecraft. Pictures of stars, special purpose photographs that required enlargements, and special purpose shadow surveys received by overseas Deep Space Network stations are not included.

The catalog for Surveyor 1 was prepared by NSSDC from analytical mosaics. Photographs used for focus ranging surveys, verification of camera parameters, or examination of small areas of interest are also included. These are situated separately on photographic plates without regard to location in azimuth or elevation. Individual frame data are also included.

The U.S. Geological Survey prepared the Surveyor 5 catalog from improved mosaics. Photographs of models of the surface areas shown in the mosaics are included, as well as basic cartographic data, individual frame data, and special purpose mosaics.

Both catalogs are available from NSSDC on microfiche. *The Atlas of Surveyor 5 Television Data* (NASA SP-341) is also available in hardcopy from the National Technical Information Service (NTIS) (N75-14665, $16.25).

Photographic Identification Information

The identifying information available for Surveyor photographs includes day of year; hour, minute, and second in UT; file number; survey number; azimuth; elevation; focus; iris setting; filter wheel setting; and lens focal length for each photograph. The data are ordered by time of transmission from the lunar surface.

Except for Surveyor 1 data, which are available on microfilm only, the identification information for each spacecraft is available on both 16-mm microfilm and on one 7-track, 556-bpi, mixed mode magnetic tape. The data are ordered by time. Surveyor 1 data exist to September 18, 1966, but are uncorrected after July 13, 1966.

Animated Sunset Sequence of Lunar First Day

This Surveyor 3, 16-mm movie film is an animated sequence of 121 wide-angle photographs of the lunar first day sunset and 9 narrow-angle photographs of twin projections that appeared on the horizon during the sequence. The sequence is shown in normal and slow motion and covers 1116 to 2055 UT on May 3, 1967. This 16-mm movie film, which runs 3½ min, is composed of negatives received from primary TV data.

Selected Mosaics

These Surveyor 5 survey panorama mosaics were processed to investigate surface detail. Compiled for interpretative work and included in the *Atlas of Surveyor 5 Television Data* (NASA SP-341), these mosaics consist of the best negatives available from the Jet Propulsion Laboratory. There are 173 10.2- x 12.7-cm (4- x 5-in.) negative film sheets of 201 improved (flat and spherical) and special purpose mosaics.

SOIL MECHANICS SURFACE SAMPLER

The soil mechanics surface sampler was carried on Surveyor 3 and 7 to provide data on the mechanical properties of the lunar surface. The sampler was designed to dig, scrape, and trench the lunar surface and to transport lunar surface material. Each operation was photographed following its completion because the TV and the sampler could not be operated simultaneously.

In addition to the information obtained by TV pictures, Surveyor 7 obtained motor current data. (Motor current data from Surveyor 3 could not be interpreted because of a telemetry anomaly.) The sampler on Surveyor 7 also was used to manipulate the alpha-scattering instrument. In addition, two horseshoe magnets were mounted on the scoop door for soil composition studies. Operations performed by the two samplers are listed in Table 3-5.

Table 3-5. Soil Mechanics Surface Sampler Experiment Performance

Operation	Surveyor 3	Surveyor 7
Bearing Tests	7	16
Depth	3.8 - 5 cm	20 - 24 cm
Trenching Operations	4	7
Depth	17.5 cm (max)	17.5 cm (max)
Impact Tests	13	2
Rocks Moved	1	4
Total Operational Time	18 h 22 min	36 h 21 min
Performance	good	flawless

Mounted below the TV camera, the sampler consisted primarily of a scoop approximately 12 cm long and 5 cm wide. The scoop consisted of a container, a sharpened blade, and an electrical motor to open and close the container. A small footpad connected to the scoop door presented a flat surface to the lunar surface.

The scoop could hold solid lunar material with an approximate diameter of 3.2 cm of granular material with a volume of 100 cm^3 at a maximum. The scoop rested on a pantograph arm that could be extended about 1.5 m or retracted close to the spacecraft motor drive. The arm could also be moved from an azimuth of +40° to -72° or be elevated 13 cm by motor drives. It could be dropped onto the lunar surface under the combined force that gravity and a spring provided.

The surface sampler surpassed operational requirements. When the alpha-scattering instrument on Surveyor 7 failed to deploy on the surface, the sampler freed it. The surface sampler also shaded the alpha scatterer and moved it for evaluation of several samples, as planned for this mission. For more details on this experiment and its scientific results, see *Jaffe and Steinbacher*, 1970, and *Jaffe*, 1969b.

Animated Field Sequence Mosaics

These Surveyor 3 mosaics have been combined to form an animated film sequence. The mosaics were produced from photographs transmitted April 27, 1967, between 0958 and 1030 UT during surface sampler trenching operations. The film sequence exhibits the crusting effects of the lunar surface material and is contained on one 16-mm movie film reel and has a running time of 2 min.

Surface Sampler Motor Current Data

These Surveyor 7 data consist of plots of surface sampler motor currents in amperes versus time. The plots cover three time periods: January 11-14, 19-20, and 20-22, 1968. They include retraction, lowering, elevation, and extension commands. The data are contained on one reel of 35-mm film. For more details and results from the surface sampler experiments, see *Jaffe*, 1971.

ALPHA-SCATTERING SURFACE ANALYZER EXPERIMENT

The alpha-scattering surface analyzer was flown on Surveyor 5, 6, and 7 and performed excellently during each mission. The instrument was designed to measure directly the abundances of the major lunar surface elements.

The instrumentation consisted of two parallel, but independent, charged-particle detector systems and six alpha sources (Curium 242) collimated to irradiate a 10-cm-diameter opening in the bottom of the instrument where the sample was located. One system, containing two sensors, detected the energy spectra of the alpha particles scattered from the lunar surface; the other system, containing four sensors, detected energy spectra of the protons produced via reactions (alpha and proton) in the surface material.

Each detector assembly was connected to a pulse-height analyzer. A digital electronics package, located in a compartment on the spacecraft, continuously telemetered signals to Earth whenever the experiment was operating. The spectra contained quantitative information on all major elements in the samples except for hydrogen and helium.

On Surveyor 5, the experiment accumulated data during the first and second lunar days; however, detector noise posed a problem in the reduction of data from the second day. The experiment functioned perfectly and returned high quality data during the first lunar day.

The Surveyor 6 analyzer obtained a total of 43 h of data. The first 30 h are chemical analysis data. The spacecraft hopping maneuver on November 17, 1967, caused the sensor head to turn upside down. Measurements then were obtained on solar protons and cosmic rays for 13 h.

On Surveyor 7, the experiment provided data accumulated from three sample measurements: (1) undisturbed local lunar surface, (2) a lunar rock, and (3) an extensively trenched area of the lunar surface. Data were obtained for 48 h during the first lunar day and for 34.5 h on the second lunar day. Articles that give more details of scientific results for this experiment are *Jaffe and Steinbacher*, 1970; *Jaffe*, 1969b; and *Turkevich et al.*, 1970.

Alpha-Scattering Data

Alpha-scattering surface analyzer experiment data held at NSSDC are the best obtained during mission operations for Surveyor 5, 6, and 7. The data include transit operations, alpha and proton data, all available commands sent to the spacecraft, and some engineering telemetry.

For Surveyor 5, the best data resulted from the second sample on the first lunar day, from September 9-23, 1967. Surveyor 6 data include stowed operations, background operations, and lunar sample analysis obtained from November 10-17, 1967, during the first lunar day. The sample measurements made during Surveyor 7 operations on the first lunar day, January 10-23, 1967, and on February 13 and February 18 of the second lunar day, are included on the tapes.

Surveyor 5 data are on three tapes, Surveyor 6 on one tape, and Surveyor 7 on two tapes. The tapes are 800-bpi, 7-track, binary magnetic tapes generated on an IBM 7094 computer. The data are blocked 500 words to a physical record. Engineering and command data are included with the alpha and proton science data. The data are merged, but can be separated.

REFERENCES/SOURCES

The following citations are annotated with A- and N-numbers where applicable. An A-number indicates those documents available from:

Technical Information Service
American Institute of Aeronautics
and Astronautics
750 Third Avenue
New York, NY 10017

N-numbers refer to documents available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

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4

THE LUNAR ORBITER PROGRAM

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Oblique view of Crater Copernicus taken by Lunar Orbiter 2. The distance from rim to rim (bottom to center) of the photograph is 90 km (56 mi), and the horizontal distance is 27 km (17 mi). The main central peaks are approximately 300 m (1000 ft) high. (L02-162H3)

N77-32132

THE LUNAR ORBITER PROGRAM

The Lunar Orbiter program consisted of five spacecraft missions launched between August 1966 and August 1967. The main purpose of the program was to locate smooth, level areas on the Moon's nearside and to confirm the areas as suitable for manned landing sites for the Apollo program. To accomplish this, photographic coverage at a ground resolution of 1 m was required. The area of interest was within 5° of the lunar equator between selenographic longitudes 45°E and 45°W (*Levin et al.*, 1968).

During the first three missions, 20 potential lunar landing sites, selected on the basis of Earth-based observations (resolution about 1000 m), were photographed from low-inclination and comparatively low-altitude orbits. Analysis of the photography indicated that nearly all Lunar Orbiter program objectives had been met. Eight promising sites were selected for manned landings with additional photography required for confirmation of five of these sites.

The fourth and fifth Lunar Orbiter missions were devoted to broader scientific objectives and were flown in polar orbits. Lunar Orbiter 4 photographed the entire nearside of the Moon from a high-altitude orbit (60- to 150-m resolution) and 95 percent of the farside, while Lunar Orbiter 5 completed the farside coverage. Lunar Orbiter 5 also acquired medium- and high-resolution (20 and 2 m, respectively) photography of 36 preselected areas containing features of interest and obtained the additional photography required for confirmation of the Apollo landing sites.

With the completion of the five Lunar Orbiter missions, 99 percent of the Moon was photographed with a resolution of 60 m or better, which is 10 times better resolution than the best observations from Earth.

Most of the photographs were acquired from a near-vertical mode, but some were acquired from an oblique mode, which produced some spectacular and unique views of the Moon. In general, the nearside was photographed under morning illumination. The farside coverage was obtained under evening illumination with the Sun's elevation between 10° and 30°.

The Lunar Orbiter spacecraft (Figure 4-1) weighed approximately 390 kg at launch, were 1.5 m in diameter, and were 2 m in length. Solar panels supplied the required power. The spacecraft were stabilized in a three-axis orientation by using the Sun and the star Canopus as primary references, and attitude control was maintained by gas thrusters. Comparative spacecraft information is given in Table 4-1.

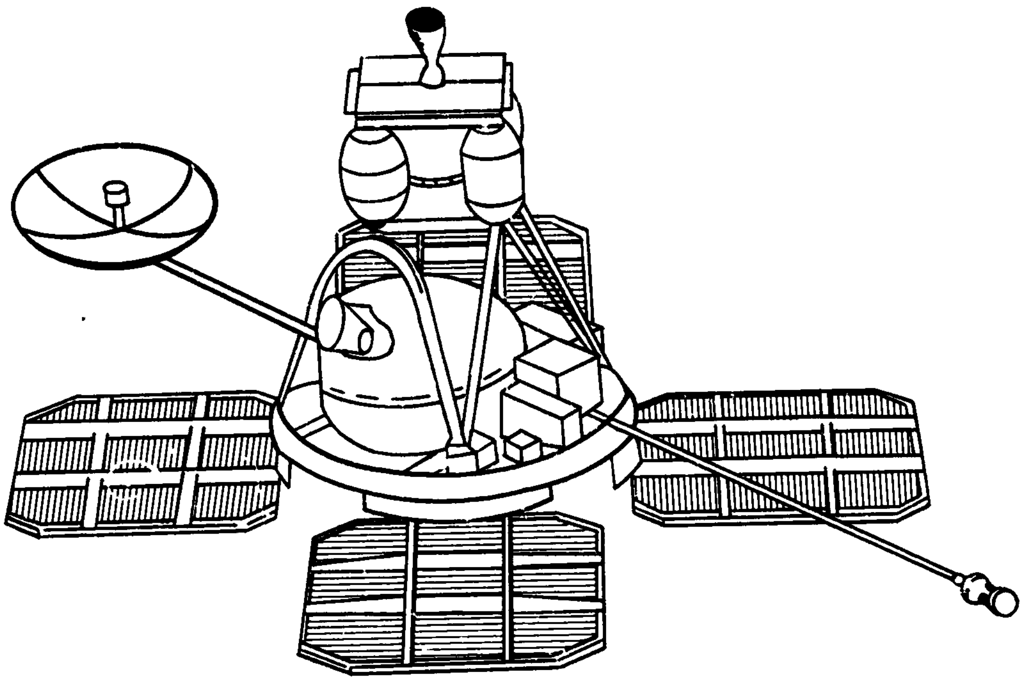

Figure 4-1. The Lunar Orbiter spacecraft.

In addition to the photographic data, tracking of the spacecraft during and following completion of the photographic data transmission provided selenodetic information. Micrometeoroid and radiation detectors also provided data. NSSDC holdings include data from the photographic, selenodetic, and micrometeoroid studies. These are described in detail in the following sections.

LUNAR PHOTOGRAPHIC STUDIES

The photographic system (*Broome*, 1967) included the spacecraft's photographic subsystem, the ground reconstruction equipment (GRE), and the communications system. The photographic system recorded a negative image on film that was developed and scanned on board to provide electrical signals for transmission to Deep Space Network stations. The video signals from the communications system were fed to the GRE, which reconverted these signals into photographic images; they were also recorded on magnetic tape.

Table 4-1. Lunar Orbiter Spacecraft Missions

Parameters	Mission Name				
	Lunar Orbiter 1	Lunar Orbiter 2	Lunar Orbiter 3	Lunar Orbiter 4	Lunar Orbiter 5
Launch Date	Aug.10,1966	Nov.6,1966	Feb.5,1967	May 4,1967	Aug.1,1967
Periselene (km) (minimum)	40.5	41	44	2668	97
Aposelene (km) (maximum)	1857	1871	1847	6151	6092
Inclination	12°	12°	21°	85.5°	85°
Period (h)	3.5	3.5	3.5	12	8.5 (initial) 3.0 (final)
Impact Coordinates	161°E 7°N	119.1°E 3°N	92.70°W 14.32°N	22°-30°W	83°W 2.79°S
Impact Date	Oct.29,1966	Oct.11,1967	Oct.10,1967	Oct.31,1967	Jan.31,1968

The photographic system contained a dual-lens camera, a film processing unit, a readout scanner, and film-handling apparatus. The two lens systems, one high resolution and one medium resolution, operated simultaneously, placing two discrete frame exposures on a common roll of 70-mm film. Each system operated at a fixed f/5.6 lens aperture at shutter speeds of 0.04, 0.02, or 0.01 s. High-resolution (HR) frames were exposed through a 610-mm narrow-angle lens and a focal plane shutter. The medium-resolution (MR) frames were exposed through an 80-mm wide-angle lens and a between-the-lens shutter.

The film supply was 79 m of unperforated 70-mm Kodak special high definition aerial film, type SO-243. This fine-grained film was capable of recording 450 lines/mm, which was well above the requirement of 76 lines/mm. The speed of the film was low enough that it was relatively insensitive to the spacecraft environmental radiation.

Image motion compensation to minimize smearing effects was achieved by an electric-optical sensor that viewed the surface and determined the rate of the spacecraft's velocity in relation to its altitude (V/H ratio). The sensor output was used to drive the camera film at the proper rate to insure image motion compensation. The sensor also controlled the spacing of exposures.

The axes of the two lenses were coincident so that the HR frame was centered within the MR frame. Exposure times were recorded in digital form alongside the MR frames. The smallest reading of time was 0.1 s. Data exposed on the frames included gray scale, resolution bars to permit later calibration and evaluation, readout operation markings, and framelet numbers for reassembly.

The Kodak Bimat diffusion transfer technique was used for onboard film processing. The film entered the processor and was laminated with the processing web which had a slightly damp gelatin layer. The web had been soaked in a monobath processing solution before being loaded into the spacecraft. The monobath solution developed the film to a negative image and transferred the undeveloped silver ions to the web where they were reduced to a positive image in 3.5 min (essentially the technique used for Polaroid Land black and white film). Coming off the processing drum, the negative and positive films separated; the negative film went through the drying section (no use was made of the positive) and then to the readout scanner. It was possible to read out selected portions of the film before photography was completed.

The readout scanner converted the photographic images into electrical signals by scanning the negative with a microscopic spot of high-intensity light from a special cathode-ray tube whose phosphor layer was coated on a rotating cylindrical metal anode. The scanner lens focused a 6.5-μm spot of light that traced a line 2.68 mm long on the film parallel to the film edge. One scan line (or raster) traverse required 22 s in which the electrical scan was repeated over 17,000 times. Before it started across the film in the reverse direction for the next trace, the film was moved 2.54 mm in the readout gate.

The resulting sections of film scanned in this manner, referred to as framelets (composed of 16,359 lines in a raster), are the basic units used for ground reassembly. A complete dual exposure scan took 43 min to complete: less than 10 min for the MR photographs of 26 framelets and less than 34 min for the HR photographs of 86 framelets.

A photomultiplier tube converted the intensity variations to an analog electrical voltage, and the readout system electronics added timing and synchronization pulses forming the composite video signal. Thus, it was possible to transmit continuous variations in density rather than the discrete steps associated with a digital system.

The video data coming from the photographic subsystem were recorded on magnetic tape and also were fed to the GRE where they were converted into intensity-modulated lines on the face of a cathode-ray tube. In a continuous-motion camera, 35-mm film was pulled past the image of this line and recorded each readout framelet at 7.18 times the spacecraft image size. This recording film was cut into 35-mm film framelets that were then reassembled into enlarged replicas of the original spacecraft frames.

Medium-resolution photographs were completely reassembled in one frame from over 26 35-mm framelets. Complete high-resolution photographs contain 86 framelets that were assembled in three separate frames with some overlap; therefore, a full HR photograph is composed of three frames. NSSDC reproductions of these frames contain the designations H for high resolution and M for medium resolution as part of the frame number. See Table 4-2 for comparative photographic mission information.

Table 4-2. Lunar Orbiter Photography

Parameters	Mission Name				
	Lunar Orbiter 1	Lunar Orbiter 2	Lunar Orbiter 3	Lunar Orbiter 4	Lunar Orbiter 5
Acquisition Dates	Aug.18-29, 1966	Nov.18-25, 1966	Feb.15-23, 1967	May 11-26, 1967	Aug.6-18, 1967
Quantity of Frames					
High Resolution	42	609	477	419	633
Medium Resolution	187	208	149	127	211
Altitude Range (km)					
Periselene	44	41	44	2,668	97
Aposelene	1,581	1,519	1,463	6,151	5,758
Framelet width (m) at Periselene*					
High Resolution	200	170	185	11,350	420
Medium Resolution	1,500	1,300	1,400	85,100	3,200
Highest Resolution† (m)					
Periselene	8§	1	1	58	2
Aposelene	275§	33	32	134	125

*Estimated from supporting data and verified in other documents.
†Highest resolution obtained by high-resolution system. Formula is R = H/46. (Medium resolution: R = H/5.75.)
§Medium-resolution system; high-resolution system malfunctioned early in photographic sequence, but did achieve resolutions of 1 m at periselene and 35 m at aposelene.

On the photographs, white reseau marks may be discerned that were pre-exposed on the film for geometrical and photogrammetrical recovery. Blemishes appear on some photographs in the form of lines (dropouts in the readout), sharp triangles (artifacts from film-processing equipment), and dots, circles, irregular marks, and freckles (Bimat processing faults). For more details on the camera system and the photography see the references listed at the end of this section.

Photographic Data

Various versions of the photographic data have been produced by Langley Research Center (LaRC), the Army Map Service (AMS, now Defense Mapping Agency Topographic Center), Eastman Kodak, and the Boeing Company. Computer corrections, enhancements, brightness, and other variations were applied to the original video output. For example, AMS used a Logetronic printer to compensate for large density variations; LaRC used video tape enhancement techniques to prepare prints of overexposed wide-angle photographs, and Kodak used a reassembly printer.

Of the types of photographic products generated, the quality of those from LaRC are so much better that LaRC data alone are announced here as available from NSSDC. They are summarized in Table 4-3 and are described individually in the following sections. Available supporting data are also listed in Table 4-3 and are described in the following sections. (The magnetic tape recordings of the imagery have not been deposited at NSSDC.) The NSSDC ID numbers, necessary for ordering photographic data, are listed in the Index to Available Data.

Table 4-3. Lunar Orbiter Photographic Data at NSSDC

Mission	Photographs			Supporting Data				
					NSSDC			
	Framelets (35-mm reels)	Frames	Microfiche Catalog Cards*	Boeing Magnetic Tapes*	Microfiche Cards*	Microfilm Reels*	Cal Tech Microfiche Cards*	Interim Site Calculations (16-mm reels)
Lunar Orbiter 1	39,000 (112)	229	15	1	12	1	9	9
Lunar Orbiter 2	32,690 (285)	817	15	1	12	1	9	12
Lunar Orbiter 3	19,050 (183)	626	15	1	12	1	9	15
Lunar Orbiter 4	18,090 (175)	546	15	1	12	1	9	6
Lunar Orbiter 5	50,066 (208)	844	15	1	12	1	9	8

*All missions on same tape, film reel, or set of microfiche cards.

NSSDC prepared a *Data Users Note* (DUN), *Lunar Orbiter Photographic Data* (NSSDC 69-05, June 1969), to provide information necessary for selection of Lunar Orbiter photography and guidance in interpreting the photographs. All photographic products (LaRC, Boeing, AMS, and Kodak) are described in this DUN and are available, if desired, from NSSDC. The DUN also describes the camera system and data reduction procedures. It provides useful tables and charts of the photographic coverage of the lunar surface by the Lunar Orbiters, quality charts, and a bibliography. A *Data Announcement Bulletin* (DAB), *Status of Availability of Lunar Orbiter TV Picture Data* (NSSDC/WDC-A-R&S 76-02), was published in February 1976 to update information on NSSDC data holdings. It is recommended that these publications be obtained from NSSDC before requesting Lunar Orbiter photographic data.

LaRC* First Generation 35-mm Framelets

First generation negative 35-mm film reels for each mission contain the individual framelets for each Lunar Orbiter photograph. These complete sets were produced by Langley Research Center from zero generation positives recorded by the ground reconstruction equipment at the ground receiving stations. These framelets are useful for a detailed analysis of lunar surface features.

LaRC Hand-Assembled Regenerated Frames

Complete sets of enhanced Lunar Orbiter photography, consisting of first generation negative 51- x 61-cm (20- x 24-in.) film sheets, were prepared by LaRC. The 35-mm framelets, assembled to make the film sheets, were produced from the original station video tapes by electronically processing the video signal prior to input to the ground reconstruction equipment (GRE).

LaRC used two enhancement procedures. One procedure involved varying the parameters of gain function, signal gain, and signal offset to optimize detail and contrast in the photographic data. The other procedure used an electronic mask to reduce the undesirable density gradients across the scan and framelet. Both procedures required point-by-point exposure adjustments.

The enhanced photographs generated from the GRE were 35-mm positive transparencies. These positive framelets were assembled in a 51- x 61-cm (20- x 24-in.) format from which contact negatives were made. One complete medium-resolution photograph (approximately 26 framelets) is contained on

*The abbreviation LRC appears on Langley Research Center data products and in NSSDC documentation prior to 1976.

one sheet, and one high-resolution photograph (approximately 86 framelets) requires three sheets. Because the photographs were controlled for surface detail, photometric studies are not recommended.

Microfiche Catalog of LaRC Photography

Enhanced Lunar Orbiter photography for each mission is contained on 10.2- x 15.2-cm (4- x 6-in.) microfiche cards. These cards were prepared by the California Institute of Technology (Cal Tech) from Langley Research Center positive film transparencies. Each card contains up to 60 numerically arranged images. In instances where a frame was not enhanced, "Frame Is Not Available" appears in the appropriate location. The primary use of this catalog is for selection purposes; however, the photography is good enough to be used for some scientific studies.

Boeing Company Revised Photographic Supporting Data

These supporting data for analysis of the Lunar Orbiter mission photography were compiled by the Boeing Company and generated in January 1970. This version is the most accurate and complete photographic supporting data available. In addition to items extracted for the NSSDC photographic supporting data (see below), detailed camera and spacecraft parameters are included. These data are on one Univac 1108 computer-processed, time-ordered, binary, 7-track, 556-bpi tape. NSSDC also holds a duplicate tape processed on an IBM 7094 computer.

Photographic Supporting Data

Photographic supporting data, necessary for the analysis of the Lunar Orbiter photographs, were selected from the Boeing Company's most recent (1970) version of supporting data. Both NSSDC and the California Institute of Technology (Cal Tech) have prepared these data.

The NSSDC and Cal Tech data are both ordered by mission and frame number and include the time of each exposure, spacecraft altitude, the spacecraft north deviation, photograph illumination parameters, latitude and longitude of the principal ground point, and corner coordinates and side lengths of each image area.

The NSSDC data also include the spacecraft swing angle, tilt azimuth, latitude, and longitude, as well as the photograph tilt distance. In addition, NSSDC prepared two brief listings: position parameters and illumination parameters, which are also ordered by mission and frame number. The NSSDC data were published in "Lunar Orbiter Supporting Data" (NSSDC 71-13, May 1971) and are available on 16-mm microfilm and on microfiche cards.

The Cal Tech data provide the forward overlap ratio, the resolution constant (highest resolution for the frame), and the magnitude of the camera axis (spacecraft to surface). These parameters are not in the NSSDC data. When extracting the data from the Boeing tapes, where more than one record existed, the better data were extracted by Cal Tech. The Cal Tech data are available on nine microfiche cards and will be supplied to requesters unless NSSDC data are specified.

Interim Photograph-Site Accuracy Calculations

These data are the results of interim calculations made by the Boeing Company to produce final report documents of photograph-site accuracy analysis. The data appear on 16-mm film reels. The calculations in the analysis through the 10th harmonic were made for various models using data reported from various stations, passes, and iterations. Some of the reels contain plots of residuals versus time for various stations, passes, iterations, sequences, and models.

SELENODESY EXPERIMENT

The instrumentation for the selenodesy experiment included a power source, an omnidirectional antenna, and a transponder to obtain information for determining the gravitational field and physical properties of the Moon. High-frequency radio signals were received by the spacecraft from Earth tracking stations and retransmitted to the stations to provide Doppler frequency measurements (range rate) and propagation times (range). The telemetry data were processed in real time on an IBM 7044 computer in conjunction with an IBM 7094 computer. They were then displayed on 100-wpm teletype machines, X-Y plotters, and bulk printers for analysis.

Data coverage was continuous while the spacecraft was visible from Earth. Information was acquired during the cislunar phase and the first several orbits of the Moon as well as during the extended mission (from the end of the photographic mission to lunar impact). Doppler, ranging, hour angle point, and declination angle point data were accumulated during tracking and are contained in the data tapes available from NSSDC. The quality of recorded data ranges from good to excellent.

Selenodesy Experiment Data

The magnetic tapes containing selenodesy data include Doppler, ranging, hour angle point, and declination point information. The tapes available from NSSDC are summarized in Table 4-4. See the Index to Available Data to obtain the correct NSSDC ID numbers that are necessary when ordering these data.

Table 4-4. Selenodesy Data Tapes at NSSDC

Mission and Time Period	Tracking Data Processor Raw Data Tapes		Orbit Determination Program Modified Data Tapes	
	Blocked	Unblocked	Blocked	Unblocked
Lunar Orbiter 1 Aug. 10 - Oct. 28, 1966	1	5	1	7
Lunar Orbiter 2 Nov. 6, 1966 - Oct. 11, 1967	1	7	1	10
Lunar Orbiter 3 Feb. 5 - Oct. 9, 1967	1	6	1	11
Lunar Orbiter 4 May 4 - July 11, 1967	1	5	1	8
Lunar Orbiter 5 Aug. 1, 1967 - Jan. 31, 1968	1	7	1	9

The Tracking Data Processor tapes contain the data in an essentially raw form. The data were converted to a common system of units, oriented to time and station, and checked for authenticity by the Jet Propulsion Laboratory (JPL). These JPL tapes are available in an unblocked format. The data from these tapes were combined and blocked by NSSDC to produce one tape per mission of blocked raw data.

Modified selenodesy data tapes were created at JPL by processing the raw data with the Orbit Data Generator (ODG) program to produce the Orbit Determination Program (ODP) file. The raw data were modified by stripping the Doppler bias, correcting the angular data, associating frequency with the Doppler bias, and labeling the time blocks. These JPL tapes are available in an unblocked format. NSSDC combined and blocked the data from these tapes to produce one tape per mission of blocked modified data.

The selenodesy tapes, both blocked and unblocked, are 7-track, 556-bpi, binary tapes created on an IBM 7094 computer.

METEOROID EXPERIMENT

Twenty pressurized cell detectors of 0.025-mm thick beryllium-copper provided direct measurements of the rate of meteoroid penetration in the near-lunar environment. The detectors were arranged on the tank deck periphery. The detector walls were 0.00127 cm thick. Each cell was a helium-pressurized semicylinder with a pressure-sensitive microswitch that remained closed until puncture of the cell's surface released the pressure. Meteoroid hits were recorded by discrete telemetry channel state changes. The total exposed area of the detectors was 0.282 m^2, and the effective area after shielding by other components was 0.186 m^2.

Micrometeoroid Penetration Data

Telemetry data obtained during the five Lunar Orbiter missions indicated that micrometeoroid penetrations occurred on all missions except Lunar Orbiter 1. Telemetry data were obtained until impact (see Table 4-1) on all missions except Lunar Orbiter 4, which ceased communications on July 17, 1967. The following list gives hit information and the time period when hit data were acquired on each Lunar Orbiter mission.

Mission	Hits	Time Period
Lunar Orbiter 1	0	Aug. 10 - Sept. 14, 1966
Lunar Orbiter 2	10	Nov. 13, 1966 - Sept. 24, 1967
Lunar Orbiter 3	4	Mar. 20 - Sept. 24, 1967
Lunar Orbiter 4	2	May 10 - May 19, 1967
Lunar Orbiter 5	6	Aug. 7, 1967 - Jan. 21, 1968

A summary of micrometeoroid data from the Lunar Orbiter missions is contained in *Lunar Orbiter Meteoroid Experiment: Description and Results from Five Spacecraft* by G. W. Grew and C. A. Gurtler (NASA TN D-6266, June 1971). The results of the Lunar Orbiter mission data are compared with the Earth-orbiting Explorer 16 and 23 mission results for similar detectors. This document is available from NSSDC on one microfiche card.

REFERENCES/SOURCES

The following citations are annotated with A- and N-numbers where applicable. An A-number indicates those documents available from:

Technical Information Service
American Institute of Aeronautics
and Astronautics
750 Third Avenue
New York, NY 10017

LUNAR ORBITER

N-numbers refer to documents available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

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"Lunar Orbiter 1 - Photography," Boeing Co., NASA CR-847, August 1967. (N67-32334)

"Lunar Orbiter 2 Photographic Mission Summary," Boeing Co., NASA CR-883, October 1967. (N67-38369)

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"Lunar Orbiter 3 Photographic Mission Summary," Boeing Co., NASA CR-1069, May 1968. (N68-24738)

"Lunar Orbiter 3 - Photography," Boeing Co., NASA CR-984, February 1968. (N68-15725)

"Lunar Orbiter 4 Photographic Mission Summary," Boeing Co., NASA CR-1054, June 1968. (N68-26814)

"Lunar Orbiter 4 - Photography," Boeing Co., NASA CR-1093, July 1968. (N68-28275)

"Lunar Orbiter 5 Photographic Mission Summary," Boeing Co., NASA CR-1095, July 1968. (N68-28891)

"Lunar Orbiter 5 - Photography," Boeing Co., NASA CR-1094, June 1968. (N68-28202)

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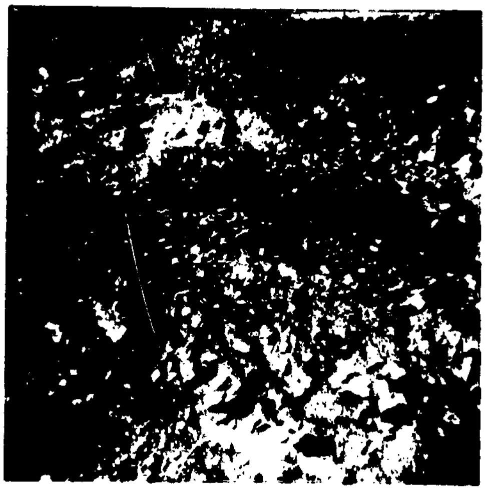
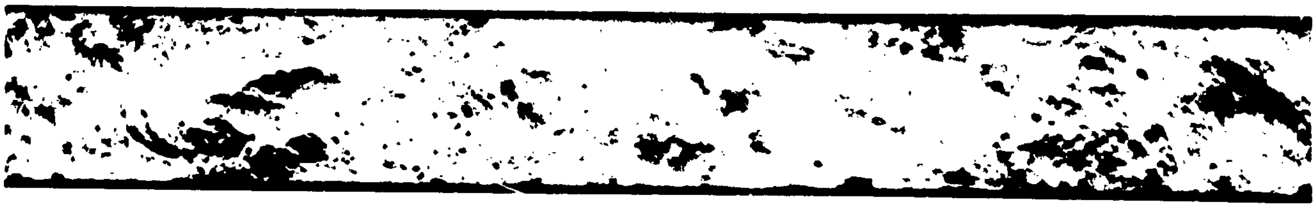
5

THE APOLLO PROGRAM





Apollo 15 70-mm Hasselblad photograph (left) with 500-mm focal length lens on the lunar surface. Taken toward the western wall (>25° slope) of Hadley Rille, 20 m of layered outcrop of the Weaver formation is visible as is fracturing of the lava. (AS15-84-11250)

Apollo 17 70-mm Hasselblad photograph (right) with 80-mm focal length lens from orbit. Crater Taruntius (60 km) appears in the center with Crater Cameron on its rim. At bottom is Glaisher (10 km). (AS17-149-22792)

Apollo 16 panoramic photograph of the lunar farside. Large crater at left is King Crater with Y-shaped central peak complex. (AS16-4998)

N77-32133

THE APOLLO PROGRAM

The Apollo program was designed to land men on the Moon and return them safely to Earth. The earlier spacecraft in the program were test vehicles that evolved in complexity and demonstrated the spaceworthiness of the launching vehicle, the Command Module (CM), the Service Module (SM), and the Lunar Module (LM). (The CM and SM, when referred to together, are identified as CSM.) The Apollo 7 was the first manned flight of the program and was an Earth-orbiting mission as was Apollo 9, which tested the performance of the Lunar Module. These missions are not discussed in this *Catalog*.

The Apollo lunar missions were informally divided into series, each series having similar spacecraft configurations, number of experiments, and complexity of tasks. Specific information on these missions is given in Table 5-1.

The "G" series spacecraft, Apollo 8 and 10, were designed to test the CM and LM components while orbiting in the vicinity of the Moon. Apollo 13 was also designated a G-series mission because its mission was limited to lunar orbit. Apollo 8 was the first manned mission to the Moon and consisted of only the CM. On Apollo 10, the CM, SM [which housed the scientific instrument module (SIM)], and LM were included. Tasks required the LM to separate, descend to within 15 km of the lunar surface, and return to the CSM and dock. Apollo 13, originally planned as a landing mission, was reassigned a lunar orbiting mission when a malfunction prevented lunar landing. Apollo 13 orbited the Moon and photographed the lunar surface as did Apollo 8 and 10. On the Apollo 10 and 13 missions, the LM and CSM combination craft returned to the vicinity of the Earth, the LM and SM were jettisoned prior to reentry, and the CM returned to Earth. In the other missions, the LM was jettisoned in the vicinity of the Moon prior to transearth coast.

The first three landing missions were designated the "H" series: Apollo 11, 12, and 14. These spacecraft were almost three times heavier than the G-series spacecraft. On these missions, two astronauts landed on the Moon in the LM, while the third astronaut remained in the orbiting CSM performing experiments. With each mission, surface stay time and life support facilities were considerably extended. Mobility of the astronauts was limited to within 100 m of the LM on Apollo 11 and to within 1.5 km on Apollo 12 and 14.

The complexity of experiments and tasks to be performed on the surface and in the CSM also increased with each mission. An experiment package was carried to the lunar surface. The package was known as the Apollo lunar surface experiment package (ALSEP) on Apollo 12 and 14 through 17 and known as the early Apollo surface experiments package (EASEP) on Apollo 11. Some of the surface experiments, such as sample collection, soil mechanics, and

Table 5-1. Apollo Lunar Missions

Apollo Series and Spacecraft Mission	No. of Experiments	Crew	Total Mission Time Period	Weight (kg)	Orbit Period (min)
SERIES G					
Apollo 8		Borman (CDR)	Dec. 21 - 27, 1968	9,979	
Command Service		Lovell			
Module	1	Anders			88
Apollo 10		Stafford (CDR)	May 18 - 26, 1969	9,979	
Command Service					
Module	1	Young (CMP)			88
Lunar Module		Cernan (LMP)			
Apollo 13		Lovell (CDR)	April 11 - 17, 1970	~29,000	
Command Service		Swigert (CMP)			
Module	1	Haise (LMP)			88
SERIES H					
Apollo 11		Armstrong (CDR)	July 16 - 24, 1969	28,860	
Command Service					
Module	7	Collins (CMP)			88
Lunar Module	5	Aldrin (LMP)			
Apollo 12		Conrad (CDR)	Nov. 14 - 24, 1969	28,850	
Command Service					
Module	12	Gordon (CMP)			88
Lunar Module	10	Bean (LMP)			
Apollo 14		Shepard (CDR)	Jan. 31 - Feb. 9, 1971	29,290	
Command Service					
Module	7	Roosa (CMP)			117
Lunar Module	12	Mitchell (LMP)			
SERIES J					
Apollo 15		Scott (CDR)	July 26 - Aug. 7, 1971	57,760	
Command Service					
Module	14	Worden (CMP)			119
Lunar Module	12	Irwin (LMP)			
Subsatellite	3		Aug. 4, 1971 - Jan. 1973	41	120
Apollo 16		Young (CDR)	Apr. 16 - 27, 1972	48,606	
Command Service					
Module	15	Mattingly (CMP)			120
Lunar Module	11	Duke (LMP)			
Subsatellite	3		Apr. 24 - May 29, 1972	36	120
Apollo 17		Cernan (CDR)	Dec. 7 - 19, 1972	48,606	
Command Service					
Module	11	Evans (CMP)			119
Lunar Module	14	Schmitt (LMP)			

solar wind, were conducted on the surface and returned to Earth, while other instrumented experiments were left on the surface and continued to acquire data. Further discussion of these experiments is contained in the section on Lunar Surface Experiments.

Table 5-1. (concluded)

Orbit Inclination	Periselene (km)	Aposelene (km)	Landing Site Coordinates (area)	Lunar Surface Time
12°	110	112		
12°	100 15	123 60		
1.25°	106	389		
1.5°	100	123	23.49°E, 0.67°N (Mare Tranquillitatis)	July 20 - 21, 1969
1.25°	100	123	23.45°W, 2.94°S (Oceanus Procellarum, near Surveyor 3)	Nov. 19 - 20, 1969
14°	100	123	17.4592°W, 3.6707°S (near Fra Mauro)	Feb. 5 - 6, 1971
26° 29°	90 102	115 141	3.6550°E, 26.1090°N (Apennine Mts. & Hadley Rille)	July 30 - Aug. 2, 1971
12° 151°	94 103.5	123 136	16°E, 9°S (Descartes region)	Apr. 21 - 24, 1972
23°	100	130	30.80°E, 20.1667°N (near Littrow & Taurus Mts.)	Dec. 11 - 14, 1972

The final Apollo missions, Apollo 15, 16, and 17, comprised the "J" series. These spacecraft were twice as heavy as the H-series spacecraft and carried more equipment. Figure 5-1 shows the Apollo J-series spacecraft components. In addition to the ALSEP, the lunar roving vehicle (LRV) was carried on the

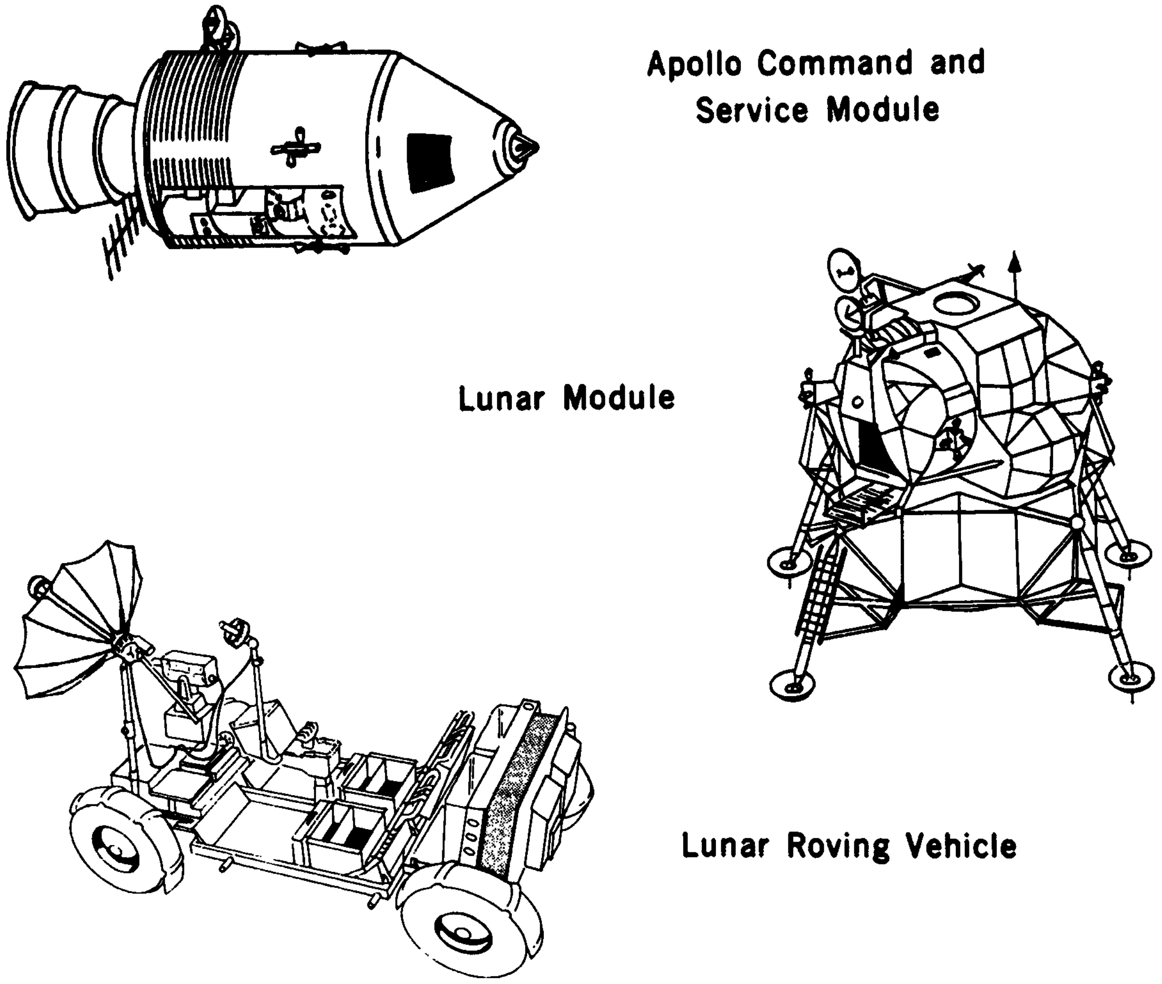


Figure 5-1. Apollo J-series spacecraft components: Apollo Command and Service Module (CSM), Lunar Module (LM), and Lunar Roving Vehicle (LRV).

LM and enabled the astronauts to drive on the lunar surface, which extended their range of activity to within a 3.5-km radius of the LM. The stay time on the surface was extended, and the number of deployed experiments was increased. On Apollo 15 and 16, subsatellites (SSs) were carried in the SIM and released to orbit the Moon. (See *Preliminary Science Reports* for each mission for more details on experiments. These are included in the References/Sources section.)

For all of the landing missions, the LM lifted off the lunar surface and rendezvoused with the CSM. After docking, the astronauts reentered the

CM, and the samples and equipment were transferred. The LM was jettisoned and crashed on the lunar surface prior to transearth coast. The CSM returned to the vicinity of the Earth, the SM was jettisoned, and the CM reentered the Earth's atmosphere and splashed down.

COMMAND MODULE AND SERVICE MODULE EXPERIMENTS

Orbital science experiments and science photography were performed on the Apollo missions during lunar orbit. An S-band transponder that tracked the spacecraft provided the data that were used to gain information on lunar gravitational fields; a bistatic radar experiment determined lunar properties; a gamma-ray spectrometer provided data for geochemical mapping of the surface; an X-ray fluorescence experiment provided information for surface composition mapping; an alpha particle spectrometer determined the lunar surface radioactivity evolution; a mass spectrometer obtained composition data; a far UV spectrometer measured radiation intensity; and a lunar sounder experiment was used for surface and shallow subsurface mapping purposes. These experiments are described following the photographic experiment sections.

Several types of cameras were used during the Apollo missions to perform the photography experiments, and these cameras are listed in Table 5-2. The Hasselblad, Maurer, and TV cameras were used on the CM and on the lunar surface; the Hycon and Nikon were used only on the CM; the closeup stereoscopic camera and the far UV camera/spectrograph (Schmidt camera) were used only on the lunar surface; and the panoramic camera and the mapping

Table 5-2. Cameras Used for Photography Experiments

Mission	Hasselblad	Maurer	Stereoscopic	Hycon	Nikon	TV	Far UV Camera/ Spectrograph*	Mapping Camera System	Panoramic
Apollo 8	X	X							
Apollo 10	X	X							
Apollo 11	X	X	X						
Apollo 12	X	X	X						
Apollo 13	X	X							
Apollo 14	X	X	X	X					
Apollo 15	X	X			X	X		X	X
Apollo 16	X	X			X	X	X	X	X
Apollo 17	X	X			X	X		X	X

*These data are described in the Lunar Surface Experiment section.

camera system (which includes the stellar camera and the laser altimeter) were used in the SM. Because of the overlapping coverage, discussion of the lunar surface and SM photography will be included in this section, with the exception of the far UV camera/spectrograph.

The objectives of the photography experiments in the Command Module were to obtain coverage of areas of geologic interest; near-terminator areas; areas not previously photographed; multispectral, vertical, and oblique stereo strips of nearside and farside regions; areas in earthshine; solar corona; zodiacal light; and to perform various maneuvers for future exploration and training purposes.

Lunar surface photographic objectives were to obtain metric and stereo photographs of emplaced experiments and their operation and of geologic samples and their surrounding areas; full panoramas of the landing site; motion pictures of the LRV (missions 16 and 17); and LM descent and ascent sequences.

The Service Module photographic objectives were (1) to obtain photographs of the lunar surface, stellar photographs, and laser altimeter data simultaneously and (2) to obtain panoramic photographs of the lunar surface with stereoscopic and monoscopic coverage.

In the following sections, the cameras and their photographic products available from NSSDC are discussed followed by a discussion of the orbiting science experiments. NSSDC ID numbers, necessary when ordering these data, are provided in the Index to Available Data. To order Apollo photographic data, it is recommended that the appropriate *Data Users Note* (DUN) or *Photographic Data Package* be acquired. These documents are listed on the order form. They were prepared by NSSDC at the completion of each Apollo mission and contain descriptions of the cameras and index maps. For the earlier missions, frame numbers and image descriptions are included, but for Apollo 15, 16, and 17, this information is obtained by ordering photographic indexes as described in the following sections. Earth photographs are not held at NSSDC, but can be obtained from the Earth Resources Observation Systems (EROS) Data Center.

U.S. Department of the Interior
U.S. Geological Survey
EROS Data Center
Sioux Falls, South Dakota 57198

HASSELBLAD 70-mm PHOTOGRAPHY

Hasselblad 70-mm cameras were carried on all the Apollo spacecraft. Two were used on Apollo 8, 10, and 13; three on Apollo 14, 15, 16, and 17; and four were on Apollo 11 and 12. Hasselblad camera settings and ranges are shown in Table 5-3.

Table 5-3. Hasselblad Camera Settings and Ranges

Film Magazine Capacity: Black and white - 190 frames; Color - thin base - 160 frames; Color - standard base - 100 frames						
Focal Length (mm)	38	60	80	105 (UV)	250	500
Focus (m)	0.5 - ∞	0.9 - ∞	1 - ∞	∞	2.6 - ∞	8.5 - ∞
Aperture		f/5.6 - f/22	f/2.8 - f/22	f/4.3 - f/8	f/5.6 - f/45	f/8 - f/64
Shutter Speed (s)	1 - 1/500	1 - 1/500	1 - 1/500	20 - 1/500	1 - 1/500	1 - 1/500
Field of View						
Side	71.7°	49.2°	37.9°	29.4°	12.5°	6.2°
Diagonal	91.1°	66°	51.8°	41.0°	17.6°	8.8°

Two Hasselblad cameras were used in the CM on all missions. They were normally fitted with an 80-mm focal length, f/2.8 Zeiss planar lens. The cameras also used a bayonet-mount, 250-mm lens for long distance Earth and Moon photography. On Apollo 15, 16, and 17 missions, a 105-mm focal length, f/4.3 Zeiss UV Sonnar lens was fitted to the camera for UV photographs. For these photographs, the camera was aimed through a CM window that had an annealed-fused silica covering to prevent blockage of UV radiation.

Generally, two Hasselblad cameras were carried in the LM, and coverage on the lunar surface was acquired with 60-mm focal length lenses. A 500-mm lens was also used on Apollo 15, 16, and 17, usually with black and white film, to photograph distant surface features, the CSM in orbit, and earthrise. The cameras were handheld and also could be bracket-mounted on the astronaut's environmental control unit or on the LRV for extravehicular activity (EVA) photography. The 500-mm lens was also used for CM photography on Apollo 12 and 14 through 17, and a 38-mm lens was available on the Apollo 11 mission.

Both color and black and white film were used. Color film included SO-368 (medium speed), SO-164, SO-168, and SO-174. Black and white film included 2485 (very high speed) for orbital photography and 3400 and 3401 for surface photography. Figure 5-2 is a sample Hasselblad photograph obtained on the Apollo 15 mission.

The Hasselblad cameras were also used to perform the multispectral photography experiment on Apollo 12. Four Hasselblad cameras were each fitted

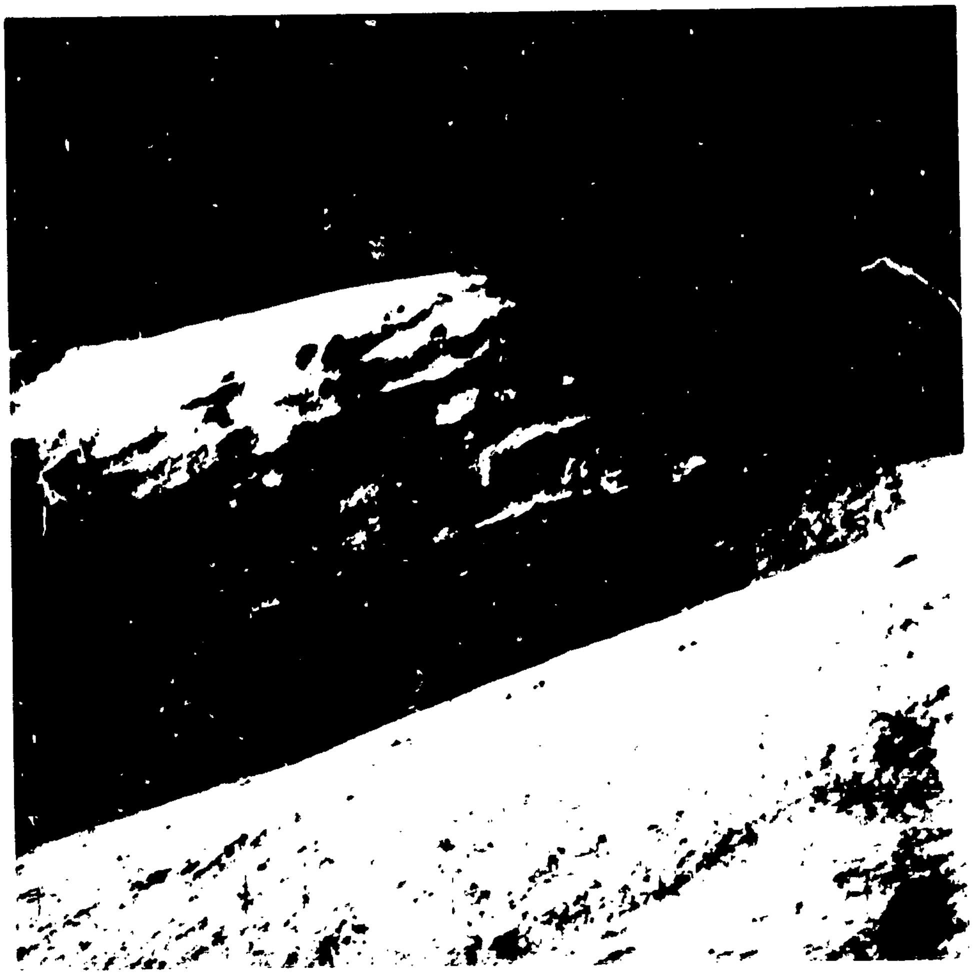


Figure 5-2. Sample Hasselblad photograph (enlarged 2 times) obtained near the Apollo 15 landing site with the 500-mm lens showing the layering in the Silver Spur mountain in the Apennines region. (Apollo 15: AS15-84-011250)

with a different filter: neutral, blue, red, and green. Using infrared black and white film type SO-246 with the black filter and black and white film type 3401 with the other filters, the photographs were simultaneously exposed. These pictures provided stereo strips of potential lunar landing sites.

Hasselblad Photography Data

The Hasselblad camera photographic products available from NSSDC are listed in Table 5-4. The NSSDC ID numbers, necessary for ordering these data, are

Table 5-4. Hasselblad 70-mm Photography Products at NSSDC

Mission	Photographs		Photographic Catalogs			Photography Indexes		Supporting Data to LAC Area on Magnetic Tape	Panoramic Mosaics		Multispectral Photographs
			Microfiche Cards		Microfilm Reels	Microfiche Cards	Microfilm Reels				
	B/W	Color	B/W	Color					B/W	Color	
Apollo 8	588*	276	11	5				2			
Apollo 10	1021*	298	19	[illegible]				2			
Apollo 11	810*	549	13	11				2			
Apollo 12	1021*	556	16	17				2	15		142
Apollo 13	95*	489		11§				2			
Apollo 14	815*	519	16§	10				2	8	2	
Apollo 15	2410*	1117	40†† (Cal Tech) 50†† (NSSDC)		1	6	1		55**	21	
Apollo 16	1165† 104§§	1499	49†† (Cal Tech) 60†† (NSSDC)		2	4	1				
Apollo 17	1193†	2040	43†† (Cal Tech) 74†† (NSSDC)		2	5	1				

*Each processed by both the logetronic and the photometric methods.
†Photometric processing only.
§Primarily color, some black and white included.
**Three microfiche catalog cards also available.
§§Onboard cabin photography of particles in fluid.
††Black and white microfiche copies of color and black and white photography.

listed in the Index to Available Data. However, because frame numbers are also necessary for ordering data, it is recommended that the appropriate *Data Users Note* or *Photographic Data Package* (listed on the order form) be obtained prior to ordering photographs.

Hasselblad 70-mm Photographs

All photographs from the Hasselblad cameras on the Apollo lunar missions are available from NSSDC. (Cabin and Earth photographs were removed from the film available from NSSDC, but are available from EROS.) These data include both the color and the black and white photographs obtained on the lunar surface and those obtained during CM activities. Each frame is identified by an alphanumeric code, for example, AS16-118-19017. The first two letters, AS, stand for Apollo satellite, the next two numbers are the mission, the following three numbers are the magazine, and the last five are the frame number. Therefore, AS16-118-19017 indicates Apollo mission 16, magazine 118, Hasselblad frame 19017.

Photometric and logetronic processes were used by the Photographic Technology Laboratory at the Johnson Space Center (JSC) to process the black and white film. The photometric process was done on a Niagara printer, and these renditions are the ones to be used for photometric and photogrammetric (albedo) analyses. The logetronic process used an SP-1070 contact printer with exposure control and dodging techniques. These techniques improve the overall contrast but slightly degrade the resolution. (See *Borgeson and Batson*, 1969, for photogrammetric calibration of Apollo cameras.)

The Hasselblad photographs are available as negatives, film transparencies, and contact and enlarged prints. The photographs generally are very good, but occasionally there are frames that are light struck, over or underexposed, doubly exposed, or show motion. Figure 5-3 is a sample Hasselblad 70-mm photograph.

Photographic Catalogs

A complete set of 70-mm Hasselblad photographs is available on microfiche cards for catalog purposes. (Note in the Index to Available Data that for missions 8, 10, 12, and 14 the color and black and white microfiche sets have been given different NSSDC ID numbers. Color and black and white appear together in the Apollo 13 microfiche catalog, and for missions 15 through 17 all microfiche is black and white for selection of both color and black and white photographs.) Although these sets are intended for catalog purposes, the quality of the photography is often good enough to permit limited scientific study. The microfiche prepared by the California

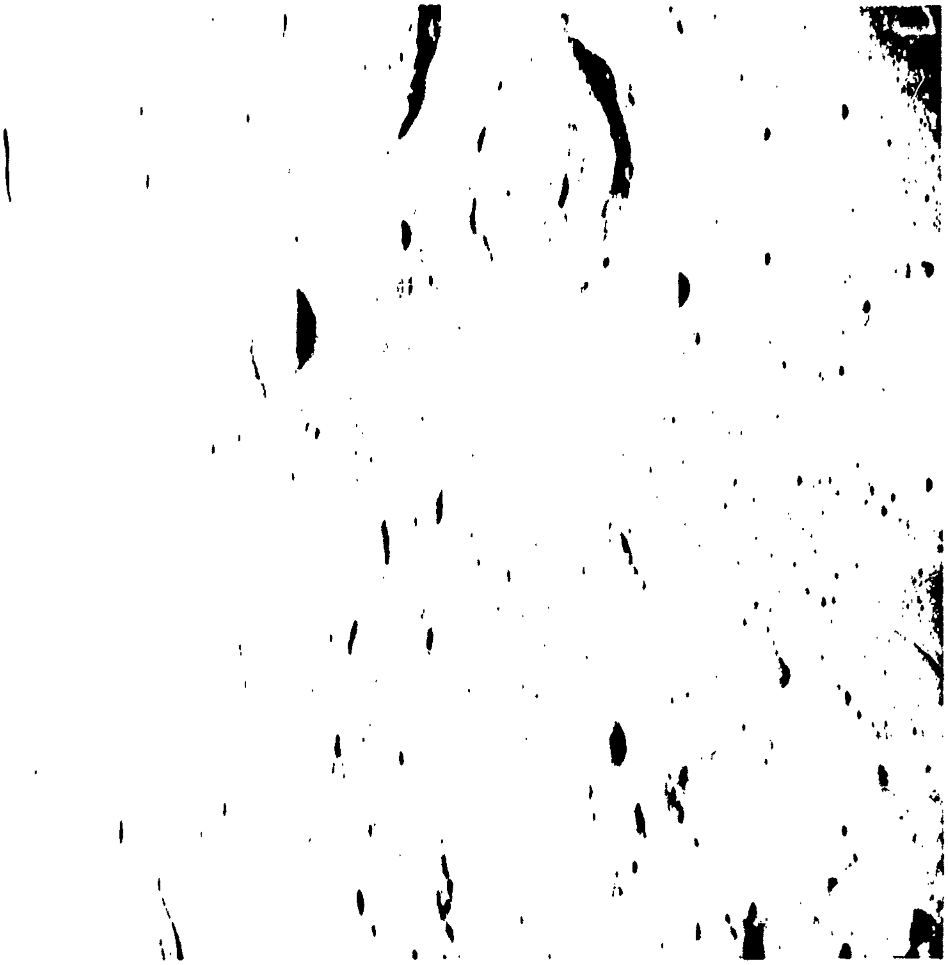


Figure 5-3. Sample Hasselblad photograph (enlarged 2 times) showing area west of the Apollo 11 landing site. Largest crater is Sabine with Hypatia graben rilles below. (Apollo 10: AS10-32-4759)

Institute of Technology (Cal Tech) for missions 15, 16, and 17 have some illegible frame numbers, while those prepared by NSSDC are legible. The latter should be used for ordering reproductions.

For missions 15, 16, and 17, catalogs are also available on 16-mm microfilm. Again, the quality is sufficiently good in some cases to permit limited scientific studies.

Photography Indexes

Complete sets of 70-mm Hasselblad photography indexes are available on microfiche and on 16-mm microfilm for Apollo 15, 16, and 17 missions. Information included is: frame number, EVA surface activity, orbital revolution number, lens focal length, altitude, principal point longitude and latitude, camera tilt and azimuth, Sun elevation, and description of the photographic content. At the top of each page, the magazine designations and film type are given. The indexes are arranged both by frame number and by longitude in increments of 10°. For some missions, these indexes are divided by surface and orbital photography.

Supporting Data by LAC Areas

These supporting data for the Hasselblad photographs correlate to the appropriate area defined by the Lunar Aeronautical Charts (LAC) series of maps issued by the U.S. Geological Survey. Mission number, orbital revolution number, magazine and frame numbers, ground-elapsed time (GET), Greenwhich mean time (GMT) (which is universal time), camera parameters, and descriptions are included. These data are on magnetic tape prepared by the Lockheed Electronics Company, Inc., and are available from NSSDC for Apollo 8 and Apollo 10 through 14. They were also published in "Lunsort List - Apollo Photographic Data by LAC Area," LEC/HASD 640-TR-025, October 1971.

Panoramic Mosaics

These composite mosaics are available for Apollo 12, 14, and 15. They provide panoramic views of the lunar surface in the vicinity of the Apollo landing sites. They were constructed from adjoining frames of the 70-mm Hasselblad photography and reproduced as 10.2- x 12.7-cm (4- x 5-in.) negatives and positives. The Apollo 12 panoramas are on 20.3- x 25.4-cm (8- x 10-in.) film. Figure 5-4 is a sample mosaic from the Apollo 12 mission. Information on the film gives EVA traverse stop number and cardinal direction faced. In addition, the Apollo 15 mosaics are also available on three microfiche cards that were prepared for catalog purposes.

Multispectral Photographs

Four Hasselblad cameras were used on Apollo 12 to obtain 70-mm photographs of the lunar surface. Three cameras used black and white 3401 film and had blue, red, and green filters, respectively, and the fourth camera used IRBWSO-246 film with a neutral filter. The cameras had the same settings and ranges as the 80-mm lens (see Table 5-3) and were mounted in a ring bracket perpendicular to the CM hatch window ±5° from nadir. They were aimed and operated simultaneously.

Figure 5-4. Sample Hasselblad panoramic mosaic showing flatness of lunar surface at the Apollo 12 landing site. Boulder in foreground is ~20 to 22 cm (8 to 9 in.) in diameter. (Apollo 12: AS12-49-7259 through 7262)

These cameras were used to photograph lunar surface color variations for geologic mapping and to photograph potential lunar landing sites. The photographs were correlated with spectral reflectance of returned samples for composition determination and were used to make comparative studies of lunar reflectance variation and wavelengths.

These photographs were supplied to NSSDC by the Photographic Technology Laboratory at JSC. Four cameras provided 126 simultaneous views, and three of the cameras obtained an additional 16 frames. The photographs are contained on one magazine of film.

MAURER 16-mm MOVIE CAMERA

Maurer 16-mm movie cameras were carried on all Apollo missions on both the CM and the LM. On the CM, the camera could be mounted on a boresight bracket. These cameras were used to record spacecraft maneuvers such as docking, rendezvous, and jettison of the SM. They also obtained landmark tracking photography, gegenschein and contamination experiment photography, Earth photography, cloud patterns, and the EVA during transearth coast. The camera was handheld for cabin footage. (Cabin and Earth photography have been removed from the film available from NSSDC, but are available from EROS.)

On the LM, the Maurer camera was attached to a LM window bracket to record descent and ascent, lunar landing, and maneuvers with the CSM. The camera was also used on the surface by the astronauts for handheld terrain photography, footage of the experiments, and surface activities.

The film magazines carried approximately 40 m (130 ft) of film. Running times were 93.3, 15.5, 7.8, and 3.7 min at film rates of 1, 6, 12, and 24 fps, respectively. The corresponding shutter speeds were 1/60, 1/125, 1/500, and 1/1000 s. The camera settings and ranges are shown in Table 5-5.

Table 5-5. Maurer Camera Settings and Ranges

Lens focal length (mm)	5	10	18	75	229*
Focus (mm)	lens - ∞	152 - ∞	305 - ∞	1067 - ∞	∞
Aperture	f/2.0 - f/16	T/1.8 - T/22	T/2 - T/22	f/2.5 - f/32	T/8
Field of view					2.1° (circular)
Horizontal	117.5°	54.9°	32.3°	7.9°	
Vertical	80.2°	41.1°	23.5°	5.7°	
Diagonal	160°	65.2°	39.2°	10°	

*Used on Apollo 17 with sextant.

For most lunar surface photography, the 10- or 18-mm focal length lens was not used with SO-368 color film. The 5-, 10-, 18-, and 75-mm lenses were used for most CM photography. Accessories for the camera included a right-angle mirror, power cable, and window brackets for mounting the camera.

Dim light photographs were also obtained with the Maurer cameras on Apollo 14 and 16 using the 18-mm lens and black and white film type 2485. For the gegenschein experiment on Apollo 14, the phenomenon was photographed in total darkness, which was achieved by photographing a 20° field of view on the opposite side of the Earth from the Sun (antisolar axis). On Apollo 16, the solar corona and contamination experiment photography (see Contamination Photography Experiment section) were obtained.

Maurer Camera Data

Table 5-6 lists the footage available from NSSDC for the Maurer camera. These films are normally provided on a 3-month loan basis, although in

Table 5-6. Maurer Camera Photography Data at NSSDC

Mission	Magazines	16-mm Movie Film m (ft)	Color Film Type	Indexes on Microfilm
Apollo 8	1	30 (100)	SO-368	*
Apollo 10	10	301 (1000)	SO-368 SO-168	*
Apollo 11	5	351 (1150)	SO-368 SO-168	*
Apollo 12	15	488 (1600)	SO-368 SO-168	*
Apollo 13	5	168 (551)	SO-368	*
Apollo 14	11	366 (1200)	SO-368 SO-168	*
Apollo 15	11	488 (1600)	SO-368 SO-168	1
Apollo 16	12	442 (1450) 76 (250)	SO-368 SO-168 2485 (B/W)	1
Apollo 17	12	671 (2200)	SO-368 SO-168	1

*Indexes for these missions are contained in the appropriate DUNs.

special instances arrangements can be made for permanent retention. The NSSDC ID numbers for these data are given in the Index to Available Data. DUNs and data packages prepared for each mission are listed on the order form and are available from NSSDC to aid in requesting these data. For the Maurer footage, magazine number and content are provided in these documents.

Maurer Films

The astronauts used the Maurer camera to photograph such subjects as Earth and lunar terrains, LM separation and docking sequences, landings, the lunar surface from the LRV, liftoff, reentry, and parachute deployment. Cabin and interior activities have been deleted from the available NSSDC data. The films are of limited scientific use; the most useful portions are those obtained prior to and during lunar landing and on takeoff.

Maurer Film Indexes

Separate indexes are available for Apollo 15, 16, and 17, but were not compiled for the earlier missions. However, indexes for the Maurer cameras for each mission are in the NSSDC DUNs. The separate indexes listed in Table 5-6 for Apollo 15, 16, and 17 were compiled by the Photographic Technology Laboratory of JSC and filmed by NSSDC for catalog and supporting data use. Included in these indexes are magazine designation, film type, lens focal length, speed of film (fps), and a brief description of the content.

CLOSEUP STEREOSCOPIC CAMERA

This 35-mm stereoscopic camera was carried on Apollo 11, 12, and 14 and was designed for the highest possible resolution of a 76-mm^2 (3-in.^{2}) area for a stereo pair with a flash illumination and fixed distance. The camera was carried in the LM modular equipment storage assembly and was used by the astronauts on the lunar surface. Photography was accomplished by holding the camera on a walking stick against the object to be photographed. The camera was powered by four nickel-cadmium batteries that operated the motor drive mechanism and an electronic flash strobe light.

The camera lens was diffraction limited to 46.12 mm at f/17 using Kodak M-39 copy lenses. It was focused for an object distance of 184.5 mm. Other capabilities, settings, and ranges for the equipment are shown in the following list.

Focus:	fixed range
Aperture:	f/22.6 fixed
Film:	9 m (30 ft), SO-368
Magnification:	0.33x
Cycling time:	10 s
Stereo angle:	9° convergent
Smallest resolution:	40 µm
Area photographed:	72 x 82.8 mm
Base-height ratio:	0.16
Particle identification:	1 mm

The quality of the photographs obtained by the stereoscopic cameras is excellent. Figure 5-5 is a sample photographic pair from Apollo 11. The photographs contain small objects, details of the lunar surface, soil particles,

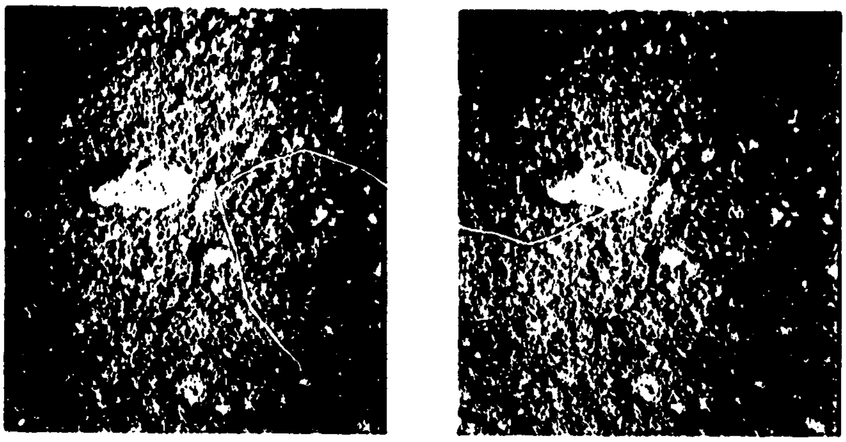


Figure 5-5. Sample stereoscopic pair of photographs showing the soil at the Apollo 11 landing site. The largest object is about 10 cm (4 in.) in diameter. For stereoscopic effect, hold at arms length, gaze above page at distant view, then between the pictures. Concentrate gaze on the center of the three images until it becomes three dimensional. (Apollo 11: AS11-45-6698A, B)

micrometeoroid pits on rocks, and glass spatter on surface material (*Gold*, 1970). The following number of stereoscopic pairs are available from NSSDC.

Apollo 11	17 pairs
Apollo 12	15 pairs
Apollo 14	16 pairs

HYCON CAMERA

This electrically operated camera was carried on board the Command Module on the Apollo 14 mission. It was a modified KA-7A aerial reconnaissance camera and was mounted in the crew access hatch window when used. A remote control box and interconnecting cable provided an automatic mode for strip photography and a manual mode for single frames. Variable forward motion compensation allowed for spacecraft orbital motion. For each frame exposed, a small clock showing the day and time was simultaneously exposed on the side of the frame.

The photographic objective of the Hycon was to obtain high-resolution photographs of future lunar landing sites and areas of scientific interest. The camera settings, ranges, and characteristics are given in the following list.

Lens focal length:	457 mm (18 in.)
Fixed aperture:	f/4.0
Focal plane shutter speeds:	1/50, 1/100, 1/200 s (only 1/200 s used)
Angular field of view:	14°7.5' - Swath width was 2.8 km (1.75 mi) at 14 km altitude; 22 km at 100 km altitude at the nadir
Frame format:	114 x 114 mm (4.5 x 4.5 in.)
Resolution (contrast 1000:1):	AWAR 150 lines/mm (3-9 m from 100 km; 1-2 m from 14 km)
Filter:	Wratten 12
Cycling rate:	Automatic from 4 to 75 frames/min, single framing
Film capacity:	standard base - 35 m thin base - 70 m

A camera malfunction that occurred during the mission caused the shutter to operate continually, resulting in a transistor failure. The malfunction was caused by a sliver of aluminum that shorted the system by lodging in the shutter pulse switching circuit. In addition, an intervalometer anomaly caused multiple exposure of the same scene, and overexposure by 2 stops occurred in this section of the film.

The Hycon camera provided vertical stereo coverage of the Descartes highland region on the fourth pass. (Apollo 16 landed in this region.) Coverage of the lunar surface is from 28°E to 17°E, which includes the area from the east rim of Theophilus to Dollond MA. Figure 5-6 is a sample Hycon photograph.

The altitude of the spacecraft while acquiring these photographs ranged from 12.5 to 20 km depending on the ground elevation. The resolution of the photographs ranged from 2 to 3 m.

Hycon Photographs

The Hycon camera used two magazines of black and white film type 3400. Of the 243 frames exposed, 207 are usable. These frames are available in both logetronic and photometric renditions.

The photometrically processed photographs were reproduced on a Niagara printer to preserve the albedo variations. These photographs may be used for photometric and photogrammetric studies. The logetronic processing reproduced the photographs with density quality control through exposure control and dodging techniques.

ORIGINAL PAGE IS
OF POOR QUALITY

APOLLO

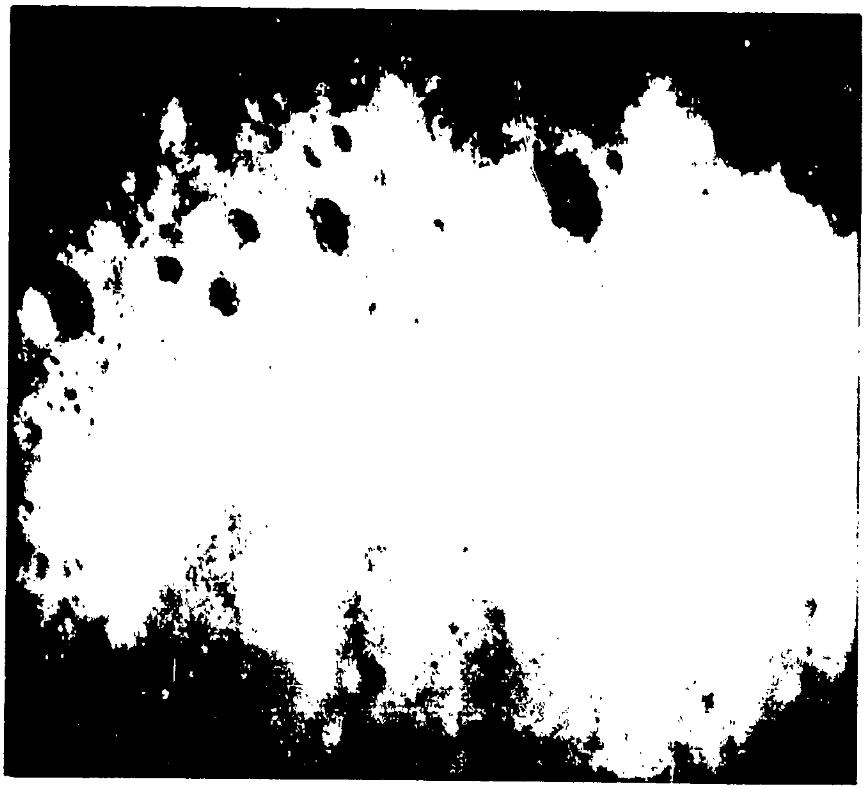


Figure 5-6. Sample Hycon photograph showing the area between Theophilus and Cyrillus with a 2-m resolution. The terrain is rolling and subdued with few sharp-rimmed craters. (Apollo 14: AS14-80-10502)

Overall quality of the usable photographs is good, although some frames appear blurred at the edges.

NIKON CAMERA

The 35-mm Nikon camera was carried on Apollo 15, 16, and 17. It had a Nikon lens with a focal length of 55 mm and a relative aperture of f/1.2. It was designed for through-the-lens viewing and metering. A very high speed black and white film, type 2485, was used. The Command Module pilot operated the camera manually when targets of interest were in view. Mission objectives for the Nikon camera included dim light photography of diffuse galactic light, the zodiacal light, gegenschein, the northern galactic pole, the solar corona, spacecraft contamination, and the Earth-lit (ashen light) portions of the lunar surface. Analysis of extent, locations, configurations, and light levels of astronomical sources can provide information on the location of interstellar concentrations of matter. Figure 5-7 is a Nikon photograph of the lunar surface. Figure 5-8 is a Nikon frame of zodiacal light exposed during the Apollo 17 mission.

The Nikon camera was also used for the gegenschein experiment. Photographs of the gegenschein were exposed from lunar orbit to attempt to confirm the possible accumulation of matter at the Moulton point. This information helps to assess the contribution to the gegenschein of light that may be reflected from the region of the Moulton point. Only Apollo 16 obtained the gegenschein and Moulton region; the gegenschein was missed on the

Figure 5-7. Sample Nikon photograph showing oblique view of the central peak and floor of the farside Crater Tsiolkovsky (180-km (120-mi) diameter) with low Sun elevation. (Apollo 17: YY-57-23852)

Apollo 15 mission. Contamination photography, described in the next section, was obtained with the Nikon camera during the Apollo 16 mission.

Nikon Photographs and Indexes

Table 5-7 provides a summary of the Nikon photographs that were obtained during the Apollo 15, 16, and 17 missions. The gegenschein experiment photographs from Apollo 16 are included.

Figure 5-8. Sample Nikon photograph of zodiacal light as seen at the Moon just before sunrise. The stars appear as streaks because of spacecraft motion. (Apollo 17: YY-160-23961)

Table 5-7. Nikon Photography Data at NSSDC

Mission	Number of Photographs	Quality	Objects
Apollo 15	125	Fair-Good	Milky Way, Zodiacal light, Lunar eclipse, Earthshine
Apollo 16	100	Fair	Zodiacal light, Gum Nebula, Galactic clusters, Earthshine, Contamination*
	11	Fair	Gegenschein, Moulton point
Apollo 17	410	Poor-Fair	Zodiacal light, Earthshine

*See following section for discussion of this experiment.

Indexes to the Nikon photographs are available on 16-mm microfilm. The indexes for Apollo 17 provide NASA photograph numbers, principal point of the photographs, camera tilt and azimuth angles, altitude, Sun elevation, and descriptive remarks. For Apollo 15 photographs, date of exposure and time, center point right ascension and declination of astronomical subjects, corner coordinates, and remarks are provided as well as the NASA frame numbers. For each mission, there are some calibration data.

CONTAMINATION PHOTOGRAPHY EXPERIMENT

The Apollo 16 contamination photography experiment had two objectives. The first was to map the scattering function of visible light produced by any residual cloud around the spacecraft. The second was to study the dynamics of particles that occur during a dump of liquids and also to determine the decay of background brightness resulting from these dumps. The results were used in planning the design and operations of the Skylab astronomical observations. The first objective utilized photographs obtained with the 35-mm Nikon camera, and the second objective employed two 16-mm Maurer cameras and a 70-mm Hasselblad camera.

The cameras were positioned to view from various windows on the CM and were cycled through a sequence of exposures with various spacecraft orientations, camera positions, and exposure times after the liquid dump. The experiment was performed successfully, and 108 usable photographs were obtained. Because of mission schedule changes, the photographs were affected by moonlight on CM windows, which in turn affected scattering values.

Contamination Photographs

Photographs of the Apollo 16 contamination environment were obtained with dim light film and are available as follows:

Camera	Magazine	Quantity
Hasselblad	TT	7 photographs
Maurer	MM, HH (revolution 38)	76 m (250 ft) of 16-mm film
Nikon	X	18 photographs

From these photographs, which were exposed during sunrise, sunset, and the transearth coast, scattering properties and brightness in the vicinity of the spacecraft may be determined.

Contamination Digitized Data

Digitized contamination data consist of microdensitometer readings of photographs from the Hasselblad, Maurer, and Nikon photography. The density readings were taken at 100-µm intervals along scans spaced 100 µm apart.

The data are on one 7-track, 800-bpi, binary magnetic tape created on a Univac 1108 computer. Each file on the magnetic tape is a complete photograph, and each record is a scan. Record lengths within one file are the same, but do vary between files, as does the number of records per file. The record length, in 36-bit words, ranges from 27 to 127 words. The number of records per file ranges from 11 to 255. There are 110 files of data, two of which contain invalid data. The records contain camera, magazine, frame, and exposure identification, as well as frame coordinate values and density readings. Between any two data records for a given sample, there is an interrecord gap. A file mark follows the last data record for a given sample.

TV KINESCOPE PHOTOGRAPHY

Television cameras were carried on all Apollo spacecraft in order to visually transmit the activities of the astronauts to Earth. Although some geology can be derived from the background of the lunar surface activity photography, this footage is not considered scientific data. There were TV experiments on the Apollo 15, 16, and 17 missions, and these data are available from NSSDC.

There were two types of cameras for the TV experiments; one was a Westinghouse, and the other was an RCA. The Westinghouse TV camera was used in the Command Module and could be handheld or mounted on a bracket. It was operated at variable f-stops from 4 to 44 and had a zoom lens. A 5-cm black and white video monitor, which could be mounted on the camera or at various locations in the CM, aided the crew in focus and exposure adjustments. A camera ring sight also enabled the crew to direct the camera lens at the desired target.

The RCA camera could be mounted on the LRV, on the modularized equipment storage assembly, or on a tripod and was used during lunar surface activities. The Mission Control Center on Earth, as well as the crew, could control and aim this TV camera. The f-stop could be varied from f/2.2 to f/22.

For both cameras, the scanning rates were the commercial 30 fps, 525 scan lines/frame. Scan conversion for black and white was not required. The resolution was 200 TV lines/picture height (limited by S-band equipment), the aspect ratio was 4:3, and the range of operation was from 54 to 120,000 lm/m^2 (5 to 12,000 fc). Color was achieved by using a rotating disk driven by a synchronous 600-rpm motor.

TV Kinescope Film and Indexes

The TV footage from both the Westinghouse and the RCA TV cameras is available from NSSDC on 300-m (1000-ft), 16-mm reels. These films can be obtained on a 3-month loan basis or special arrangements can be made for permanent retention. Cabin photography has been removed from the footage. LM docking and the lunar landing site sequences from the CSM are available along with the lunar surface activities and liftoff sequences. Approximately 20 hours of running time are available for each mission. Total film is given in the following list.

Apollo 15 - 22 reels, 6,906 m (22,659 ft)
Apollo 16 - 34 reels, 10,647 m (34,932 ft)
Apollo 17 - 40 reels, 11,916 m (39,095 ft)

Smaller segments may be obtained, and indexes are available to aid in selection of segments. The indexes are in the form of paper prints and contain an identification number, the time span of data, and the subject matter. The films are in chronological order.

PANORAMIC CAMERA

The 610-mm (24-in.) ITEK panoramic camera experiment obtained high-resolution panoramic photographs, in both stereoscopic and monoscopic modes, of the lunar surface during the Apollo 15, 16, and 17 missions. The camera provided 1- to 2-m resolution photography from an orbital altitude of 111 km (60 nautical miles). The panoramic camera was located in the SM. Panoramic photographs supported photographic data for the other Command Service Module cameras and for the SIM experiments scanning the lunar surface from lunar orbit by providing greater areal coverage and higher resolution for given regions. The following list provides the principal camera specifications.

Lens focal length:	610 mm (24 in.)
Field of view:	108° crosstrack 10.4° along track
Image coverage:	322 x 21 km
Image size:	114 x 1150 mm (4.5 x 45.25 in.)
Film:	Black and white type 3414
Film capacity:	1981 m (6500 ft.); 1600 frames

The panoramic camera was composed of four main components: (1) a roll frame assembly that rotated continuously in the cross-track scan direction during camera operation (panoramic scanning); (2) a gimbal assembly that tilted fore and aft to provide 25° stereoscopic convergence between frames as well as forward motion compensation; (3) a main frame with a velocity/height sensor that governed the rotation rate of the roll assembly; and (4) a gaseous nitrogen pressure vessel assembly that provided gaseous nitrogen for certain film roller gas bearings. (This gaseous nitrogen pressure vessel assembly was also used by the mapping camera system.) The camera optics system, the camera film drive and control system, and the film cassette completed the camera system.

This camera was rigidly mounted in the SIM bay between two SIM shelves. The camera lens was automatically stowed when "off-nominal" lens thermal conditions were experienced. This protected the lens from contamination. The crew could control the camera system, select stereoscopic or monoscopic modes of operation, and verify camera operational status from the Command Module. The film cassette was retrieved by a crew member during the transearth coast extravehicular activity.

Panoramic Photography Data

The complete photographic coverage by the panoramic cameras on Apollo 15, 16, and 17 is available from NSSDC along with supporting and selection data as listed in Table 5-8. These data are described in the following sections. *Data Users Notes* and *Photographic Data Packages* were prepared by NSSDC for the Apollo missions and contain more detailed information and ordering materials. These documents are listed on the order form. (Also see *McCash*, 1973.)

Table 5-8. Panoramic Photography Data at NSSDC

Mission	Photographs	Rectified Photographs	Support Data Microfilm 16 mm	Indexes		Catalog Microfilm 35 mm
				M'film 16 mm	M'fiche	
Apollo 15	1572 Logetronic 1572 Photometric 149 Terminator*	1465	3	1	4	1
Apollo 16	1586 Photometric	1415	1	1	5	1
Apollo 17	1574 Photometric	1574	1†	1	3	1

*Kodak 2420 film.
†Laser altimeter supporting data (on microfiche) also available.

The areas photographed by the panoramic camera were the following.

- Apollo 15 - 180°E to 70°W longitude and ±25° latitude
  Farside, nearside maria, Apollo 15 and 17 landing sites, terminator, and special features.
- Apollo 16 - 180°E to 48°W longitude and ±11° latitude
  Farside, nearside maria, Apollo 16 landing site, Apollo 17 possible landing sites, and terminator.
- Apollo 17 - 180°E to 44°W and 154°W to 180°W longitude and ±23° latitude
  Farside, nearside, special features, Apollo 17 landing site.

The quality of the photographs from all missions is good; however, Apollo 16 film does contain light streaks, and Apollo 17 film is overexposed in some areas. Figure 5-9 is a panoramic frame obtained on the Apollo 15 mission.

Figure 5-9. Sample panoramic photograph shows the lunar landscape across the Apennine Mountains, Palus Putredinus, and the 3-km-wide Hadley Rille. The Apollo 15 landing site is designated by an arrow. (Apollo 15: AS15-9377)

Panoramic Photographs

Complete sets of panoramic photographs are available from NSSDC. Photometric photographs are available for the Apollo 15, 16, and 17 missions and were prepared from black and white positives on a Niagara printer. The photographs are 127 x 1220 mm (5 x 48 in.) and are suitable for photometric and photogrammetric investigations.

The quality of the photographs is generally very good for Apollo 15. The photographs obtained on Apollo 16 are generally good, although a horizontal light streak appears in the center of the frame. Those photographs taken near the terminator at low light levels are excellent. On Apollo 17, a camera malfunction caused overexposure in the light areas on some of the frames. This is partly overcome by special development techniques but at the expense of dark areas. Many of the photographs were obtained in the stereo mode, and stereo pairs are five frame numbers apart.

Apollo 15 photographs were also prepared with density quality control (logetronic) using exposure control and dodging techniques. Near terminator photographs obtained during the Apollo 15 mission are available as a separate set of 149 photographs and also are included in the complete sets of panoramic photographs. The separate set of terminator photographs were reproduced on Kodak 2420 film from the originals. These photographs show small changes in relief in the topography at relatively high resolutions.

Panoramic Rectified Photographs

Nearly all the panoramic photographs (see Table 5-8) have been rectified and are available from NSSDC. The central 100- x 950-mm section of the original 127- x 1220-mm frames were rectified by a process that corrected the camera and viewing distortions. This process results in a vertical projection of the lunar surface.

These photographs are more accurate for stereoscopic use and need no further magnification. The photographs are slightly degraded because of the rectification process, but are generally good and have resolutions that provide useful scientific information. A more detailed description of the rectification procedure is contained in a *Data Users Note, Apollo 17 Lunar Photography* (NSSDC 74-08).

These rectified panoramic photographs have been reproduced on 229- x 2032-mm (9- x 80-in.) film and have frame numbers that are identical to the original panoramic photographs. The indexes and supporting data for the panoramic photographs are relevant for selection of these rectified frames.

Panoramic Photography Supporting Data

Supporting data for the panoramic camera photography are available on 16-mm microfilm. SIM bay photographic supporting data (laser altimeter readings) are available on microfiche and are described in the Laser Altimeter Photographic Supporting Data section. Information contained on the microfilmed supporting data includes summary tables and explanations of each of the parameters given. These data are applicable to both the original and rectified frames. Detailed parameters are given for each photographic frame and include spacecraft parameters such as latitude and longitude, state vectors, radius, and altitudes; photographic parameters such as date and time of exposure, transformation matrix from selenocentric to camera, direction cosines, local horizontal to camera transformation matrix, photographic footprint latitude and longitude, direction to stellar photograph center, tilt azimuth, and north deviation angle; and solar parameters such as solar azimuth and Sun elevation at principal point. Other relevent data are included.

A catalog of Apollo photographic evaluation (APE) data is available on microfiche as supporting data for the Apollo 15 panoramic camera and mapping camera. Explanations and definitions of data elements are provided; data for light side sequences are summarized; and brief descriptions of trajectory reconstruction, telemetered data used, and constants employed for data processing are given.

Panoramic Photography Indexes

Indexes to the panoramic camera photography are on both 16-mm microfilm and on microfiche cards. A brief description of features in each frame is given as well as the frame number, camera look direction, stereoscopic companion frame number, principal point latitude and longitude, altitude, revolution (pass) number, and Sun elevation.

Additional information is provided giving a tabular summary of the panoramic camera photography, camera characteristics, number of photographs obtained during each pass, and orbital coverage footprints on a lunar map. These indexes may be used for both the original and rectified frames. For missions 16 and 17, the information is indexed in chronological order and by longitude in increments of 10° progressing westward. Typographical error headings appear in the Apollo 17 indexes, which read A-16 instead of A-17. The quality of the microfilm and microfiche is generally poor.

Panoramic Photography Catalogs

These catalogs contain complete sets of the usable frames of the lunar surface from the panoramic camera on Apollo 15, 16, and 17 and are contained on 35-mm microfilm. Paper prints of the panoramic camera photographs were mounted four to a board and then photographed on 35-mm microfilm such that one 35-mm frame contains four camera frames. The frame number for each picture appears at the center of the lower margin of the frame.

The surface photographs are preceded by frames containing a brief description of the panoramic photography, the use of the catalog, the technical supporting data, and NSSDC ordering procedures. The quality of the catalogs is adequate for some limited scientific studies. The catalogs may be used to order the rectified photography as well as the original panoramic photographs.

MAPPING CAMERA SYSTEM

The mapping camera system (MCS) obtained photographs of high geometric precision of lunar surface features overflown by the spacecraft (Apollo 15, 16, and 17) in sunlight. These were obtained while simultaneously exposing stellar photographs for precise orientation of the spacecraft and recording laser altimeter data for determination of spacecraft altitude. The MCS contained three major components.

- Mapping (metric) camera
- Stellar camera
- Laser altimeter

The fixed angle between the optical axis of the mapping camera and the optical axis of the stellar camera was nominally 96°, with the stellar camera pointing 6° above the horizon on the right side of the spacecraft when the mapping camera was pointing vertically toward the lunar surface and the spacecraft was moving forward. The laser altimeter transmission and receiving optical axes were nominally parallel to the mapping camera optical axis. The actual angular orientation between the mapping and stellar cameras and the location of the altimeter subpoint in the mapping camera frame are given as part of preflight calibration data. The midpoint of exposure of the mapping camera, stellar camera, and laser altimeter was synchronized to ±1 ms. The MCS used a gaseous nitrogen pressure vessel assembly, shared with the SIM panoramic camera, as a source of gaseous nitrogen to provide an inert and pressurized atmosphere within the cameras.

The mapping camera system was mounted on the top shelf in the SIM bay and was deployed on a rail-type mechanism when acquiring photographic data in order to provide an unobstructed field of view for the stellar camera. This mechanism insured that the star field photographed was not obscured by either the lunar horizon or the SM mold line. A cover attached to the SIM shelf protected the mapping camera lens and laser altimeter optics from spacecraft contamination sources during reaction control system and service propulsion system firings and effluent dumps. This cover had provisions for multiple opening and closing cycles.

A control panel in the CM provided for on/off/standby, track extend/retract, and image motion compensation switches.

The MCS flight plan was devised to provide 78 percent overlap between successive mapping camera images photographed on the same pass and a 55 percent sidelap between adjacent photographic passes. The stellar camera provided attitude information, and the laser altimeter provided measured distance from the spacecraft to the lunar surface (altitude) in synchronism with each mapping camera exposure. The 78 percent overlap provided stereo coverage that can also be used for topographic information.

Exposed film from both mapping and stellar cameras was accumulated in a removable film record container. This container was recovered from the SIM bay by the Command Module pilot during the transearth coast EVA.

Mapping Camera

The mapping (metric) camera provided 20-m resolution photographs from an orbital altitude of 111 km (60 nautical miles). Camera ranges and settings are as follows.

Focal length:	76 mm (3 in.) (f/4.5)
Field of view:	74° x 74°
Image area at 110-km altitude:	170 x 170 km (92 x 92 nautical miles)
Image size:	114 x 114 mm (4.5 x 4.5 in.)
Film capacity:	457 m (1500 ft); 3500 frames
Film type:	Black and white 3400
Film width:	127 mm (5 in.)

The mapping camera obtained photographs at maximum aperture with varying shutter speeds. The shutter consisted of a pair of continuously rotating disks and a capping blade. An exposure was made when the holes in the rotating disk came into line while the capping blade was turned to the open position. To insure geometric precision of successive photographs, the film was held in a plane during exposure at a fixed distance from the lens nodes by a glass stage plate with a reseau inscribed on its surface. The reseau made it possible to correct every frame for film shrinkage and for any local film distortions. Fiducial marks, which defined on the film the location of the optical axis at the instant of the flash, were exposed just outside the frame format. These were required to cope with complications caused by stage plate movement, and film forward motion was compensated by driving the plate in the direction of flight during exposure.

Raw laser altimeter data were directly recorded on the film outside the image area.

The photography had 78 percent overlap for each frame and 55 percent side overlap between consecutive revolutions, providing stereo coverage for most of the lunar surface photographed. A frame covers approximately 165 km on a side. The quality of the photographs from all three missions is generally good. The data available for the mapping camera are listed in Table 5-9 and described in the following sections. Figure 5-10 is a sample mapping camera photograph obtained during the Apollo 17 mission.

Table 5-9. Mapping Camera Photography Products at NSSDC

Mission	Photographs	Supporting Data Microfilm Reels	Indexes		Catalogs		
			Microfilm Reels	Microfiche Cards	Microfilm Reels	Microfiche Cards	
						NSSDC	Cal Tech
Apollo 15	3375 Logetronic 3375 Photometric 1515 Terminator	3	1	4	2	59	45§
Apollo 16	3480 Photometric	1	1	5	2	57	21§
Apollo 17	1412 High gain 3298 Low gain	2*	1†	3†	1	60	59§

*One reel of original data and one reel of supplemental data and preflight calibration; laser altimeter supporting data (on microfiche) is also available.
†Very poor quality.
§Frames with no data are identified.

Mapping Camera Photography

These photographs are available on 127-mm (5-in.), black and white film with a frame format of 114 x 114 mm (4.5 x 4.5 in.) that were reproduced from the original black and white film type 3400 exposed by the 76-mm (3-in.) mapping camera located in the SIM bay.

Different types of reproductions were made of the film. For Apollo 15 film, a logetronic process was used in which the reproductions were made with quality control on the density using exposure control and dodging techniques. Apollo 16 film and a second set of Apollo 15 film were processed by a photometric procedure using a Niagara printer that allows photometric and photogrammetric (albedo) measures to be made. The process used for Apollo 17 film involved gain adjustments, and both high gain and low gain reproductions were made. High gamma (gain) brings out details in the highlight areas. Low gamma reproduction is the normal procedure, but details in highlight and shadowed areas are lost.

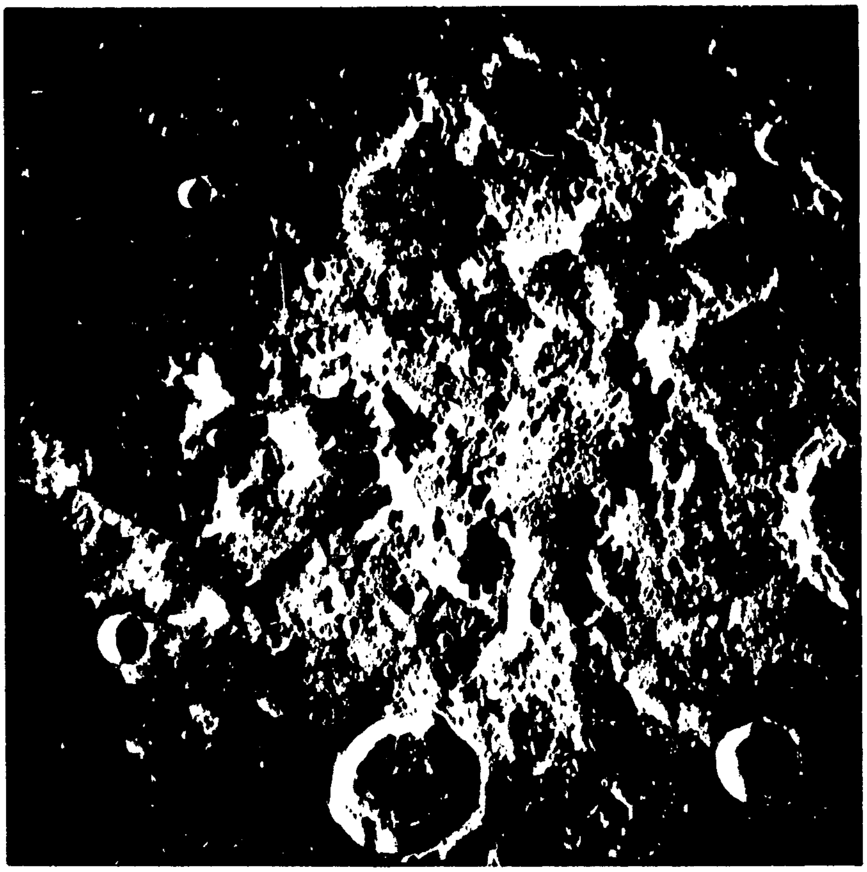


Figure 5-10. Sample mapping camera photograph showing the general vicinity of the Apollo 17 landing site. Crater Littrow is the dark, flat-floored crater near the top center. The mountains are part of the Taurus mountain range. (Apollo 17: AS17-0595)

Apollo 15 photographs of the near terminator areas were extracted from the original photography and are available as a set on one roll of black and white film. These photographs show the lunar terrain in strong relief due to the very low Sun angles as the terminator (sunrise and sunset lines) is approached. Lava flows, low ridges, and depressions are visible. The Aristarchus environs can be seen in bold relief. Other areas are of the LM landing site near the Hadley Rille, the Apennines mountains, Archimedes and its nearby rilles, Plinius and its rilles, Dawes on the nearside of the Moon, and Tsiolkovsky and its environs on the farside.

Mapping Camera Photography Supporting Data

The supporting data for the mapping camera photography for Apollo 15, 16, and 17 are available on 16-mm microfilm. These microfilmed data give detailed photographic parameters for each frame and include spacecraft parameters such as latitude and longitude, state vectors, radius, and altitudes; photographic parameters such as date and time of exposure, sigmas of longitude of camera axis intersect, local horizontal to camera transformation matrix, photographic footprint latitude and longitude, direction to stellar center, tilt azimuth, and north deviation angle; and solar parameters such as solar azimuth and Sun elevation at principal point. Other relevant data are included. Explanations and definitions of the parameters are given.

SIM bay photographic supporting data (laser altimeter readings) are also available for Apollo 15, 16, and 17 on one microfiche card. These data are described in the Laser Altimeter Photographic Supporting Data section along with geodetic reference data derived from the mapping camera system. For Apollo 15, Apollo photographic evaluation (APE) data are available for the Apollo 15 mission panoramic and mapping cameras. These data are described in the Panoramic Photography Supporting Data section.

Mapping Camera Photography Indexes

These indexes to the mapping camera photography are available on both 16-mm microfilm and on microfiche cards. Information given in the indexes for each photographic frame include frame number, revolution (pass) number, approximate altitude, principal point latitude and longitude, camera tilt and azimuth, forward overlap, Sun elevation, and a brief description of features to be seen. Additional information given at the beginning of the reels (for each mission) includes summary tables of camera coverage, camera characteristics, and orbital coverage footprints on lunar maps. For missions 16 and 17, the listings are indexed in two ways: by frame number (chronologically) and by longitude in 10° increments progressing westward.

Mapping Camera Photography Catalogs

These catalogs contain complete sets of mapping camera photographs for ordering purposes. For each mission, there are three complete catalogs available. One catalog is on 16-mm microfilm reels, and the other two are on 102- x 152-mm (4- x 6-in.) microfiche cards. The California Institute of Technology prepared microfiche catalogs using a technique that provided careful registry to fit special automatic retrieval readers when a coded metal edge attachment is applied. These cards, which contain 60 images per card, may also be used in any microfiche reader. Although the photography is very good, the special registry frequently caused some frame numbers not to register; therefore, these cannot be used for general catalog purposes.

NSSDC generated its own microfiche catalog, which insured the appearance of the frame numbers. There are 50 images per card in the NSSDC version. While Cal Tech and NSSDC microfiche both may be used for some scientific studies, the NSSDC version is to be used for ordering photographs.

Stellar Camera

The objective of the stellar camera was to photograph the star field in synchronism with the mapping camera exposures and laser altimeter pulses. By measuring the position of identified star images, the orientation of the stellar camera in the celestial coordinate system could be determined. By means of preflight calibration, this orientation was transferable to the mapping camera or to the laser altimeter.

The stellar camera was mounted at an angle of 96° from the mapping camera, carried an f/2.8 lens with a 76-mm focal length, and had a picture format of 24 x 32 mm (0.96 x 1.25 in.) on black and white 3401 film. The photographs were originally recorded on 35-mm roll film and later contact-printed on 70-mm film. There were four naturally illuminated fiducials. The fixed-glass focal plane contained a reseau that was edge-illuminated to record on each frame. The exposure time for the stellar camera was fixed at 1.5 s, and the midpoint of this exposure was synchronized with the midpoint of the metric camera and laser altimeter to ±1 μs. The data are generally good; however, on Apollo 16 the glare shield jammed, and glare appears on those photographs.

Stellar Camera Photographs

Complete sets of stellar camera photographs are available. The stellar photographs contain the star fields, in a fixed relation to the nadir point on the lunar surface, simultaneously exposed with the mapping camera and/or the laser altimeter firings. These photographs, although free from atmospheric effects, are only useful for selenodetic studies. There are no frame numbers on the Apollo 15 photographs, and there is some dirt degradation. For Apollo 16, stellar frame numbers are offset from mapping camera frame numbers by +79; therefore, add 79 to the Apollo 16 mapping camera frame for the correlating stellar frame number. Some Apollo 16 photographs have static marks, some have fog, and some have light leaks. For Apollo 17, stellar frame numbers are offset by -18; therefore, subtract 18 from mapping frame numbers to obtain correlating stellar frame numbers. The following quantities of photographs are available.

Apollo 15 - 3350
Apollo 16 - 3561
Apollo 17 - 3300

Stellar Camera Photography Supporting Data

SIM bay photographic supporting data (laser altimeter readings) for the Apollo 15, 16, and 17 stellar cameras are available on one microfiche card. Geodetic reference data derived from the mapping camera system data are also available as supporting data. Both of these types of supporting data are described in the Laser Altimeter Photographic Supporting Data section.

Laser Altimeter

The ojective of the laser altimeter carried on Apollo 15, 16, and 17 was to provide ranging data for use in determining the altitude of the Apollo spacecraft above the lunar surface. The time-correlated, slant-ranging data were acquired with 1-m resolution and were measured parallel to the optical axis of the mapping camera. These data supported mapping and panoramic photography, provided precision altitude data for other orbital experiments, and related and defined lunar topographic features with 15-m resolution for a better definition of lunar shape. They were also used in conjunction with tracking data to improve lunar orbital calculations.

The altimeter operated in the following two modes.

- The coupled mode with the mapping camera caused the altimeter to automatically emit a laser pulse corresponding to the midframe ranging (approximately 1 range pulse every 24 s).
- The decoupled mode allowed for independent ranging measurements (solo operation), one firing every 20 s, when the mapping camera was inoperative.

In the coupled mode, the ruby laser was activated when a signal was received from the mapping camera, and the light pulse was transferred to the transmission optics that had an angular field of 30[illegible]nd illuminating an area 33 m in diameter on the lunar surface from the n[illegible]l altitude of 110 km. A portion of the output was used to start the range counting clock. The return pulse reflected from the lunar surface was applied to the photomultiplier tube through the receiver telescope, which had an angular field of 200 μrad. The output of the photomultiplier stopped the range counter, which measured 6.67-ns intervals (equivalent to a 1-m round trip). The altitude was recorded both on the mapping camera film and in the spacecraft data system. Frequency of data transmission was 3 data points/min when the mapping camera was off and 2.5 data points/min when on.

Performance of the altimeter on the three missions was the following.

- Apollo 15 - 682 firings - Operated normally until revolution 24, partially until revolution 38, and was then inoperative.

- Apollo 16 - 2372 firings - Measurements were obtained during revolutions 3, 4, 17, 18, 28, 29, 37-39, 47, 48, 60, and 63. Overall reliability was 64 percent; measurements made at 50 percent reliability to revolution 60; by revolution 63 reliability was 5 percent.

- Apollo 17 - 4026 firings - Measurements were obtained during revolutions 1, 2, 13-15, 23, 24, 27-29, 38, 39, 49, 62, 63, and 65-74. Complete sets of data containing measurements for the entire circumference in the orbital plane were obtained. The instrument operated normally throughout the mission.

Laser Altimeter Incidence Data

Reduced and analyzed altimeter incidence data are available on one 7-track, 800-bpi, BCD magnetic tape created on a CDC-6400 computer. There are three files on the tape: two for Apollo 15 and one for Apollo 17. A decimal dump of this tape is supplied on microfiche with the magnetic tape as supporting material and includes some Apollo 16 data (less than one orbit: part of orbit 17 and part of 18). The data tape includes: mission, time of observation, tabulation of the laser incidence coordinates determined and their associated covariance data (where derivable) in a selenographic reference frame, and estimates with associated uncertainties for (1) lunar radius, (2) offset of the center of figure from the center of mass, and (3) the best fitting geometry parameters for each lunar profile.

The data available for Apollo 15 were obtained on July 30, 1971, during orbits 15 and 21. These data are complete for both revolutions. The available Apollo 17 data are for revolutions 65 and 66 and were obtained on December 15, 1972.

Laser Altimeter Photographic Supporting Data

SIM bay photographic supporting data for the Apollo 15, 16, and 17 panoramic camera and the mapping camera system (which includes the stellar camera and the laser altimeter) are available on microfiche. These data correlate the laser altimeter readings to the MCS and panoramic camera photography and include premission and mission camera calibrations, exposure times of each photograph, and a brief summary of mission results for these experiments. Photographic ephemerides, Apollo 17 timing system and GMT conversion, and burns and other events are also given.

Also available as supporting data for Apollo 15, 16, and 17 mapping camera systems is the final report on the selenocentric geodetic reference system that includes terrain and exposure station position tables. This report is supplied on microfiche. The data in the geodetic reference documentation are based on data from the mapping camera system. The terrain positions were derived from photogrammetric techniques using mapping camera photographs, altimeter data, and stellar camera attitude data. Exposure station points were obtained from tracking data. The procedures used are described in the text. The terrain and exposure point tables include point number; Cartesian X, Y, and Z positions; and spherical position as latitude, longitude, and radial. Maps accompany the terrain point tables.

S-BAND TRANSPONDER

The S-band transponder, which was carried on the Apollo 12 and 14 through 17 missions, measured the gravitational field to provide information on the lunar mass distribution and its correlation with surface features. The lunar gravitational field was measured by observing the dynamic motion of the spacecraft in free-fall orbits.

The observational data were the precise Earth-based radio tracking measurements used initially for real-time navigation. However, these line-of-sight velocity measurements could only be obtained while the spacecraft was in view of the Earth; therefore, no farside data are available. The data were derived from radio tracking data in the following manner. A 2115-MHz radio signal was transmitted from the Earth to the spacecraft where it was multiplied by a factor of 240/221 and retransmitted to Earth at the new frequency. On the Earth, the initial transmitted frequency, multiplied by 240/221, was subtracted from the spacecraft signal. The resulting cycle count differences were recorded, along with the time at which they were measured. Because the fractional part of a cycle count was measured, the resolution was 0.01 Hz, or 0.6 mm/s.

S-band transponder data were also obtained from the LM on Apollo 12, 14, and 17 and on the subsatellites on Apollo 15 and 16 in the same manner. New detailed gravity measurements of many nearside features such as Copernicus, Sinus Medii, and Mare Fecunditatis were obtained from S-band transponder data.

S-Band Transponder Data

Because the data from the subsatellites (SSs) and LMs are included with the CM data, these are described in this section. Table 5-10 shows the data stored at NSSDC. NSSDC ID numbers, necessary when ordering data, are provided in the Index to Available Data.

Table 5-10. S-Band Transponder Acceleration Data at NSSDC.

Mission	Time Period	Remarks	Analyzed Data on Magnetic Tapes	Plots on Microfilm Reels*
Apollo 12				
CSM	Nov. 19, 1969	Orbit number 14		1
LM	Nov. 19, 1969	Descent data and Crash data (corrupted)		1
Apollo 14				
CSM	Feb. 4-5, 1971	Orbits 3-5, 7, 8, 10, 11, 13, 14	1	1
LM	Feb. 7, 1971	Crash data		1
Apollo 15				
CSM	July 30-31, 1971	Orbits 3-11, 16		
	July 30 - Aug. 4, 1971	Orbits 15-70	2	2
SS	Nov. 30, 1971 - Feb. 23, 1973		3	5
Apollo 16				
CSM	Apr. 20-21, 1972	10 orbits (not specified)	2	1
SS	May 2-19, 1972		1	1
Apollo 17				
CSM	Dec. 11-12, 1972	10 orbits (not specified)	2	1
LM	Dec. 15, 1972		1	(1 m'fiche)

*Seven reels total.

Acceleration Data

These S-band transponder data, received from the experimenter, are analyzed data listed on 16-mm microfilm and on magnetic tapes for the Apollo 12 and 14 through 17 CSMs; the Apollo 12, 14, and 17 LMs; and Apollo 15 and 16 SSs. Time and the Doppler residual are included. Time is in (1) GMT, (2) minutes, (3) minutes since the reference epoch, and (4) minutes on the associated plot for that particular data point. The Doppler residual (in Hz) was calculated from a theoretical model containing (1) planetary perturbations, (2) Earth rotation, (3) precise station locations,

(4) tropospheric model, and (5) precise station transit times removed from the returned signal. Also listed are spacecraft altitude, spacecraft selenographic latitude and longitude, theoretical value of the Doppler shift calculated by the spline program used in the least squares fit, acceleration determined by analytic differentiation of the spline at the reference point, and a residual in Hz. Good data show an rms residual of about ±0.005 Hz. In the cases of the LMs, the data cover the LM descent (10-s and 1-s resolutions) and the LM ascent stage crashes. (For Apollo 12, LM crash data were corrupted by rocket firings.)

On the microfilm, the first four pages for each orbit printout contain selected program parameters. An article published in *Science* that reports some data results is also included with the microfilmed data as is the program used to analyze these data.

The identical data are also available on 7-track magnetic tapes written in BCD at 800 bpi. The data include the subsatellite lunar latitude and longitude in 2° increments and the acceleration in mm/s^2 or Hz. The Apollo 17 data also lists the spline fit for the Doppler residual. The data are time ordered, although time is not listed explicitly.

BISTATIC RADAR

The bistatic radar experiment utilized the S-band (13 cm) and very high frequency (116 cm) transmitters on the CSMs of Apollo 14, 15, and 16. The CSM was oriented to direct the transmissions to an area from 5 to 10 km in [illegible]ameter on the lunar surface. The radio signals reflected from the lunar [illegible] received on Earth in a manner that preserved the frequency, [illegible]ation, and amplitude information. Differences between the [illegible]eristics of the echoes from the lunar surface were used in [illegible]th scattering theory to derive quantitative inferences about th[illegible] lunar properties inferred were the dielectric constant, the average slope and slope probability, density, small scale surface roughness, and embedded rocks to a depth of 20 m.

Bistatic Radar Data

Data available from NSSDC, described in the following sections, are on magnetic tape in the form of reduced short-time averages for the 13-cm and 116-cm observations. These tapes are referred to by the experimenters as JM Doptrack tapes. Combined 13-cm and 116-cm observation data, derived from the JM Doptrack tapes, are also available. These tapes are referred to by the experimenter as integral tapes. Table 5-11 lists the number of magnetic tapes available for each type of data. When ordering these data, refer to the Index to Available Data to obtain the NSSDC ID numbers necessary for satisfactory request completion.

Table 5-11. Bistatic Radar Data at NSSDC on Magnetic Tape

Mission	Date of Observation	Reduced Short-Time Averages		
		13-cm	116-cm	Combined Data*
Apollo 14	Feb. 6, 1971	1	1	1
Apollo 15	Aug. 1, 1971	2	1	1
Apollo 16	Apr. 23, 1972	2	1	1

*All combined data on one magnetic tape.

Reduced Short-Time Averages

These data are on 9-track, 800-bpi, binary magnetic tapes written in XDS Sigma 5 machine images. The 13-cm and 116-cm data have been corrected for instrumental effects, but are unedited. The tapes include observations merged with trajectory data and certain ancillary data computed from the trajectory.

Each tape file contains a header record followed by many data records. The header record includes a file identifier, the date the data were taken, the time increment between the midpoints of each data-averaging frame, and the number of records following the header record.

The data records are grouped in frames of six records each. The first five records contain observational data, and the sixth contains ephemeris data. The five data records in each frame contain elements of the coherency matrix (J). Record 1 contains J11 (K), record 2 contains J22 (K), record 3 contains the real part of J12 (K), record 4 has the imaginary part of J12 (K), and record 5 has the fractional polarization of the received signal. Record 6 of each data frame lists UT2 at the midpoint of the frame, the reflected Doppler shift minus the direct Doppler shift, the predicted bandwidth for an rms surface slope of 0.1, the angle of incidence, the spacecraft altitude and speed, the radar cross-section predicted for a smooth conducting Moon, the radar cross-section divided by the receiver power, as well as the components of selenographic unit position vectors for the position and velocity of the spacecraft, the vector for the position of the specular point, and the vector from the center of the Moon to the center of the Earth. Also included are the selenographic latitude and longitude for the spacecraft and specular point positions, the component of the Doppler shift relevant to the Earth's rotation, the total Doppler shift of the reflected signal, the speed of the specular point on the surface of the Moon, vehicle look angle to Earth, and Euler angles of local horizon coordinates.

The combined data are complete sets of analyzed data records derived from the reduced data records (the JM Doptrack tapes) and are referred to as the integral tapes by the experimenters. These data were received from the experimenters and are on 9-track, 800-bpi, binary tapes written in XDS Sigma 5 machine images. The data contain certain properties of the reduced data as well as inferred properties of the lunar surface.

Each tape file is composed of one header record followed by many data records. Each header record contains a file identifier, the date data were taken, the time increment between the midpoints of each data-averaging frame, and the number of data records following the header record. Data records include the polarized power, normalized power, unpolarized power, equivalent bandwidth, normalized absolute moment bandwidth, normalized second moment bandwidth, centroid of the echo spectrum, rms slope inferred from equivalent area bandwidth, handscaled half-power echo bandwidth, a data validity flag, spacecraft antenna gain (or zero), and all the ephemeris and ancillary data contained on data record six in each data frame of the reduced short-time averaged data tapes.

GAMMA-RAY SPECTROMETER

The gamma-ray spectrometer was carried on the CSM on Apollo 15 and 16. It was used to conduct geochemical mapping of the lunar surface by observing the emitted gamma-ray radiation. In addition, during the transearth coast phase of the mission, this experiment was used for gamma-ray astronomy. The instrument consisted of a 7- by 7-cm thallium-activated sodium iodide scintillation crystal enclosed in a plastic scintillator shield. The shield was placed in anticoincidence with the sodium iodide crystal to eliminate counting events caused by charged particles. In normal operation, the instrument was deployed on a 7.6-m boom, which reduced its response to cosmic-ray interactions and radioactive sources in the spacecraft. The instrument responded to gamma rays from 0.5 to 30 MeV and had an energy resolution of approximately 8 percent. The angular resolution of the lunar surface was approximately 2° to 3° or 70 km.

The experiment on Apollo 15 operated from July 28 to August 7, 1971, and on Apollo 16 from April 20 to 27, 1972. Some energy resolution problems occurred during the Apollo 15 mission. NSSDC has data for the Apollo 15 mission only. Refer to the Index to Available Data to obtain the NSSDC ID numbers necessary for ordering these data.

Gamma-Ray Spectrometer Merged Data

Forty-four magnetic tapes containing merged spectrometer data from Apollo 15 are available from NSSDC. These tapes are 7-track, 800-bpi, IBM 7094, binary tapes with 36-bit words and unblocked records that contain mixed data. The data are written in a repeating series of four records and contain the following information.

- Record 1 - Trajectory parameters: GMT, lunar coordinates, etc.
- Record 2 - Gamma-ray and X-ray spectrometer parameters: GMT of ground receipt, SIM bay temperature, engineering flags, etc.
- Record 3 - Housekeeping parameters: electronics, detector, and boom temperatures; boom position; etc.
- Record 4 - Gamma-ray spectrometer data: GMT, counts measured in channels 0 to 511 at 3.2768-s intervals.

The data were obtained between July 28 and August 6, 1971.

Gamma-Ray Count Rate Data

These gamma-ray count rate data from the Apollo 15 mission are on one 16-mm reel of microfilm. They are in the form of latitude-longitude matrix tables prepared by summing 2° x 2° areas of the lunar surface overflown by the Apollo 15 CSM. The summed counting rates are for 20 energy intervals ranging from 0.334-0.371 MeV to 6.37-8.00 MeV.

X-RAY FLUORESCENCE

This experiment, carried in the scientific instrument module (SIM) of the Apollo 15 and 16 CSM, was used for orbital mapping of the lunar surface composition and X-ray galactic observations during transearth coast. The instrument consisted of three large-area, 0.0025-cm thick, beryllium window proportional counters with state-of-the-art energy resolution; a set of two large-area filters for energy discrimination among the characteristic X-rays of aluminum, silicon, and magnesium; and a data handling system for count accumulation, for 8-channel pulse-height analysis, and for relaying data to the spacecraft telemetry system. Also included was a solar X-ray monitor. The large-area proportional counters were collimated to fields of view of about 60° and yielded a resolution on the lunar surface of 111 x 148 km. The data were obtained from an orbital height of 18 x 106 km on both Apollo 15 and 16. NSSDC ID numbers, necessary for ordering these data, are found in the Index to Available Data.

Lunar Orbit X-Ray Data

These data are reduced lunar surface data supplied by the investigator on one magnetic tape for each mission. The tapes are 9-track, 1600-bpi, IBM 360, binary tapes. The fundamental data are the count rates for each channel of the three lunar surface oriented detectors as a function of lunar position. (The solar detector data are useless because of saturation effects.) The data are time ordered. FORTRAN programs are included to help the user in the preliminary analysis of these data. The data are available for the following dates.

Apollo 15 - July 30 to August 4, 1971
Apollo 16 - April 20 to 24, 1972

ALPHA PARTICLE SPECTROMETER

The alpha particle spectrometer, carried on Apollo 15 and 16, was designed to determine the lunar surface radon evolution and, with the other geochemical experiments (gamma-ray spectrometer and X-ray fluorescence), determine lunar surface composition and identify localized sources of enhanced radon emission that may correspond to regions of enhanced lunar outgassing. The data obtained on the gross rate of surface radon emanation and on localized sources of enhanced radon emission were used in constructing radiation maps showing lunar surface inhomogeneities.

Measurements of alpha particle emission from deep space background were made during lunar orbit and transearth coast. The spectrometer used in this experiment was composed of a 2 x 5 array of 10 silicon surface barrier detectors housed in the same enclosure as the X-ray fluorescence experiment. Each of the 10 sensors looked toward the Moon with a 90° full angle field of view.

Each sensor had its own preamplifier, the outputs of which fed into a common analog-to-digital converter that in turn sorted the pulses into 256 energy channels in the range 4.5 to 9.0 MeV. The instrumentation was designed to turn off the other nine detectors when an event was registered in one of the detectors. The other nine detectors remained off until the event had been analyzed. Pulse-height channel information for up to a bit-rate-limited value of 10 events/s was telemetered. The average alpha particle rate encountered was about 1 count/s. Controls were available in the CM to activate or deactivate the experiment. The experiment performed normally throughout the missions. NSSDC ID numbers, necessary for ordering these data, are located in the Index to Available Data.

256-Channel Pulse-Height Analyzer Data

These data, submitted by the experimenters, are reduced pulse-height analyzer data from the 256-channel pulse-height analyzer, alpha particle spectrometer. The data are on 9-track, 800-bpi, binary magnetic tapes generated on an IBM 360 computer. There are two magnetic tapes for each mission covering the following time spans.

Apollo 15 - July 29 to August 5, 1971
Apollo 16 - April 19 to 25, 1972

There are a variable number of physical records per tape with 20 logical records per physical record, and each logical record is 48 8-bit bytes in length. Each logical record corresponds to 1 s of spacecraft telemetry, i.e., to one of the good records in the unreduced telemetry tape. A "good," unreduced, telemetry record is one that has no more than 19 "bad" data flags set. Each record contains the time, 3 temperature measurements, data flags, 10 pulse-height channel numbers and detector identification for each, and several housekeeping parameters.

MASS SPECTROMETER

A mass spectrometer experiment was included on the Apollo 15 and 16 missions (*Hoffman*, 1972). The objective was to obtain composition data in order to study sources, sinks, and transport mechanisms of the ambient lunar atmosphere. The analyzer was a dual-collector, single-focusing, sector-field spectrometer and was mounted on a retractable boom. When fully extended, the boom placed the spectrometer 7.3 m from the spacecraft, a distance anticipated to be beyond the outgassed molecular cloud.

Control of the experiment functions and boom motion was provided by a set of five switches in the CM, which were operated by a crew member according to the mission time line or by instruction from the ground controller. Instrument weight was 11 kg, and its dimensions were approximately 30 x 32 x 23 cm.

A scoop mounted on the top of the package was the gas inlet plenum. This inlet was oriented along the spacecraft velocity vector for maximum ram when ambient measurements were obtained, and it was oriented in the wake direction to determine background spectra and instrument outgassing. The plenum contained the spectrometer ion source, which had redundant filaments mounted on either side of the ionization chamber. Several outgassing operations during flight maintained the ion source in a reasonably outgassed state. On Apollo 16, an inner plenum was heated to about 520 K then held constant at 343 K.

Use of a two-collector system in the analyzer permitted the simultaneous scanning of two mass ranges: 12 to 28 and 28 to 66 u. Mass resolution was approximately a 1 percent valley at mass 40 u. The mass sweep was achieved by varying the applied high voltage in a series of 590 steps over the range from 620 to 1560 V with a dwell time of approximately 0.1 s. Thirty additional steps at 0 V were used to determine the background counting rate and to apply internal calibration, and 62 s were required to complete a mass scan. The voltage step number that determined the mass number of the ion being measured was identified by counting from step one (a sweep start flag). Bendix electron multipliers were used as pulse amplifiers to determine the counting rate of ions passing each collector slit for each voltage step. Prelaunch experiment calibration included operation in a molecular beam facility.

The mass spectrometer experiment on Apollo 15 operated for a total of 90 h: 40 h during lunar orbit and 50 h during transearth coast. During lunar orbit, the Apollo 16 obtained approximately 100 h of data, but malfunction of the boom before transearth insertion prevented further operation. More details on this experiment can be found in *Hoffman*, 1972, and in the Apollo 15 and 16 *Preliminary Science Reports*.

Mass Spectrometer Data

These data are complete mass spectra available on magnetic tape and on 16-mm microfilm. The data include the background count level of each analyzer channel, the amplitude of each mass peak, decommutated housekeeping data, and pertinent spacecraft trajectory information including orbit number, latitude and longitude, velocity, altitude, and relative Sun position.

The data on magnetic tape are formatted as blocked, variable-length records that are not labeled. These 800-bpi, 7-track tapes were produced on an IBM 360 computer. All integers and real numbers are internal IBM 360 binary and floating point representations, respectively. Each spectrum of data is contained in three records.

The microfilm data are a formatted output of the data on magnetic tape. The format presents sequential pairs of mass spectra (high- and low-mass channels) along with background and other data on the magnetic tape. Each summary chart covers several hours of experiment operation. The following mass spectrometer data are available from NSSDC. Refer to the Index to Available Data to obtain NSSDC ID numbers necessary when ordering these data.

Apollo 15 - July 30 to August 7, 1971
(Three magnetic tapes and six reels of microfilm)

Apollo 16 - April 20 to 24, 1972
(Four magnetic tapes and four reels of microfilm)

FAR ULTRAVIOLET SPECTROMETER

The ultraviolet spectrometer carried on Apollo 17 provided observations of the lunar surface, lunar atmosphere, zodiacal light, solar atmosphere emissions, and galactic and stellar emissions (*Fastie*, 1973). The sensor was an Ebert spectrometer, with a 0.5-m focal length that measured the radiation intensity as a function of wavelength from 1180 to 1680 A. Its optical components included an external baffler, entrance slit, Ebert mirror, scanning diffraction grating, exit slit, exit slit mirrors, and a photomultiplier. The grating had an area of approximately 100 cm^2 with 3600 grooves/mm. A grating mechanism included a rotating cam, with a cam follower that tilted the grating back and forth within the spectral region. The complete scan from 1180 A was achieved once every 12 s. A fiducial mark indicated the end of the scan, and its output synchronized the data word format. The photomultiplier tube produced an electrical signal that was related to the intensity of the incident light. An electronics module included all the signal-processing circuitry for telemetry. This experiment obtained data from December 10 to 19, 1972.

Far UV Spectrometer Data

These data were provided by the experimenter and are available on five 7-track, binary magnetic tapes that were written at 556 bpi by an IBM 7094 computer. They are also on five 16-mm microfilm reels. The data were obtained from December 10 to 19, 1972.

Each magnetic tape contains one file of data. Each 12-s spectrometer scan is represented by a physical record containing 125 36-bit integer words. Record word numbers 6 to 120 are data words and represent the number of photoelectrons/0.1 s. The wavelength interval corresponding to each data word is identified. Calibration information is provided so that the output can be converted to brightness in rayleighs. Some of the parameters included in the aspect data are the distance to the Earth, the optic axis right ascension and declination of the UV spectrometer (UVS), the angle between the UVS optic axis and the Sun, and the angle between the UVS optic axis and the Moon. The data are time ordered and include all the data obtained.

The data on five microfilm reels are graphic displays of some of the data that are on the magnetic tapes. These data are not ordered by time; they are displayed in two forms: averages of the spectra and time variations in the intensities observed at 1216, 1275, 1304, 1470, 1556, and 1657 Å. The five spectra used in each display frame are identified, and the actual elapsed time (hours, minutes, and seconds) of the first spectrum is given. The ordinate shows average counts/bin, and the abscissa displays bin number (wavelength interval). The counts shown are the average over five spectra. The average counts/bin value can be converted to brightness in rayleighs. The time variation plots on the microfilm show the brightness in rayleighs (ordinate) as a function of actual elapsed time expressed in decimal hours. Each variation plot contains 1 h of data with the wavelength given. The accompanying aspect data are the same as those on the magnetic tapes. NSSDC ID numbers, necessary for ordering these data, are located in the Index to Available Data.

LUNAR SOUNDER EXPERIMENT

The Apollo 17 lunar sounder experiment (ALSE) was designed to:

- Map the subsurface electrical conductivity structure to infer geologic structure,
- Make surface profiles to determine lunar topographic variations,
- Produce surface imaging, and
- Measure galactic electromagnetic radiation in the lunar environment.

The ALSE was a 3-wavelength coherent synthetic aperture radar (CSAR) operating at 60, 20, and 2 m (5, 15, and 150 MHz). The radar data were recorded on 70-mm photographic film in a conventional CSAR format and returned to Earth for processing.

There were three frequencies. The first high frequency (HF-1) system (5 MHz) was capable of the deepest exploration. The second high frequency (HF-2) system (15 MHz) was operated simultaneously with the HF-1 system to provide partial overlap in the depth of exploration, trading off for improved resolution. The very high frequency (VHF) system (150 MHz) was designed for shallow sounding and for surface imaging. Chirped pulses were transmitted at various rates of pulses per second. All three frequencies were capable of surface profiling. Separate transmit/receive antenna systems were provided for the HF and VHF ranges. The returned data were optically processed and provide good profiles of the lunar surface/subsurface. NSSDC ID numbers, necessary for ordering these data, are located in the Index to Available Data.

Lunar Sounder Data

These sounder data at frequencies of 150 MHz (VHF), 15 MHz (HF-2), and 5 MHz (HF-1) are filmed plots prepared by the Environmental Research Institute of Michigan on 70-mm film. The images were produced with variable azimuth demagnification for the various frequencies. The frequency-plane aperture was set to achieve various slant-range and azimuth resolutions. The pulse sidelobes were degraded by a range weighting factor.

The film scale parameters vary with the frequency along the film and across the film. Time ticks occur every 9 s for the HF-2 and HF-1 and every 45 mm along the signal film for the VHF. Locations can be determined by measuring from the breaks in data when the sounder was turned on and off.

A holographic viewer is required for interpreting the data on these plots. Because of instrument variations, different viewers could give results that do not agree with each other.

These data were obtained from December 11 to 16, 1972. There are two reels of 70-mm film for the VHF data and one each for the HF-2 and HF-1 data. Table 5-12 provides additional information about these data.

Table 5-12. Apollo 17 Lunar Sounder Data

Parameter	System		
	VHF	HF-2	HF-1
Frequency (MHz)	150	15	5
Translation Rate (pps)	2000	400	400
Azimuth Demagnification	3.42	69.85	69.85
Resolution (m)	10 (sl range) 60 (Az)	100	300
Sidelobe Degradation Factor	2.2	2.2	2.2
Film Scale (mm/s)			
Along	1.46	7.16×10^{-2}	7.16×10^{-2}
Across	7.14×10^{5}	4.04×10^{4}	4.04×10^{4}

Lunar Sounder Supporting Data

Supporting data and explanatory information for the Apollo 17 lunar sounder experiment were produced by the Environmental Research Institute of Michigan and are on seven microfiche cards. Included are descriptions of the VHF, HF-1, and HF-2 optically processed lunar sounder data supplied to NSSDC.

LUNAR SURFACE EXPERIMENTS

Lunar surface experiments were deployed and, in some cases, operated by the astronauts. The experiments forming the early Apollo surface experiments package (EASEP) on Apollo 11 and the Apollo lunar surface experiments package (ALSEP) on Apollo 12 and 14 through 17 were deployed on the lunar surface as far from the LMs as possible and on the most level surface available. Figure 5-11 shows the deployed ALSEP from the Apollo 12 mission.

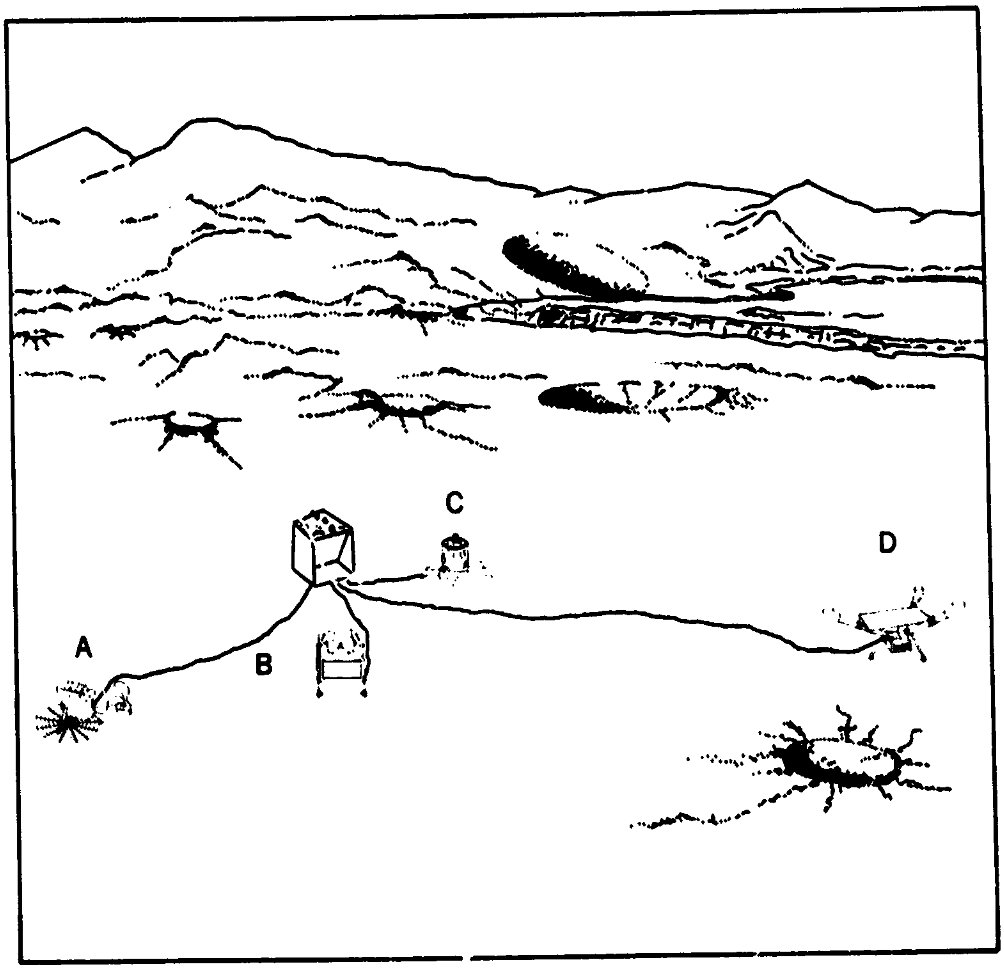


Figure 5-11. Deployed Apollo 12 ALSEP experiments: A - Cold cathode gage experiment; B - Solar wind spectrometer; C - Passive seismic experiment; D - Lunar surface magnetometers.

Most of the ALSEP experiments were connected to a central station that consisted of a radioisotope thermoelectric generator to supply power. A base antenna allowed for transmitting the data to Earth.

In addition to these powered instruments, surface experiments were performed by the astronauts on the surface and were returned to Earth in the CM. These included lunar field geology, surface mechanics, and solar wind experiments. To facilitate the lunar surface tasks, a modularized equipment transporter (MET) was designed for the Apollo 14 mission. The MET could be pulled across the lunar surface and contained tools for the astronauts. To extend the range of the astronauts, the lunar roving vehicle (LRV) was carried on the LM on Apollo 15, 16, and 17. This vehicle was driven by the astronauts and increased their mobility to a distance of approximately 30 km within a 3.5-km radius from the LM. See Table 5-13 for more information on surface activities.

Table 5-13. Lunar Surface Activities

Mission	ALSEP Deployment Coordinates*	Radial Distance Traveled (km)	Total Distance Traveled (km)
Apollo 11	23°30'E, 0°42'N	0.1	0.2
Apollo 12	3°11'S, 23°23'W	1.5	3
Apollo 14	3°40'S, 17°27'W	1.5	3
Apollo 15	26°06'N, 3°39'E	3	20
Apollo 16	9°S, 15°31'E	3	20
Apollo 17	20°1'N, 30°46'E	3.5	30

*Selenographic coordinate system.

The experiments for which NSSDC has data are listed in Table 5-14, and these experiments and data are described in the following sections.* Some of the ALSEP experiments are still active as noted in Table 5-14. See the Index to Available Data to obtain the NSSDC ID numbers, which are necessary when ordering these data. More detailed discussion of the lunar surface

*NOTE: The photography and S-band transponder data were described in the Command and Service Modules section.

Table 5-14. Lunar Surface Experiments for which NSSDC has Data

Experiment	Mission					
	Apollo 11	Apollo 12	Apollo 14	Apollo 15	Apollo 16	Apollo 17
Lunar Field Geology	X	X	X	X	X	X
Soil Mechanics	X	X	X	X	X	X
Passive Seismic	X	X*	X*	X*	X*	
Active Seismic			X		X	
Seismic Profiling						X
Laser Ranging Retroreflector	X*		X*	X*		
Surface Magnetometer and Portable Magnetometer		X		X	X*	
Heat Flow				X		X*
Traverse Gravimeter						X
Surface Electrical Properties						X
Neutron Probe						X
Suprathermal Ion Detector		X	X	X*		
Cold Cathode Ion Gage			X	X*		
Charged Particle Lunar Environment			X*			
Atmospheric Composition						X
Solar Wind Spectrometer		X		X		
Cosmic Ray					X	X
Far UV Camera/Spectrograph					X	
Lunar Dust Detector			X	X		

*Actively returning data as of January 26, 1977.

experiments can be found in *Apollo Scientific Experiments Data Handbook* (NASA TM X-58131, August 1974), prepared by JSC. An update to this document was prepared in August 1976.

LUNAR FIELD GEOLOGY INVESTIGATION

The lunar field geology investigation was designed to obtain a better understanding of the nature and development of the landing areas and the processes that modified the surfaces through the study of documented lunar geological features and returned lunar samples. This experiment was conducted by the Apollo Lunar Geology Experiment Team, in consultation with the Manned Spacecraft Center (now JSC) Science Working Panel representing the requirements of principal investigators for sample analyses. See Table 5-15 for lunar sample information.

The major equipment used for this experiment included hammers, tongs, an extension handle, a small sampling scoop, a gnomon/color patch, a spring

Table 5-15. Lunar Field Geology Investigation

Mission	Whole Rocks	Weight (kg)	Surface Cameras Used*
Apollo 11	> 20	22	Hasselblad, Maurer, Stereo
Apollo 12	50	34	Hasselblad, Maurer, Stereo
Apollo 14	69	43	Hasselblad, Maurer, Stereo
Apollo 15	335†	77	Hasselblad, Maurer, TV
Apollo 16	> 110	95	Hasselblad, Maurer, TV
Apollo 17	> 300	110	Hasselblad, Maurer, TV

*Data included with Command Module photography.
†Includes core tubes and soil fines.

scale, documented sample bags, sample collection bags, special environmental sample containers, a closeup stereo camera, other cameras, and sample return containers. Geology core samples were obtained with the use of the Apollo lunar surface drill that consisted of core stems, bits, and caps. The hand tools used for this experiment were carried by the astronauts on Apollo 11 and 12 and were located on the modularized equipment transporter on Apollo 14 and on the Apollo lunar hand tool carrier attached to the lunar roving vehicle aft pallet on the last three missions.

Lunar Field Geology Data

The lunar field geology data described in the following sections are listed in Table 5-16. The NSSDC ID numbers, necessary when ordering these data, are given in the Index to Available Data. Other identifying information is necessary to insure satisfactory request completion. These data can be retrieved when requested by specific sample numbers, or a representative photograph can be supplied if a mineral type is specified. In some cases where samples have been named (e.g., "Great Scott"), photographs can be provided by the name identification. Some thin-section photographs (photomicrographs) taken by experimenters are available from NSSDC. Those experiment photographs not stored at NSSDC can sometimes be located by NSSDC in response to requests. To order lunar field geology data, it is suggested that the catalog and index described in the following sections be ordered first. These will aid in selection, but note that NSSDC does not have photographs of all the samples described. The lunar sample data base, also described here, is another source for determining useful sample data.

Table 5-16. Lunar Field Geology Data at NSSDC

Mission	Photographs							Lunar Sample Data Base*	Index	Catalogs		Drawings
	35-mm	70-mm		4 x 5 in.		8 x 10 in.			M'film Reels*	M'fic. Cards	M'film Reels*	
	B/W	B/W	Color	B/W	Color	B/W	Color					
Apollo 11	719	335		164	4			1	1	7	1	
Apollo 12	63	1825	71	2005	530			1	1	6	1	3
Apollo 14	38	50		1591	15	1783	243	1	1	3	1	10
Apollo 15			1631	333	55	2150	306	1	1	6	1	30
Apollo 16	3			69	704			1	1	7	1	
Apollo 17				95	355			1	1	8	1	

*All missions on one reel of microfilm.

Photographs of Geologic Samples

Photographs of geologic samples returned from the Moon were received as 35-mm, 70-mm, 10.2- x 12.7-cm (4- x 5-in.), and 20.3- x 25.4-cm (8- x 10-in.) frames, some in color and some in black and white. (See Table 5-16 for specific information.) These frames can be supplied as enlarged paper prints. The photographs show the samples in a variety of ways: (1) in their containers, (2) beside a centimeter scale, and (3) in arbitrary orientations designated by cardinal compass points. For Apollo 17, photographs of samples mounted on a disk with compass orientations as they were at the lunar location of the rocks are also available. Where lunar rocks have been broken, each piece is shown separately. Assigned sample numbers are on some of the photographs. This number is a combination of the mission number and sample number. In some cases, the first digit of the mission number has been dropped; thus, 6035 identifies sample 35 from Apollo 16. Some of the 35-mm frames of thin sections, slices, and coarse fines have no identification other than frame number. Details are very good in much of this photography, and the photographs may be used for scientific studies.

Lunar Sample Data Base

These data are the current edition of the lunar sample data base for samples returned by all Apollo landing missions. The data base is maintained by the Curator's Office at NASA/JSC. The version available from NSSDC is contained on 16-mm microfilm and includes (1) a bibliography of published papers concerning lunar samples, (2) the analysis printout of the lunar sample data base, and (3) the book printout of the lunar sample data base. The bibliography is for a collection of published papers concerning the lunar samples and other related topics. A copy of the bibliography with author index may be obtained from the Curator's Office at NASA/JSC or from NSSDC by requesting the "Bibliography and Author Index of Formally Published Papers Concerning Lunar Samples." Each reference has an accession number in which the first two digits are the year of publication, followed by sequential numbers for each year.

The remainder of the lunar sample data base is a collection of published chemical, isotopic, age, and modal (mineralogic) data concerning the samples. Noble gases, light gases, and organic molecules are not included. The data base available from NSSDC comprises over 30,000 entries.

There are an additional 70,000 entries in the data base that are analyses of individual minerals, glasses, and lithic fragments. These data are not available from NSSDC but may be obtained from Dr. J. L. Warner, Code TN6, NASA/Johnson Space Center, Houston, Texas 77058.

The data bases from NSSDC and JSC include sample number, phase (physical type of material, e.g., chip, glass, whole sample, etc.), element (an analyzed property such as age, elements, oxides, minerals, etc.), value (measured quantity), units of measurement, tag (a number to eliminate redundancy in replicate analysis), method of analysis (e.g., alpha spectroscopy, colorimetry, or atomic absorption), and accession number (the assigned logging number in the bibliography). The block printout represents one determination, which is the value for one "element." The entries are listed by sample number. Within each sample number, the entries are listed by element, first by modal, then by age and chemical data. All entries are for total samples only. Specific portions of the data base may be obtained when requested by sample number. The data base for all missions is on one reel of microfilm, and portions cannot be obtained by mission number.

Lunar Sample Indexes

Indexes to the lunar field geology photographs are available on 16-mm microfilm. The indexes provide frame number, sample number, orientation of the sample as photographed, and film type (B for black and white; C for color). The indexes are for all sample photographs and may include samples for which NSSDC has no photographs.

Lunar Sample Catalogs

These data catalogs of lunar sample information contain documentation, binocular descriptions, photographs, and a complete inventory of the lunar samples. Though compiled somewhat hastily and intended for internal use only, they are useful for determining those specimens an investigator might want to study. Samples themselves must be obtained through the Curator's Office in Houston, but photographs of the samples may be obtained from NSSDC.

Included in the catalogs are elemental abundances, inorganic and rare-gas summaries, and petrological information from gamma-ray detectors, pyrolysis-flame ionization detectors, and other detectors for some samples. Tables and graphs are also included. The photographs are of identified samples. The catalog may be obtained on either microfiche or 16-mm microfilm. The quality of the film reproduction is poor.

Drawings of Rock Sample Cuttings

These cut-away drawings of rock samples from the Apollo 12, 14, and 15 missions were received as 20.3- x 25.4-cm (8- x 10-in.) positive film sheets. The cut-aways illustrate how the rock sample was cut, how many pieces, the orientation of the rock, and the piece designation. These cut-aways may be used as a catalog for selecting sample photography. Drawings are not available for all the specimens for which we have photographs, and in some cases we have drawings for which we have no sample photographs. When rock sample photographs are requested of samples for which we have only cut-away illustrations, drawings will be supplied.

SOIL MECHANICS EXPERIMENT

The objective of the soil mechanics experiment was to obtain data on the composition, texture, mechanical properties, and variation of lunar soils. These data were used to formulate, verify, or modify theories of lunar processes and history. Of particular importance are the characteristics of particle size, shape, distribution, density, strength, compressibility, dielectric properties, gas diffusion, erosion, and surface contamination. Data were obtained by photography, observation by the astronauts, examination of returned samples, spacecraft behavior telemetry at landing, and a self-recording penetrometer.

A sampling scoop penetrometer was included with this experiment on Apollo 15 and 16. The scoop had interchangeable load plates and three cones of various diameters used in trenching activities. The self-recording drum, weighing 2.3 kg, could penetrate to a maximum of 76 cm and could measure a penetration force of a maximum of 111 N. A lunar reference plane rested on the surface while measurements were obtained and served as a reference datum for penetration depth measurements. The astronauts removed the head containing the self-recording drum from the penetrometer and brought it back to Earth. Mechanical properties measured were soil cohesion, porosity, particle size, density, coefficient of friction, friction angle, and packing characteristics.

Soil Mechanics Data

Soil mechanics data are available from NSSDC as shown in Table 5-17. Results from the penetrometer instrument carried on Apollo 15 and 16 are

Table 5-17. Soil Mechanics Data at NSSDC

Mission	Time Period Coverage	Data Format	Remarks
Apollo 11	July 20, 1969	Published Report*	Surface soil is soft, slightly cohesive; granular fine to medium grains
Apollo 12	Nov. 19-20, 1969	Published Report*	Soil similar to Apollo 11, incompressible
Apollo 14	Feb. 5-6, 1971	Published Report*	Strength increased with depth; greater variation than at previous sites
Apollo 15	July 31 - Aug. 2, 1971	35-mm film	Penetration 3.0 cm min. to 15.8 cm max. Stress 1.0 N min. and 1.6 to 34.8 N max.
Apollo 16	Apr. 21-24, 1972	35-mm film	Penetration 1.8 cm min. to 74 cm max. Stress 1 to 6.5 N min. to 3 to 120 N max.
Apollo 17	Dec. 11-13, 1972	Published Report*	Density in core higher than at any other site.

**Preliminary Science Report* for appropriate experiment on microfiche.

available on 35-mm microfilm. This film contains tables and graphs on the characteristics of the soil, with notes and corrections to the raw data. The data are divided into sections. Section A contains graphs, one for each index (station). Each graph shows the penetration depth (in cm) as a function of the stress (in N/cm^2). Section B presents raw and reduced data in tabular form. The tables include information on lunar penetration data reduction for the lunar drum at each index. Tabular information includes drum load angle, drum circumference, load, stress, ratio of initial drum depth, drum depth reading, penetration depth, and correction applied.

Notes include times and locations of samplings, weight of the package, and condition and performance of the equipment. Section C for Apollo 16 data and Sections C and D for Apollo 15 data include postflight notes and correction factors, including load calibration graphs depicting load (in N) versus circumferential deflection (in mm), penetration and load, penetration correction factors, and weights. Section D for Apollo 16 data and E for Apollo 15 data contain preflight calibration graphs for the drum and for the actual/recorded penetration ratio. These data pertain to a penetrating cone with a 30° apex angle, a base area of 3.22 cm^2, and a bearing plate with a 2.54- x 12.7-cm area. The six measurements (indexes) were made at station 8 on Apollo 15 and stations 6 and 16 on Apollo 16.

For Apollo 11, 12, 14, and 17, soil mechanics data are contained in the *Preliminary Science Reports* for each mission. These papers include a discussion of procedures and conclusions drawn from the data.

PASSIVE SEISMIC EXPERIMENT

The passive seismic experiments (PSEs), carried to the lunar surface on Apollo 11, 12, 14, 15, and 16, were designed to monitor lunar seismic activity and to detect meteoroid impacts and free oscillations of the Moon. A PSE was carried on lunar landing missions as part of the ALSEP and measures seismic signals from both external and internal sources of seismic energy on the Moon. The measurements obtained have been used to determine the internal structure of the Moon, the rate of energy release, and the number and mass of meteoroids impacting on the Moon.

As a part of the experiment, lunar surface impacts of the spent Saturn booster rockets and LM ascent stages were used as external calibration sources for the seismometers. The known mass and velocity of these stages at surface impact and the lunar impact point coordinates enabled the computation of energy generated at impact and the point of energy application from the measured seismometer responses.

The passive seismic experiments were deployed about 100 m from the LMs. They each consisted of two seismic assemblies: a long period (LP) seismometer (triaxial, orthogonal) with a seismic frequency response from 0.004 to 3 Hz (80-dB dynamic range) and a short period (SP) seismometer (uniaxial, vertical motion) with a seismic frequency from 0.05 to 20 Hz (80-dB dynamic range). They were cable-connected to the central ALSEP power stations and had radioisotope heaters. The minimum detectable signals of the PSE seismometers were 0.3 μm at a frequency of 1 Hz for the SP seismometer and 0.3 μm for the LP output signal in the flat response mode.

The seismometers were housed in a drum-shaped enclosure rounded at the bottom. This enclosure rested on a support structure and was covered by a thermal shroud after deployment. The three components of the sensor assembly were aligned along the two horizontal axes, LPX and LPY, and the vertical axis, LPZ. The instruments form a seismic network on the Moon.

Four major discoveries have resulted from these experiments: (1) the existence of a crust, mantle, and core, (2) cyclic moonquakes at 800 km (deep focus), (3) shallow focus moonquakes (depth about 300 km), and (4) efficient scattering of energy in a near-source region.

Of the five passive seismometers that were deployed, four are still providing some data. The Apollo 11 passive seismometer ceased functioning on August 27, 1969, but those from Apollo 12, 14, 15, and 16 continue to obtain data. In addition, the gravimeter experiment and the seismic profiling experiment on the Apollo 17 mission can function as passive seismometers with the seismic profiling experiment used as part of the seismic network.

For Apollo 11, only seismograms on microfilm are available. For Apollo 12, 14, 15, and 16, the types of data available are the following.

- Passive Seismic Event Data (magnetic tape)
- Passive Seismic Continuous Data (magnetic tape)
- Compressed Scale Playouts (microfilm)
- Compressed Scale Event Playouts (microfilm)
- Expanded Scale Event Playouts (microfilm)
- Artificial Lunar Impact Data (magnetic tape)
- Selected Seismic Event Data (magnetic tape)
- Compressed Scale Playouts of Selected Events (microfilm)
- Expanded Scale Playouts of Selected Events (microfilm)
- Catalog of Selected Events (microfiche)
- Seismic Event Log (magnetic tape and microfilm)

These data are individually described in the following sections, and the time periods for which they are available are given. Because data are obtained on a continuing basis, time periods will change as new data are received. Refer to the Index to Available Data for NSSDC ID numbers, necessary for ordering these data. In addition, a *Data Users Note, Apollo Seismological Investigations*, is being prepared at NSSDC and will be available in the latter part of 1977. It is listed on the order form for preordering purposes. This DUN describes the seismic experiments and data in more detail than attempted here.

Passive Seismograms

The Apollo 11 PSE data for July 20 to August 27, 1969, are contained on two reels of 35-mm microfilm. The microfilm records were made from hardcopy seismograms obtained from the EASEP-PSE analog tapes at the Lamont-Doherty Geological Observatory. The tapes were received by NSSDC from NASA/JSC. Each seismogram contains approximately 6 h of data. The seismograms are numbered in chronological order, with those obtained on the first lunar day numbered from 1 to 52 and those obtained on the second lunar day numbered from 53 to 78. The original seismograms were 90 cm wide and approximately 25 cm in height. Tick marks are displayed for each minute of data. The calibration of the records was determined by using the width of the seismograms as an exact scale and a full-scale amplitude deviation of ±3 cm equal to ±512 digital units at 1x recorder magnification. Changes in recorder magnification are marked at the top of each seismogram. Accompanying documentation indicates change in short period seismometer gain, and the seismometer magnification curve is in digital units per centimeter of ground displacement. Time on the records is shown in UT. Occasional data dropouts visible in the seismograms were present on the original digital tapes. There has been no filtering performed on these data.

Passive Seismic Event Data

Seismic event data on magnetic tapes were obtained for LP components (resonant period of 15 s) by manual search by the experimenter of the compressed scale playouts. Copies were then made of the original PSE tapes for the time periods when seismic events were observed. Each event tape contains data from one station only, but data (traces of ground motion amplitudes versus time) from the same time periods were copied in chronological order onto separate tapes for each station. Therefore, intervals that may contain no detectable signal can be on the event tape because an event was detected at another station.

The 7-track tapes are binary with 800 bpi and odd parity. Several computers were used in processing these data. The data start times are approximately the LM landing day for each mission (see Table 5-1) and, for all missions, are continuous to February 29, 1976. The following number of tapes are available for each mission.

Apollo 12 - 255 tapes
Apollo 14 - 228 tapes
Apollo 15 - 203 tapes
Apollo 16 - 161 tapes

Passive Seismic Continuous Data

Passive seismic continuous data are on magnetic tapes that contain all SP data recorded during continuous operation of the lunar seismic systems for a period of one lunation from July 14 through August 13, 1973. These data were obtained by the passive seismometers carried to the Moon on Apollo 12, 14, 15, and 16. The tapes are 7-track, binary, 800-bpi, odd parity, with standard IBM end-of-file notation. Data were recorded on separate tapes for each of the ALSEP stations for each day of operation, and there are approximately 30 tapes per mission.

Compressed Scale Playouts

These experimenter-produced plots are available on 35-mm microfilm and contain 15-s resonance long period X, Y, and Z (LPX, LPY, and LPZ) and 1-s resonance short period Z (SPZ) seismic values. To enhance the signal-to-noise ratio for higher frequency events, a difference method was employed in reduction of the data. The absolute value of the difference between consecutive data points was summed over 40 points for LP data (320 points for SP data), and this value was plotted, yielding one value for every 6 s of data. Consecutive points were plotted with opposite polarity to yield a line with the appearance of a seismogram. Within the plots, components are arranged LPX, LPY, LPZ, SPZ, with LPX at the top and SPZ at the bottom. Tick marks are displayed for every 10 min of data and each hour is labeled in UT. The year and day are displayed for every 6 h of data.

The plots contain the values for each of the Apollo stations (Apollo 12, 14, 15, and 16) for the times they are in operation, and these are simultaneously displayed on the analog chart. These plots are used to identify seismic events and to determine their start and stop times. The SPX axis has malfunctioned on Apollo 12 since deployment, and no data have been received from it. The data from all the missions begin on the day of each lunar landing (see Table 5-1) and are current to February 29, 1976. There are six reels of microfilm each for the Apollo 12 and 14 missions and five reels of microfilm each for the Apollo 15 and 16 missions.

Compressed Scale Event Playouts

These plots of selected events were produced by the experimenter from the seismic event tapes and the artificial impact event tapes to provide, in compressed scale, a visual display on 35-mm and 16-mm microfilm of the contents of each event tape. These playouts have the same format as the compressed scale playouts with the exceptions that the time is not continuous and the amplitude scale on the plots is twice that of the compressed scale playouts. For the Apollo 12 and 14 seismic stations, there are two microfilm reels per mission; for Apollo 15 and 16 there is one microfilm reel per mission. The data coverage is from the date of lunar landing for each mission (see Table 5-1) to October 5, 1975, for all missions.

Expanded Scale Event Playouts

These expanded time scale playouts were taken directly from the passive seismic event data on magnetic tapes and were not processed in any way (e.g., no filtering, smoothing, or signal averaging). The playouts (usually 10 min in length) were generated on microfilm for all LP seismic events observed from November 26, 1969, to August 8, 1972, with peak-to-peak signal amplitudes of two or more digital units. The annotated format consists of year (in which the playout begins), skip X mag C (where "skip" equals the tape identification number, "mag" equals a multiplicative factor that adjusts the signal amplitude of an event for plotting, and "C" equals the long period component where X is LPX, Y is LPY, and Z is LPZ), day of the year on which the playout begins, and universal time at which the playout begins. Tick marks are placed at 1-min intervals. These tick marks are not corrected for possible clock errors. Notations on the seismograms, such as phase ticks (e.g., P or S) or experimenter-assigned event classifications, are not primary data but interpretations of the data and should be recognized and used as such.

There are two microfilm reels per mission and data coverage is from the day of lunar landing (see Table 5-1) or shortly thereafter for each mission to August 8, 1972, for all missions.

Artificial Lunar Impact Data

These seismic data of lunar impacts by man-made objects are on magnetic tapes. The tapes are identical in format to the seismic event data tapes described previously.

There are two magnetic tapes with Apollo 12 lunar impact data and one each for Apollo 14, 15, and 16. The data coverage is from the day of lunar landing for each mission (see Table 5-1) to August 3, 1970, for Apollo 12; to December 16, 1971, for Apollo 14 and 15; and to December 15, 1972, for Apollo 16.

Selected Seismic Event Data

Selected seismic event data are available on magnetic tape for large meteoroid impacts (24 tapes), high frequency teleseismic events (5 tapes), and selected moonquakes (7 tapes). The data held by NSSDC were selected from data obtained between April 13, 1971, and May 4, 1975, from the seismometers placed on the Moon during the Apollo 12, 14, 15, and 16 missions. There is a total of 11 magnetic tapes of Apollo 12 data, 9 each of Apollo 14 and 15 data, and 7 of Apollo 16 data. These experimenter-selected magnetic tapes have the same format as the seismic event tapes described previously. The data are also available as compressed and expanded scale plots on microfilm as described in the following sections.

Compressed Scale Playouts of Selected Events

These data are recordings of selected meteoroid impacts, high frequency teleseismic events, and moonquakes that were recorded by at least two stations of the passive seismic network with compressed scale amplitudes of 10 mm or larger. The data held by NSSDC are available on 16-mm microfilm. There is one reel of microfilm for each type of data. The events were selected from data obtained between April 13, 1971, and May 4, 1975, from seismometers placed on the Moon during the Apollo 12, 14, 15, and 16 missions.

The absolute value of the difference between consecutive data points is summed over 40 points for long period data and 320 points for short period data. Consecutive points are plotted with opposite polarity to yield a line with the appearance of a seismogram. Components are arranged LPX, LPY, LPZ, SPZ with long period X at the top and short period Z at the bottom. Tick marks indicate each 10 min of data, and each hour is labeled in UT. The year and day are given for every 6 h of data. These plots are used to determine start and stop times of the selected seismic events.

Expanded Scale Playouts of Selected Events

These data are recordings of selected meteoroid impacts, high frequency teleseismic events, moonquakes (type A), and artificial impacts that were recorded by at least two stations of the passive seismic network. The data held at NSSDC are available on 16-mm microfilm. There is one reel of microfilm for each type of data. The events were selected from data obtained between April 13, 1971, and May 27, 1975, from seismometers placed on the Moon during the Apollo 12, 14, 15, and 16 missions.

These time scale playouts are expanded so that 1 min of data is displayed in 10 cm. The data are not processed in any way (e.g., no filtering, smoothing, signal averaging, etc.). The annotated format consists of year (in which the playout begins), skip X mag C (where "skip" equals the corresponding seismic event tape number, "mag" equals a multiplicative factor that adjusts the signal amplitude of an event for plotting, and "C" equals the long period component where X is LPX, Y is LPY, and Z is LPZ), the day of the year on which the playout begins, and universal time at which the playout begins. Tick marks are placed at 1-min intervals and are not corrected for possible clock errors.

Catalog of Selected Events

Listings of selected seismic events are available on microfiche in a catalog format. Data are from each of the passive seismic network stations. There are three sections to the listings: (1) meteoroid impacts, (2) moonquakes, and (3) high frequency teleseismic events. The events are identified by year, day of year, start and stop time to the nearest minute (UT), amplitude at each station, expanded scale playout availability, quality factor, and type/class of the event. The data include selected event data obtained between April 13, 1971, and May 27, 1975, from Apollo 12, 14, 15, and 16 passive seismic stations and are on the same microfiche card.

Seismic Event Log

These catalogs identify all seismic events observed by the experimenter on the long period components of the lunar seismic network. The catalogs were supplied by the experimenter and are available on magnetic tape, prepared from IBM cards, and on microfilm, prepared from a hardcopy listing.

Events are presented in chronological order with the following parameters: year, day of year, event start and stop times (in UT), maximum signal amplitudes, playout, quality, and type class. A stop time of "9999" implies that the event overlaps the next event. The amplitudes given are for the vertical axis. Amplitudes were picked from the compressed scale playouts described previously. Motion amplitudes, expressed in mm, are picked from records plotted at a scale of 400 digital units per inch. A "1" in the playout column implies that an expanded scale playout, also described previously, is available for that event. A quality factor is assigned whenever the record for an event is other than normal. Priority is given to the smallest appropriate number: (1) no data at the time the event occurred, (2) clock-rate error, (3) noisy record, and (4) record masked by another event. The event type is an interpretation of the possible origin of the event, where (A) is a classified moonquake, (M) is a suspected moonquake, (C) is a suspected meteoroid impact, (Z) is mostly short period, (X) is an unusual event, (L) is a LM impact, and (S) is a Saturn IV-B impact. The event class gives the classification number for type A events. All events in the same class have matching waveforms. This log is available for Apollo 12, 14, 15, and 16 on one reel of microfilm and on magnetic tape. It includes events from the lunar landing day of each mission (see Table 5-1) to July 9, 1975, for all missions.

ACTIVE SEISMIC AND SEISMIC PROFILING EXPERIMENTS

The active seismic experiment (ASE) on Apollo 14 and 16 generated and monitored seismic waves near the lunar surface in order to study the internal structure to a depth of 460 m. For the seismic profiling experiment on Apollo 17, specific objectives were to measure seismic signals produced by detonation of explosive charges on the lunar surface, monitor natural seismic activity resulting from moonquakes or meteoroid impacts, record the seismic signals resulting from the ascent of the LM, and record the seismic signals resulting from the impact of the spent LM ascent stage. See Table 5-18 for other experiment information.

Table 5-18. Active Seismic and Seismic Profiling Experiments

Mission and Experiment	Geophone Distances from Central Station (m)	Surface Layer p-Wave Measured (m/s)	Depth Explored (m)	Predominant Frequency of Signals (Hz)
Apollo 14 Active Seismic	3,46,91	104	460	27-89
Apollo 16 Active Seismic	3,43,93	114	100	22*
Apollo 17 Seismic Profiling	148,187, 190,244	250	5000	1-2

*For Apollo 16, impact signal frequency was 10 Hz and grenade launch signal frequency was from 15 to 20 Hz.

The equipment used for the active seismic experiment was a thumper device that contained 21 small explosive charges that were fired at distances of about 5 m apart. The mortar package, containing high-explosive grenades that were operated by Earth command, was not detonated on Apollo 14 to avoid damaging the other experiments. On Apollo 16, three of the grenades were fired.

The thumper device equipment consisted of a staff with charge initiators connected by cable to the ALSEP central station, geophones (miniature seismometers) for recording the waves, and a three-channel amplifier with log compressor for telemetering to the Earth. The thumper and its small explosive charges were carried and detonated by the astronauts. The charge initiators generated seismic waves in the range from 3 to 250 Hz with a frequency response of ±3 dB from 3 to 100 Hz.

On Apollo 14, the data recordings after the detonations indicate that two p-wave velocities were measured at the Fra Mauro site, where the near surface has a wave velocity of 104 m/s, and that a sublayer exists (starting at a depth of 8.5 m) with a velocity of 299 m/s. The thickness of this sublayer is estimated to be between 38 and 76 m.

The equipment for the lunar seismic profiling experiment (LSPE) on Apollo 17 consisted of four geophones, marker flags, a geophone module with a marker flag, an electronic package in the ALSEP central station, a transmitter, an antenna, and eight explosive packages. The major components of the explosive package were a receiving antenna, a receiver, an explosive train, a signal processor, and a firing pulse generator. The antennas, geophones, geophone module, and electronics packages were deployed and connected to the ALSEP station. The explosive packages were deployed at designated sites during the lunar traverses. This experiment yielded detailed information on lunar geologic characteristics to a depth of 5 km. The experiment was also operated in a mode that yielded seismic data to cover a complete lunation span, collected during approximately 1 year. The LSPE is now being used as part of the lunar seismic network along with passive seismometers.

The data held at NSSDC from these experiments are shown in Table 5-19 and described in the following sections. Refer to the Index to Available Data

Table 5-19. Active Seismic and Seismic Profiling Data at NSSDC

Mission	Active Event Data on Magnetic Tapes	Event Plots on Microfilm Reels	Seismic Profiling for One Lunation on Magnetic Tapes
Apollo 14	Feb. 15, 1971 (1)		
Apollo 16	Apr. 21 - May 23, 1972 (4)	April 21 - May 23, 1972 (1)	
Apollo 17	Dec. 14-18, 1972 (3)		Aug. 15, 1974 - May 16, 1975 (209)

for NSSDC ID numbers, necessary when ordering these data. In addition, a *Data Users Note, Apollo Seismological Investigations*, is being prepared at NSSDC and will be available in late 1977. It is listed on the order form for pre-ordering purposes. This DUN describes the seismic experiments and data in more detail than attempted here.

Active Seismic Event Data

These geophone seismic data signals were recorded on magnetic tape. The data were obtained after grenade firings from a mortar activated by a signal from Earth and after small explosions (13 for Apollo 14 and 19 for Apollo 16) were created by a thumper activated by the astronauts. The data are reformatted log-compressed tapes. For each thumper firing, 5 s of seismic data were recorded. Twenty-one thumper shots were planned, but several were skipped to gain EVA time. Successful shots for Apollo 14 were recorded at positions 1 (located at geophone 3); 2, 3, 4, 7, 11, (located at geophone 2); and 12, 13, 17, 18, 19, 20, 21 (located at geophone 1). Nineteen shots were fired successfully on Apollo 16. The seismic signals produced by thumper firings within 9 m of a geophone had extremely impulsive beginnings and saturated the dynamic range of the amplifier for about 0.5 s. The predominant frequency of these signals ranges from 27 to 89 Hz. Shots farther from the geophones (up to 91 m) have more emergent beginnings, with the wave train building to a maximum amplitude within the first 0.25 to 0.5 s from onset of the signal and then gradually decreasing in amplitude. The peak amplitude of the recorded signals typically decreases by a factor of approximately 60 in 61 m. Because the launch signals are closely reproducible from launch to launch, a simple noise subtraction process can be used to obtain the actual signals. Launch signals on Apollo 16 did not completely decay to prefiring conditions. Signals were also recorded while the ASE was operating in a passive listening mode. The desired signal can be recognized by a change of frequency from the predominant frequency. The LM ascent was also recorded by the Apollo 16 instrument and is included in these data.

These data are on 800-bpi, 7-track, binary, odd parity, magnetic tapes created on a Univac 1108 computer.

Active Seismic Event Plots

Active seismic event data were obtained for the astronaut-activated thumper on Apollo 14 and 16. For Apollo 16, data were also obtained during firing of a mortar package that contained rocket-launched grenades and during the lunar module ascent. These data are available as plots on microfilm. The plots are of log-compressed digital data versus time.

Seismic Profiling Data for One Lunation

Seismic profiling data for one lunation, obtained by the Apollo 17 instrument, are contained on 800-bpi, 7-track, binary, odd parity, magnetic tapes created on a Univac 1108 computer. The data were generated while the seismic profiling experiment was in a passive listening mode to pursue a study of meteoroid impacts and thermal moonquakes covering one full lunation. The data were collected at intervals of approximately 4 days per month for 1 year to cover all Sun angles. Eclipse data from May 25, 1975, were also obtained. The data are contained on 209 magnetic tapes and cover a time span from August 15, 1974, to May 16, 1975.

LASER RANGING RETROREFLECTOR

The laser ranging retroreflector (LRRR) carried on Apollo 11, 14, and 15 permits Earth-based stations to conduct short-pulse laser ranging to corner reflector arrays on the lunar surface. Three arrays were deployed, forming a network well separated in latitude and longitude. The ranging data obtained included information on lunar motion, lunar libration, and Earth rotation.

The LRRR equipment included a folded panel structure incorporating 100 individual fused-silica optical corner reflectors (300 on Apollo 15) and a simple alignment/leveling device. The Apollo 15 LRRR, possessing three times as many corner reflectors, reflects pulse images that are twice as bright as the images reflected by the Apollo 11 and 14 LRRRs and permits the use of smaller telescopes for ranging. The network permits a complete geometric separation of the lunar librations and can be used to measure Earth surface motions. The Earth's pole position can be measured to within 15 cm.

On Apollo 11 and 14, the LRRRs were carried by hand and were deployed within 30 m of the LM. The lunar roving vehicle was used on Apollo 15 to transport the LRRR to the Hadley Rille site. All LRRRs are oriented toward the Earth. The LRRR is a passive instrument and can be used indefinitely. The data provided permit more refined distance measurements than were previously available. To order data, refer to the Index to Available Data to obtain NSSDC ID numbers.

Filtered and Unfiltered Laser Photon Detections

Data from the Apollo 11, 14, and 15 LRRR experiments are on 800-bpi, binary, 7-track magnetic tapes. The data were written originally on a CDC 6600 computer.

APOLLO

The filtered data consist of photon detections submitted to a data filtering procedure assuming linearity of O-C residuals over a relatively short time interval and relying on Poisson statistics for the level of confidence in a collection identified by the filter. Unfiltered data are real data heavily interspersed with noise photons from any of the various sources of stray light. Normal points that are derived from the filtered observations are also available as part of the data.

An attempt to use the data in a simple gaussian application would result in a solution closely adhering to the prediction ephemeris used to control the detector range grating. Some filtering process must be applied to the data for effective use.

There are two types of data: run data, which are designated by a "Z" in the beginning of every 80-character logical record, and shot data, which are designated by a "P" in the beginning of every 80-character logical record. The run data recorded include Julian day, clock error, ambient temperature, ambient relative humidity, percent of saturation, and wind speed. The shot data include laser energy in J x 10, laser frequency in Hz x 10, pulse length in s x 10, observational resolution, photomultiplier dark count (background), Moon count rate, star count rate, calibration star identification, filter spectral width, filter spatial width, number of shots fired this run, year, month, and day.

The number of tapes available from NSSDC and their timespans are as follows:

Apollo 11 - July 21, 1969 - March 24, 1976
(nine magnetic tapes)

Apollo 14 - February 5, 1971 - March 24, 1976
(eight magnetic tapes)

Apollo 15 - August 2, 1971 - March 24, 1976
(seven magnetic tapes)

LUNAR SURFACE MAGNETOMETERS AND LUNAR PORTABLE MAGNETOMETERS

Two types of magnetometers were carried to the Moon by Apollo astronauts: (1) lunar surface magnetometers (LSMs) that were deployed and left on the lunar surface to telemeter to Earth data on temporal variations in ambient fields and (2) lunar portable magnetometers (LPMs) with which the astronauts made a few local measurements of the ambient field and that provided no data after the astronauts' departure from the Moon. The LSMs were primarily intended to yield data useful in studies of global electric and magnetic characteristics of the lunar interior, and the LPMs were intended to yield data on local remanent magnetization.

Each LSM consisted of three orthogonal fluxgate sensors mounted at the ends of 100-cm orthogonal booms. The sensors were 150 cm from each other and 75 cm above the lunar surface. Each sensor on Apollo 15 and 16 had ground-commandable operating ranges from zero to ±50, ±100, and ±200 nT (gamma), with resolutions of 0.1 nT (gamma). For the Apollo 12 magnetometers, these ranges were from zero to ±100, ±200, and ±400 nT (gamma). Each sensor was periodically flipped to check for zero-level drift and calibrated to check for sensitivity variations. Three magnetic vectors/s were telemetered to Earth.

The Apollo 12 LSM provided useful data between November 19, 1969, and April 3, 1970, except that lunar nightside gaps occurred during this interval. Very limited data exist after this interval. The Apollo 15 LSM provided useful data between July 31, 1971, and September 20, 1972. The Apollo 16 LSM has provided useful data since April 21, 1972, except for a major gap between February 15, 1973, and August 17, 1973. Data available from NSSDC for the LSMs are listed in Table 5-20. NSSDC ID numbers, necessary when ordering these data, are given in the Index to Available Data.

Table 5-20. Lunar Surface Magnetometer Data at NSSDC

Mission	Magnitude and Component Averages on Microfilm Reels	0.3-s Magnetic Vectors on Magnetic Tapes	Filtered and Decimated Data on Magnetic Tapes*
Apollo 12	Nov. 19, 1969 - Apr. 3, 1970 (2)	Nov. 19, 1969 - Apr. 3, 1970 (35)	Nov. 28, 1969 - Dec. 3, 1969 (1)
Apollo 15	July 31, 1971 - Sept. 20, 1972 (8)	July 31, 1971 - Sept. 20, 1972 (138)	July 31, 1971 - Aug. 15, 1971 (1)
Apollo 16	April 21, 1972 - Sept. 21, 1974 (10)	April 24, 1972 - Feb. 6, 1974 (158)	

*NSSDC will acquire additional data as required.

The lunar portable magnetometers (LPMs) consisted of three orthogonal fluxgate sensors mounted on top of a tripod that was positioned 75 cm above the ground. The Apollo 14 LPM had 1.0-nT (gamma) resolution while the Apollo 16 LPM had 0.2-nT (gamma) resolution. A series of measurements was made by the astronauts at various locations near the two landing sites. The final data from these LPM experiments are found in *Dyal et al.*, 1973. For further details, see *Dyal et al.*, 1974.

Total Magnetic Field Magnitude and Components

These data are on 16-mm microfilm that was generated at NSSDC from the original hardcopy plots submitted by the experimenter. Each frame contains 30 or 60 min of data. Either 3- or 6-s averaged values of magnetic field magnitude and of each of three Cartesian components are plotted per frame. The coordinate system used has the X-axis normal to the local surface, and the Y- and Z-axes normal to the X-axis and directed eastward and northward, respectively. NSSDC can supply these plots for the time periods shown in Table 5-20.

0.3-s Magnetic Vectors

These LSM magnetic vector data are available on experimenter-supplied magnetic tapes written in 556 bpi. These 7-track, DCS binary format tapes were created on an IBM 7040/7094 computer. Logical and physical records have 751 and 460 words, respectively. Each logical data record contains the time for the first data point and the Cartesian components of 500 successive magnetic field vectors. Because one data point was obtained every 0.3 s, each logical record covers 2.5 min of data. Field components are given in a coordinate system with X radially outward from the local surface and Y and Z tangent to the surface and directed eastward and northward, respectively. Typically, each tape contains 3 days of data. The Apollo 12 data contain four data gaps: December 12 to 18, 1969; January 4 to 17, 1970; February 3 to 15, 1970; and March 6 to 17, 1970. Apollo 16 data are being received on a continuing basis. Currently available data are shown in Table 5-20.

Filtered and Decimated Magnetic Field Data

These filtered and decimated magnetic field data from the LSMs are on 7-track, 556-bpi, BCD, magnetic tapes submitted by the experimenter as samples of the available data. The tapes contain a header record and successive groups of three physical records where each group constitutes one logical record. The 1602-character header record includes the degree of decimation and the filter weights used. The first physical record in each logical record contains the time of the first subsequent vectors. The second and third physical records each contain 50 magnetic vectors (Cartesian components in ALSEP coordinates and field magnitude). NSSDC holds a list of times for which the original data were subjected to filtering and decimation and will acquire appropriate tapes from the experimenter as requested. Currently available tapes are listed in Table 5-20.

HEAT FLOW EXPERIMENT

The heat flow experiment, which was part of the ALSEP on Apollo 15, 16, and 17, was designed to determine the rate of heat loss from the lunar interior. The experiment detected the following types of lunar temperature information: high sensitivity, low sensitivity, difference, probe ambient, thermocouple reference, probe cable ambient, and local surface brightness.

The instrumentation consisted of two 1.2-m probes that were inserted into the lunar surface, a special tool for probe insertion, and an electronics package that was cable-connected to the probes and the central station. To place the probes into the surface, two 3-m holes were drilled into the surface by an astronaut, using the Apollo lunar surface drill (ALSD). The ALSD was equipped with core stem caps and retainers, core stems, core bits, a bore/bit drill adapter, a treadle, and a bore stem/core stem wrench. The bore stem assemblies used in drilling remained in the holes to provide a casing to prevent collapse of the hole walls during insertion of the probes. Temperatures were obtained during lunar days, lunar nights, and a total eclipse on August 6, 1971. The heat flow through the surface provided data on the lunar soil conductivity, contributed to the resolution of issues concerning lunar internal heating processes, and established limits of constraint on interior temperatures and composition of the Moon.

The Apollo 16 probe cable was broken during deployment and no data were obtained. The Apollo 15 probes were deployed on July 31, 1971, to depths of 1.0 and 1.4 m and continue to obtain data. The heat flow value is 3.1 x 10^{-6} W/cm^2. The Apollo 17 probes were deployed on December 11, 1972, to depths of 2.4 m each and continue to operate. Heat flow values from these probes are 2.8 x 10^{-6} W/cm^2. NSSDC ID numbers, necessary for ordering these data, are located in the Index to Available Data.

Thermal Conductivity

Heat flow experiment data, containing thermal conductivity measurements, are available on 7-track, 800-bpi, binary, magnetic tapes generated on an IBM 1130 computer. The data consist of a chronological sequence of time points, each of which are associated with several temperatures and temperature differences. The time is measured in milliseconds from the beginning of each experiment, and the temperature data are in K. The data are organized in five groups; each group is a combination of the four parameters: temperature (T), temperature difference (DT), gradient bridge (G), and ring bridge (R). The identifying letters are associated with two numbers. The first number refers to the probe (1 or 2), and the second number designates the probe section (upper--1, lower--2) or the thermocouple number (1 or 4). For example, DTG11 refers to a temperature difference measurement from the gradient bridge in the upper section of probe 1. Other parameters in the data are TREF, which is the temperature of the thermocouple reference bridge, and TC, which is a thermocouple temperature. There are two magnetic tapes available for Apollo 15 and for Apollo 17 (four tapes total), and the data are from the date of deployment (see Table 5-1) to December 28, 1974, for both experiments.

Heat Flow Error Analysis

A report on the Apollo 17 heat flow thermocouple error investigation, provided by the Science Requirements Branch of Johnson Space Center, is available on one reel of 16-mm microfilm. Thermoelectric errors are defined by thermal models of the electronics unit and reference sensor. Temperature differentials between spurious junctions are resolved to better than 0.3 K. The models are verified by data acquired from environmental tests of a specially modified heat flow experiment instrument. Apollo 15 and 17 site temperature profiles are applied to a thermal model that establishes a 0.04 K difference between sensors of the Apollo 17 temperature field. All errors affecting the data are summarized and error characteristics are shown for all thermocouple temperatures. The data cover a time period from December 12, 1972, to December 31, 1973.

TRAVERSE GRAVIMETER EXPERIMENT

The traverse gravimeter experiment on Apollo 17 provided gravity data for a high-accuracy relative survey of the lunar gravitational field in the lunar landing area. The data are also used for an Earth-Moon gravity tie. Specific objectives were to measure the values of gravity at selected known locations along the lunar traverse, relative to the value at a lunar base station, and to measure the value of gravity at a known point on the lunar surface (base station), relative to the gravity at a known point on Earth. Gravity anomalies on Earth have led to major discoveries such as isostasy, tectonogenesis, lateral density variations in the crust and mantle, strength of the mantle, geometry, geosynclines, margins, batholiths, and the figure of the Earth. Surface gravity measurements on the Moon can lead to an understanding of features such as mare ridges, the edge effects of mascons, craters, rilles, scarps, thickness variations in the regolith and lava flows, density variations in the basement, and mare highland interfaces. The equipment for this experiment consists of a portable gravimeter that was transported on the LRV to selected sites. Traverse measures were taken while the gravimeter was mounted on the LRV. The crewmen activated the appropriate switches in the required sequence and read and reported the numbers appearing on the digital display register. These measures were taken during the stay of the landing mission, from December 11 to 13, 1972. NSSDC ID numbers, necessary for ordering these data, are located in the Index to Available Data.

Traverse Gravimeter Experiment Final Report

A microfiched copy of the principal investigator's final report on the traverse gravimeter experiment is available from NSSDC. The report contains sections on the basic theory of interpretation, a description of the equipment used, the results, and analysis and discussion of the results. Twenty-three valid gravity values were obtained. The following data for each value are included: location, elapsed time at which the measurement was initiated (h:min:s), the displayed value, the difference between the displayed value and the value at the LM site, raw Δg value, Δg value after application of an empirical correction, the elevation in meters, and comments. The data were acquired between December 11 and 13, 1972.

SURFACE ELECTRICAL PROPERTIES EXPERIMENT

The surface electrical properties experiment on Apollo 17 obtained data about the electromagnetic energy transmission, absorption, and reflection characteristics of the lunar surface and subsurface for use in the development of a geological model of the upper layers of the Moon. This experiment determined layering, searched for pressure of water below the surface, and measured electrical properties in situ, determining these as a function of depth. The selected frequency range was chosen to measure these properties in a range from a few meters to a few kilometers in depth. The transmitter produced continuous waves at 1, 2.4, 4, 8.1, 16, and 32.1 MHz, successively. These waves permitted measurement of the size and number of scattered bodies in the subsurface. Any moisture present was easily detected because minute amounts of water in rocks of subsoil change the electrical conductivity by several orders of magnitude.

The equipment for this experiment consisted of a deployable self-contained transmitter, a multiple-frequency transmitter antenna, a portable receiver/recorder on the LRV, a wide-bandwidth mutually orthogonal receiver antenna, and a retrievable data recording device. The crew transported and set up the transmitter about 100 m from the LM and then deployed the antennas. The receiver/recorder was placed on the LRV. The crew established the location of the LRV in relation to the transmitter for each data stop during the traverse. Wheel turns were counted for distance, and azimuth was recorded using the navigation system. The recorder was then returned to Earth. The experiment obtained data from December 11 to 13, 1972. NSSDC ID numbers, necessary for ordering these data, are located in the Index to Available Data.

Demultiplexed Data

Demultiplexed electrical property data are available on one BCD, 556-bpi, magnetic tape generated on an IBM 360 computer. This tape contains all the data of one type, which were digitized and demultiplexed, in a single array. The data on the tape consist of (1) receiver operating mode compared to time, (2) receiver temperature compared to time, (3) received signal strength during the time when the transmitter was turned off (six detection frequencies, three components), (4) receiver calibration signals from the detection of calibrated noise sources (six detection frequencies, three sources), and (5) data for each experiment frequency. The data for each experiment frequency consist of the range compared to time array and the detected signal strength compared to time for six components (two transmitter antennas and three receiver antennas). The tape also contains navigation data. There are two files of data. The first file contains straightened science and navigation data. The second file contains unstraightened science data.

Data Plots

Data plots and the final technical report on the surface electrical properties (SEP) experiment are available on microfiche. Included is a description of the system used in processing the data, the method of obtaining digitized data from the analog tape produced on the Moon, the processing to demultiplex the data, the method used to merge navigation and science data, the procedures used to generate the plots, a comparison with very long based interferometry, and the reconstruction of the SEP antenna patterns during the 360° turnaround. The plots are frequency versus range.

NEUTRON PROBE

The lunar neutron probe on Apollo 17 was designed to measure the rates of low-energy neutron capture as a function of depth in the lunar regolith. The experiment made use of two particle-track detection systems. The first system was a cellulose triacetate plastic detector used in conjunction with boron-10 targets to record the alpha particles emitted with the neutron capture on boron-10. The second system used mica detectors to detect the fission fragments from neutron-induced fission in uranium-235 targets.

The neutron probe had the form of a rod and yielded an essentially continuous record of the neutron capture rate from the lunar surface down to a depth of 2 m. The probe was activated and deactivated by a rotational motion that brought the target and detector system in and out of alignment. An on-off mechanism was necessary to prevent accumulation of background events produced in flight by neutrons from the ALSEP power generator and from cosmic-ray induced neutrons in the spacecraft. Point sources of uranium-238 were included at three positions along the probe to provide fiducial marks to verify that the probe was properly activated. In addition, cadmium absorbers were included in the center and bottom of the probe to obtain a neutron energy spectrum with a threshold of 0.35 eV. Further spectral information was obtained from analysis of krypton-80 and krypton-82 produced by bromide neutron capture in potassium bromide contained in evacuated capsules that were inserted at the top, middle, and bottom of the probe.

The experiment performed normally from activation on December 12, 1972, to termination at the end of the third EVA on December 13, 1972. There will be no unpublished data from this experiment appropriate for submission to NSSDC; however, published reports of experiments are available and are listed in the following section. The NSSDC ID numbers, necessary for ordering these publications, are located in the Index to Available Data.

Published Reports

These published reports, submitted to NSSDC in hardcopy form, each contain a description of the experiment, equipment, data history, experiment operational history, and data processing techniques. The actual experiment specimens require refrigeration and are stored at the NASA/JSC Lunar Sample Curatorial Facility. The following published reports are contained on microfiche at NSSDC.

Burnett, D.S., and D.S. Woolum, "Lunar Neutron Capture as a Tracer for Regolith Dynamics," *Proc. Fourth Lunar Sci. Conf., 2, Geochim. et Cosmoch. Acta,* 2061-2074, 1974.

Woolum, D.S., and D.S. Burnett, "In-Situ Measurement of the Rate of U-235 Fission Induced by Lunar Neutrons," *Earth and Planet. Sci. Lett., 21* (2), 153-163, January 1974.

Woolum, D.S., D.S. Burnett, and C.A. Bauman, "Lunar Neutron Probe Experiment," *Apollo 17 Preliminary Science Report*, NASA SP-330, 18-1 to 18-12, 1973.

Woolum, D.S., D.S. Burnett, M. Furst, and J.R. Weiss, "Measurement of the Lunar Neutron Density Profile," *Moon, 12*, 231-250, February 1975.

SUPRATHERMAL ION DETECTOR EXPERIMENT

The ALSEP suprathermal ion detector experiment (SIDE) was placed on the lunar surface during the Apollo 12, 14, and 15 missions. It measures ions generated from ultraviolet ionization of the lunar atmosphere and from the free-streaming and thermalized solar wind/lunar surface interaction. From the data obtained, flux, number density, velocity, and energy per unit charge can be determined. A curved plate analyzer with crossed electric and magnetic fields (E x B) with a velocity selector (filter) detected ions with normal velocities from 0.4 to 93.5 km/s and energies from 0.2 to

48.6 eV, enabling species discrimination of masses up to 1000 u. A separate curved plate analyzer (without a velocity filter) counted protons in selected energy intervals from 10 to 3500 eV. The orientation of these directional instruments prevented direct observation of solar wind ions except in the tailward sheath. However, ions reflected from or generated toward the bow shock were observed.

Suprathermal Ion Data

The SIDEs experienced some loss of data caused by arcing and are operated only when temperatures are <85°C. This change in operations occurred on March 18, 1970, for the Apollo 12 SIDE; on October 20, 1971, for the Apollo 14 SIDE; and on December 16, 1971, for the Apollo 15 SIDE. Previous to these dates, the data are continuous and normal from the date of deployment (see Table 5-1). Data available from NSSDC are shown in Table 5-21 and are described in the following sections. NSSDC ID numbers, necessary when ordering these data, are given in the Index to Available Data.

Table 5-21. Suprathermal Ion Detector Experiment Data at NSSDC

Mission	Mass Analyzer and Total Ion 24-s Resolution Data on Microfilm Reels		Mass Analyzer Data on Magnetic Tapes	Engineering Parameters on Microfilm Reels	Ion Spectrograms on Microfilm Reels	Total Ion Detector Data on Microfilm Reels
	Plots	Listings				
Apollo 12	24	207	13	1	1	14
Apollo 14	144	98	12	1	2	13
Apollo 15	278	303	12	6	1	8

Mass Analyzer and Total Ion 24-s Resolution Data

Both plots and listings of mass analyzer and total ion 24-s resolution data are available on 16-mm microfilm. The experimenter-generated listings and plots include (1) the total ion data in 20 channels from 3500 eV/Q to 10 eV/Q and (2) the mass spectrometer data in 6 energy ranges from 48.6 to 0.2 eV and in 20 mass ranges from 1 to 1000 u plotted against frame number.

The data for Apollo 12 range from 10 to 1000 u, for Apollo 14 from 6 to 750 u, and for Apollo 15 from 1 to 90 u. For Apollo 12 and 14, data prior to those available from NSSDC can be obtained from the principal experimenter (Dr. J.W. Freeman, Dept. of Space Sciences, P.O. Box 1892, Rice University, Houston, Texas, 77001). The time periods of available data are listed below; additional data is expected.

Apollo 12 - September 14, 1971, to December 31, 1973
Apollo 14 - August 26, 1972, to December 31, 1973
Apollo 15 - August 26, 1972, to September 9, 1974

Both total ion and mass spectrometer data appear on each plot. Each set of spectra required 24 s to be obtained in the normal experiment mode. Interpretation of the plots requires reference to the housekeeping data contained with the listings.

Mass Analyzer Data

These analyzer data are available on 7-track, 800-bpi, odd parity, binary, IBM compatible tapes. The words are 24-bit binary integers with negative numbers represented at two's complement. There are 28 words per logical record, 100 logical records per physical record, and 1850 physical records per file. Each logical record contains time, mass analyzer data channels of accumulated counts, and housekeeping parameters as required. Unreliable data are replaced by insertion of -1. Data tapes are available for the following time periods.

Apollo 12 - November 19, 1969, to March 3, 1973
Apollo 14 - February 6, 1971, to April 11, 1973
Apollo 15 - August 3, 1971, to June 2, 1973

Engineering Parameters

These engineering parameters are available on 16-mm microfilm supplied to NSSDC by the experimenter. The data are in the form of listings that contain appropriate experiment status words as functions of time. These listings are useful for interpreting other data from the suprathermal ion detector experiment. These listings were also included, as appropriate, with other total ion and mass analyzer data. The microfilmed listings are available for the following time periods.

Apollo 12 - August 17, 1972, to December 31, 1972
Apollo 14 - August 26, 1972, to December 31, 1972
Apollo 15 - August 24, 1972, to December 31, 1973

Ion Spectrograms

These three-dimensional plots of 20-min averaged mass analyzer data summarize the large-scale features observable using the SIDE data and are available on 35-mm microfilm. One complete lunation is presented on a frame. The count-rate energy spectra are plotted on log-log scales in the plane of the frame, and time is represented by offsetting each energy-versus-flux plot up and to the right to simulate the third dimension. Energy along the X-axis is in eV/Q.

These plots were generated by the experimenter and microfilmed by NSSDC. NSSDC also has produced 20.3- x 25.4-cm (8- x 10-in.) negatives of these data for production of publication-quality prints for instances where the 35-mm microfilm is inadequate for a user's purpose. These reproductions can be supplied for specific frames. These data are available for the following time periods.

Apollo 12 - November 19, 1969, to August 11, 1972
Apollo 14 - February 6, 1971, to April 1, 1973
Apollo 15 - August 20, 1971, to January 9, 1973

Total Ion Detector Data

These experimenter-generated data are on 7-track, 800-bpi, odd parity, binary magnetic tapes that are IBM compatible. The data are from the ALSEP total ion detectors (TIDs) on Apollo 12, 14, and 15 for the following time periods.

Apollo 12 - November 19, 1969, to March 14, 1973
Apollo 14 - February 6, 1971, to April 11, 1973
Apollo 15 - August 3, 1971, to December 29, 1972

The words are 24-bit binary integers with negative numbers represented as two's complement. There are 28 words per logical record, 100 logical records per physical record, and 1850 physical records per file. Each tape is one file. Each logical record contains time, 20 TID data channels of accumulated counts, and housekeeping parameters as required. Unreliable data are replaced by insertion of -1.

COLD CATHODE ION GAGE EXPERIMENT

The cold cathode gage experiment (CCGE), which was carried to the Moon on Apollo 12, 14, and 15, determined the amount of gas (atmosphere) on the lunar surface in terms of concentration of particles per unit volume (pressure). A typical cold cathode ion gage was used that depended on the ambient temperature. The results from this experiment, combined with those from the suprathermal ion detector experiment (SIDE), were used to determine the pressure and density of the lunar atmosphere. The electronics of the CCGE were contained in the SIDE experiment as well as the CCGE command and data processing systems. The CCGE determined pressures from 1.33 x 10^{-4} to 1.33 x 10^{-10} N/m^2 (1 x 10^{-6} to 1 x 10^{-12} torr) of the ambient lunar atmosphere. The CCGE operations were the following.

- Apollo 12 - From November 19 to 20, 1969 - No data at NSSDC.
- Apollo 14 - From February 5, 1971, to April 15, 1973 - Some engineering data lost on April 5, 1971; February 1972, nighttime data lost; little or no usable data after April 15, 1973.
- Apollo 15 - From July 31, 1971, to February 22, 1973 - Limited daytime operations because of high-voltage restrictions; substandard data after February 22, 1973.

The NSSDC ID numbers, necessary for ordering these data, are located in the Index to Available Data.

Plots of Lunar Atmosphere Density versus Time

These experimenter-generated plots contain lunar atmosphere density measurements and are available on 35-mm microfilm reels. The density measurements are from 1 x 10^5 to 1 x 10^{11} parts/cm^3 on a logarithmic scale, and gage temperatures are from 0 to 400 K on a linear scale. Quarter-minute averages are plotted against time, with 15 h of data on each frame. All time values are UT. These data are available for Apollo 14 and 15 on three reels of microfilm for the following time periods.

Apollo 14 - February 9, 1971, to December 31, 1973
Apollo 15 - July 31, 1971, to December 9, 1973

CHARGED PARTICLE LUNAR ENVIRONMENT EXPERIMENT

This experiment, carried only on Apollo 14, was designed to measure the energy spectra of low-energy charged particles striking the lunar surface. The main part of the instrumentation consisted of two electrostatic analyzers. One of these pointed toward local lunar vertical, and the other to a point 60° from vertical toward lunar west. As a first approximation, both detectors could be considered to point in the ecliptic plane.

Each analyzer consisted of a set of direction-defining slits; deflection plates; five small-aperture, C-shaped, channel electron multipliers; and one large-aperture channel electron multiplier. For a given applied deflection voltage, the five multipliers were arranged to count particles of one polarity with differing energies, while the large-aperture multiplier made a wide-band measurement of particles of the opposite polarity. During each 19.2-s interval in the automatic mode of experiment operation, deflection voltages of zero (twice) and ±35, ±350, and ±3500 V were applied to the deflection plates of both analyzers for 2.4 s at each voltage. The infrequently used manual mode permitted the continuous application of a single deflection voltage, thus increasing temporal resolution for particles in a limited portion of the spectrum.

Useful data obtained during each 19.2-s interval (automatic mode) were, for each analyzer, 1.2-s accumulated counts of electrons in 18 energy windows between 40 eV and 20 keV and ions in 12 energy windows between 0.17 and 20 keV. The experiment worked normally from deployment on February 5, 1971, until April 8, 1971, when the analyzer pointing away from lunar vertical failed. The other analyzer continued to function normally until June 6, 1971, when a partial failure occurred. Operation of this analyzer was intermittent for the rest of 1971. During most of 1972, operation was continuous during lunar night and intermittent during lunar day. Operation was continuous from December 1972 to February 1973. After this time period, high-voltage problems occurred again. For further details, see *Burke and Reasoner*, 1972. The available data are described below. NSSDC ID numbers, necessary for ordering these data, are located in the Index to Available Data.

Count Rate Data

Data acquired between February 5, 1971, and March 2, 1973, are available on 53 experimenter-supplied magnetic tapes. Each tape is 7-track, 556-bpi, binary, produced on an SDS computer, with 10 logical records per physical record and 111 36-bit words per logical record. Each logical record contains all the particle counting data taken over one 19.2-s sequence, in addition to the necessary time and mode identification information.

Position and Orientation Information versus Time

These are available on one 7-track, 556-bpi magnetic tape in binary integer 36-bit format that was generated by the experimenter on an SDS 92 computer. The data cover a time period from February 5, 1971, to December 31, 1973. There are three files, one for each year. One set of data is given for every 2 h in each record. Data include (1) look direction information for each experiment analyzer relative to Moon-Sun and Moon-Earth lines and in geocentric solar ecliptic and solar magnetospheric coordinates and (2) instrument-location information, relative to local midnight and in geocentric solar ecliptic and solar magnetospheric coordinates. Note that some computed parameters are included for a time period prior to the lunar emplacement of the instrument.

200-eV Electron Count Rate Plots

Eighteen hardcopy plots, submitted by the experimenter, are available on one reel of 35-mm microfilm generated at NSSDC. Each plot contains 2 days of 5-min-averaged, 200-eV electron count rates. This mode was chosen because it includes the peak in the plasma sheet electron spectrum and portions of the photoelectron and magnetosheath electron spectra. The plots include the time period February 6, 1971, to March 12, 1971, which contains the first orbit of the Moon about the Earth after the emplacement of the instrument on the Moon. The experimenter has marked on the plots physically significant transitions (e.g., from the magnetotail to the magnetosheath) and the monthly 18-h period of solar ultraviolet-induced photoelectron contamination. The experimenter also has generated similar plots for other times and other modes that were scientifically interesting to him, but not on a routine basis. All his data are to be found in the count rate magnetic tape data described in a previous section.

ATMOSPHERIC COMPOSITION EXPERIMENT

To study the composition and variations in the lunar atmosphere, a miniature magnetic deflection mass spectrometer was deployed on the lunar surface during the Apollo 17 mission and was oriented to intercept and measure the downward flux of gases. The ion source contained two filaments selectable by command. Three collector assemblies were placed to collect ion beams in the ratio 1:12:27.4, so that three mass ranges were scanned simultaneously: 1 to 4, 12 to 48, and 27.4 to 110 u. For the high-mass channel, the resolution was set at 100 for a mass of 82 u. Electron multipliers, pulse amplifiers, discriminators, and counters were used; one system was used for each mass range.

In normal operation, the electron bombardment energy was fixed at 70 eV, and then the instrument sensitivity to N_2 of 3.77×10^{-3} A/N m^{-2} (5.0×10^{-5} A/torr) was sufficient to measure the concentration of gas species in the 1.33×10^{-13}-N/m^2 (1.0×10^{-5}-torr) range. An alternate operating mode provided four different electron energies of 70, 27, 20, and 18 eV, which were cycled by successive sweeps of the mass spectrum. A voltage scan of the mass spectrum was employed using a high-voltage stepping power supply. The sweep voltage varied through 1330 steps from 320 to 1420 V, with a dwell time of 0.6 s/step. Because each step was synchronized to a main frame of the telemetry format, the telemetry word position served as the identifier of atomic mass number. The sweep time was 13.5 min. The instrument was calibrated inside a molecular beam facility.

The data available from NSSDC for the atmospheric composition experiment are described in the following sections. NSSDC ID numbers, necessary for ordering these data, are located in the Index to Available Data.

Mass Peak Summary Data

Mass peak summary data are available on two magnetic tapes and on microfilm. The magnetic tape data are on 1600-bpi, binary, 9-track tapes produced on an IBM 360 computer, with spanned variable-blocked records. A logical record is 324 bytes, and the block size is 3224 bytes. Tape number 1 contains the summarized data from lunation 1 through lunation 5. Tape number 2 contains lunations 6 through 9. Each record gives a summary of the data obtained from one mass spectrum, formatted in 80 binary words of 4 bytes each. Parameters included in each record are time of start of spectrum with January 1, 1973, set as day equal to zero; peak amplitudes for the following gas species (in u): 4, 28, 32, 35, 36, 37, 38, 40, 44, and 92; gas concentrations for helium and argon; and solar ephemeris data for the Apollo 17 site.

The microfilmed data are a printed record of the data on the summary tapes. Each frame consists of a table of values, and the headings for the first two columns are date and the normal elevation, which is part of the solar ephemeris data for the Apollo 17 site. Five different table headings are given: peak amplitudes, concentrations, ephemeris, housekeeping, and sweep high voltage. The tables are displayed in groups: first, peak amplitudes, then concentrations, etc. The peak amplitude tables contain values for the following gas species (in u): 4, 28, 32, 35, 36, 37, 38, 40, and 44. The concentration table gives values for helium and argon. The lunation number is printed in the top right-hand corner of each frame.

The time period for the microfilmed data is from January 2, 1973, to September 2, 1973. The magnetic tape data cover the time period from May 24, 1973, to September 3, 1973.

Tables of Mass Peaks

Tables of mass peaks are available on both microfilm and magnetic tape. The microfilmed data have six pages of data for each mass spectrum: two each for the low-, mid- and high-mass ranges. Values for several other parameters are also given including dates and times of the measurements; the mass range; the Sun's elevation, azimuth, and zenith angle; lunar surface temperature; and experiment monitors.

The mass peak data are also available on 10 magnetic tapes provided by the experimenter. These are 9-track magnetic tapes written at 1600 bpi on an IBM 360 computer. Record format is variable span. Flag words fill data time gaps to insure proper spectra identification. In addition to mass peak data, there are several other parameters presented including measurement of time; azimuth, zenith, and elevation of the Sun; lunar surface temperature; and experiment monitors. The data time period coverage for both the microfilm and the magnetic tapes is from January 2, 1973, to October 4, 1973.

SOLAR WIND SPECTROMETER

A solar wind spectrometer was part of the Apollo 12 and 15 ALSEP packages, and each was left on the lunar surface. The spectrometers were designed to measure energies, densities, incidence angles, and temporal variations of the electron and proton components of the solar wind plasma. The energy ranges on the Apollo 12 spectrometers were from 6 to 1330 eV (electrons) and from 18 to 9780 eV (protons). On Apollo 15, the ranges were 10 to 1,480 eV (electrons) and 50 to 10,400 eV (protons).

The spectrometers consisted of seven modulated faraday cups opened toward different, but slightly overlapping, portions of the lunar sky. The instruments were used to observe the directional intensities of the electron and positive ion components of the solar wind and magnetic tail plasma that strike the surface of the Moon. Ion observations are useful for solar wind plasma parameters, and electron observations are indicative of the lunar surface environment.

The solar wind spectrometer on both missions operated well. Apollo 12 data exhibit more distortion due to the instrument location on the lunar surface. In November 1971, two energy levels on the Apollo 12 spectrometer encountered trouble; on the Apollo 15 spectrometer, two channels experienced intermittent modulation dripping.

The solar wind spectrometer data listed in Table 5-22 are available from NSSDC and are described in more detail in the following sections. The NSSDC ID numbers, necessary for ordering these data, are located in the Index to Available Data.

Fine Resolution (28-s) Plasma Parameters

These data are the highest resolution (28 s/spectrum) plasma data available from the experiment. The data were processed on a Univac 1108 computer and are written on 7-track, 800-bpi, BCD, even parity tapes. Physical records are blocked to 384 words, and each physical record contains 32 logical records of 12 words each, at 72 BCD characters to every 12 words. Each record contains time, proton density, alpha-to-proton ratio, bulk speed, angle of flow, most probable thermal speed, and various housekeeping and goodness-of-

Table 5-22. Solar Wind Spectrometer Data at NSSDC

Mission	Fine Resolution (28-s) Plasma Parameters on Magnetic Tapes	Hourly Averaged Plasma Parameters	
		Magnetic Tapes	Microfilm Reels
Apollo 12	Nov. 19, 1969 - Dec. 31, 1974 (16)	Nov. 19, 1969 - Dec. 31, 1973 (2)	Nov. 20, 1969 - Dec. 31, 1974 (1)
Apollo 15	July 31 - Dec. 8, 1971 (1)	July 31 - Dec. 8, 1971 (1)	Aug. 2, 1971 - June 30, 1972 (1)

fit parameters relating to the reliability of the calculated plasma parameters. The first record on each tape contains labeling information to identify the tape contents for a user. Each tape contains one file. NSSDC expects to receive additional Apollo 12 and 15 plasma data of this type.

Hourly Averaged Plasma Parameters

Hourly averaged plasma parameters are available on 7-track, 800-bpi, even parity, BCD tapes produced on a Univac 1108 computer. They are also available on microfilm. These data were supplied by the experimenter. Each set of averages on magnetic tape is in two logical records; there are two logical records and 216 BCD characters per physical record. Four sets of hourly averaged parameters are computed with the following criteria: (1) all fine time scale parameters (FTSP), (2) all FTSP computed from spectra with small rms error on curve-fitting and thermal speeds less than one-half the bulk velocity, (3) all FTSP computed from spectra that satisfy the requirements of criterion 2 as well as having only one flow-angle that can be directly measured, and (4) all FTSP computed from spectra that satisfy criterion 2 as well as having both flow angles directly measurable. Each tape contains one file. Contained in each of the four sets of averages are the proton density, alpha-to-proton ratio, bulk speed, angle of flow, number of spectra, and rms deviations of each average.

Experimenter-generated plots of hourly averaged plasma parameters as functions of time are available on 35-mm microfilm. There are 22 days of data on each frame. Contained in each plot are the hourly averaged proton bulk speed, most probable thermal speed, proton density, and angle of flow from the hourly averaged data on the magnetic tapes that satisfy criterion 2.

COSMIC-RAY EXPERIMENTS

There were two similar cosmic-ray experiments. One was the cosmic-ray detector (CRD) experiment on Apollo 16, and the other was the lunar surface cosmic-ray (LSCR) experiment on Apollo 17. The CRD experiment was designed to measure the charge, mass, and energy spectrum of the solar wind and heavy cosmic rays (in the energy ranges from 0.5 to 10 keV/nucleon and from 0.2 to 200 MeV/nucleon), to provide calibration data for glass detectors including tektite glass, to measure the thermal neutron flux at the lunar surface, and to assess the problem of argon-40 implantation. The experiment obtained data enroute to the Moon as well as on the surface. The shield mechanism (on the surface) failed to retract completely, thus obscuring the field of view of the detector. The exposure time for the CRD was 1 week, and a solar flare occurred during this time. The CRD was returned to Earth.

The LSCR experiment had the following objectives: (1) to measure the flux of solar wind particles with atomic number 2 to 26 using mica detectors; (2) to determine the flux of light, rare gas, and solar wind ions using metal foils; (3) to measure the flux of low-energy particles in space, both solar and galactic, during quiet Sun conditions using plastic, glass, and mica detectors; and (4) to determine the radon concentration in the lunar atmosphere using mica detectors. These detectors were hung from the LM, some of them in the shade of the LM with the detectors pointed toward space and the rest in the direct sunlight. All detectors were brought back to Earth for analyses of the particle tracks. The total exposure time was 45.5 h, and the detectors were sensitive to charged particles from about 1 keV/nucleon to several MeV/nucleon.

NSSDC ID numbers, necessary for ordering the published experiment reports described in the following section, are located in the Index to Available Data.

Published Reports

Experiment results are available in published reports that contain descriptions of the CRD and LSCR experiments, equipment, data history, experiment operation history, and data processing techniques. The CRD results are published in "Lunar Surface Cosmic Ray Experiment S-152, Apollo 16 General Electric Experiment Final Contract Report" by R. L. Fleischer, et al., and the LSCR results are published in "Apollo 17 Lunar Surface Cosmic Ray Detector Final Report," by R. M. Walker. The actual test sheets used for particle detection must be refrigerated for archiving and are held in storage at the NASA/JSC Lunar Sample Curatorial Facility.

FAR UV CAMERA/SPECTROGRAPH

This experiment, carried on Apollo 16, constituted the first planetary-based astronomical observatory and consisted of a tripod-mounted 76-mm (3-in.) electronographic Schmidt camera with a cesium iodide photocathode and film cartridge. Spectroscopic data were provided in the 300- to 1350-A range (30-A resolution), and imagery data were provided in two passbands (1050 to 1260 A and 155 to 1200 A). Difference techniques allowed Lyman-alpha (1216 A) radiation to be identified. The astronauts deployed the camera in the shadow of the LM and then pointed it toward objects of interest. Specific planned targets were the geocorona, the Earth's atmosphere, the solar wind, various nebulae, the Milky Way, galactic clusters and other galactic objects, intergalactic hydrogen, solar bow cloud, the lunar atmosphere, and lunar volcanic gases (if any). At the end of the mission, the film was removed from the camera and returned to Earth. Data were acquired between April 21 and 24, 1972. NSSDC ID numbers, necessary for ordering these data, are located in the Index to Available Data.

Far UV Photographs/Spectra

A second generation negative copy of the 35-mm film returned from the Descartes landing site on the Apollo 16 mission is available on 70-mm film and comprises 209 frames obtained between April 21 and 23, 1972. Included are preflight calibration exposures (frames 1 to 18), a black frame (frame 19), and the 190 exposures taken from the lunar surface (frames 20 to 209). The mission frame number for each picture is on the film, but no other information is given. However, supporting data, described in a subsequent section, are provided by NSSDC when these data are requested.

The lunar surface exposures are distributed over 10 specific target pointings. There are both imagery and spectral frames. Imagery was done with a lithium fluoride or a calcium fluoride corrector plate, while the spectra were taken using either the lithium fluoride corrector plate or no corrector plate.

Catalog and Supporting Data

A catalog of the far UV photographs and supporting information for digitized scans of these photographs (which are expected to be received at NSSDC) were supplied by the experimenter and are available on 16-mm microfilm. Information for each scan is contained on a single catalog page. The nature of the information given for each scan makes this catalog useful for three purposes. First, it is a source of general information on each of the mission frames because data such as camera pointing, filters used, exposure time, and visible objects are provided. Second, it is a useful adjunct to the viewing of the mission frames. Third, it is an essential guide in determining the location of the microdensitometer scan(s) of the frames on the digitized-scan magnetic tapes and is the source of information on how the scans were performed and the size of the scans.

LUNAR DUST DETECTOR

The ALSEP lunar dust detector experiment (engineering experiment) was carried to the Moon on Apollo 11, 12, 14, and 15. Sufficient data from Apollo 11 and 12 were not collected to permit analysis of the degradation result. The purposes of the experiment were to separate and measure high-energy radiation damage to three NPN 10-ohm-cm silicon solar cells (1 x 2 cm each), mounted on the ALSEP Sun shield, to measure solar cell output reduction caused by dust accumulation, and to measure reflected infrared energy and temperatures for use in computing lunar surface temperatures. One solar cell was intentionally damaged by irradiation, another had no cover glass, and the third cell was a control.

The dust detector had two components: a sensor package mounted internally and externally on a vertical side of the ALSEP central station and a printed circuit board located within the ALSEP central station and interfaced with the power distribution unit of the ALSEP data subsystem. The irradiated cells had a power drop of 2.5 percent/year for Apollo 14 and 1 percent/year for Apollo 15. The power drop for the Apollo 14 nonirradiated cell was 4.3 percent/year and for Apollo 15, 3.5 percent/year. Data from this experiment are described in the following sections. NSSDC ID numbers, necessary for ordering these data, are located in the Index to Available Data.

Daytime Data

Data plots for the Apollo 14 and 15 dust detectors are available on 19 reels of 16-mm microfilm for the following time periods.

Apollo 14 - May 5, 1971, to February 24, 1976
Apollo 15 - July 31, 1971, to February 22, 1976

These plots consist of voltages from each solar cell and temperatures from the three thermistors during daytime conditions. Dust thermal radiation engineering measurement outputs consist of internal temperature, cell temperature, external infrared temperature, bare-cell output, 0.15-mm irradiated-cell voltage, and 0.15-mm cell voltage as a function of time. Temperatures from the cells range from 298 to 398 K (25° to 125°C). Voltages from the cells range from 0 to 70 mV during sunlight conditions depending on Sun angle and individual cell characteristics.

Eclipse Data

Data plots of temperatures from the three thermistors and voltages from the solar cells of the ASLEP package on Apollo 14 during eclipse events on January 30, 1972, are available on one reel of 16-mm microfilm. The plots consist of internal temperatures, cell temperatures, external infrared temperatures, bare-cell output, 0.15-mm irradiated-cell voltages, and 0.15-mm cell voltage as a function of time.

SUBSATELLITE EXPERIMENTS

The Apollo 15 and 16 missions each carried a subsatellite (SS) equipped with experiments designed to study interplanetary magnetic fields and particles. The subsatellites were deployed from the CSM's scientific instrument module bay while in lunar orbit. This occurred after the lunar surface mission, rendezvous of the LM with the CSM, and transfer of astronauts and lunar samples from the LM to the CM were completed.

As each subsatellite was released into lunar orbit, three equally spaced, folded booms automatically deployed. These booms were mounted at the base of the subsatellite and were 1.5 m long. (See Figure 5-12.) After boom deployment, the subsatellite spin rate stabilized at 12 rpm. The subsatellite spin axis was approximately perpendicular to the ecliptic plane.

The Apollo 15 SS, after the first 6 months of operation, experienced an electronic failure and continued operating in a partial mode for the next 11 months when, because of a power failure, it ceased operations. The Apollo 16 SS operated for approximately 1 month and then decayed. SS orbital parameters are given in Table 5-1.

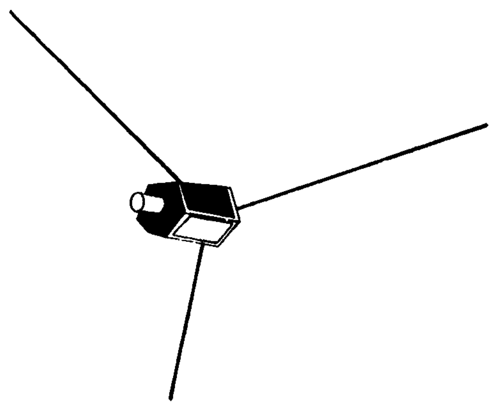


Figure 5-12. The Apollo subsatellite.

Data available from NSSDC for the lunar particle shadows and boundary layer experiment and the biaxial fluxgate magnetometer experiment carried on the SSs are described in the following sections. The S-band transponder data were described in the Command and Service Module Experiments section.

LUNAR PARTICLE SHADOWS AND BOUNDARY LAYER EXPERIMENT

The lunar particle shadows and boundary layer experiment was designed to study the plasma regimes through which the Moon moves, interaction of the Moon and plasmas, and some features of the structure and dynamics of the magnetosphere. Two 2-element, solid-state particle telescopes and four electrostatic analyzers were used. The two telescopes were aligned along the spacecraft spin axis and differed in that one had an organic foil in which incident electrons lost little energy relative to protons. Each telescope was operated at six discrimination levels that corresponded on both telescopes to electron threshold energies of approximately 20, 40, 85, 155, 320, and 520 keV. The unshielded telescope was sensitive to protons of approximately the same energies as electrons in the six discrimination states, but the shielded telescope was sensitive to protons with six thresholds between about 340 and 700 keV. Species resolution was determined from the relative responses of the two telescopes.

The electrostatic analyzers were oriented perpendicular to the spacecraft spin axis and measured both large fluxes of electrons in the energy windows 0.53 to 0.68, 1.9 to 2.1, and 5.9 to 6.4 keV and small fluxes of electrons in the energy windows 5.8 to 6.5 and 13.5 to 15.0 keV. These analyzers did not count protons. Spin-integrated counts were obtained for all energy windows except the 13.5- to 15.0-keV window in which four-sectored data were obtained. The instruments worked as planned for the life of the subsatellites. Data available from NSSDC are shown in Table 5-23 and described in the following sections. The NSSDC ID numbers, necessary for ordering these data, are listed in the Index to Available Data.

Table 5-23. Lunar Particle Shadows and Boundary Layer Experiment Data at NSSDC - Averaged Particle Count Rates

Mission and Time Period	24-s and 10-min Data on Microfilm Reels	10-min and 2-h Data on Magnetic Tapes	2-h Data Orbital Summary on Microfilm Reels
Apollo 15 Aug. 4, 1971 - Jan. 23, 1973	21	2*	1†
Apollo 16 Apr. 25, 1972 - May 29, 1972	4	1	1

*Substandard data after February 24, 1972, is included.
†End date is February 3, 1972.

10-min and 2-h Averaged Particle Count Rates

These magnetic tape data are 10-min and 2-h averages of proton and electron fluxes. The magnetic tapes are 7-track binary written at 800 bpi and generated on a CDC 6600 computer. There is one file per tape, and each physical record consists of 276 60-bit words. The first 16 words of a physical record give the orbit number, date, and fractional day of the start of the orbit, followed by the number of minutes of operation during the orbit (2 h) of the 0.53- to 0.68-keV electron mode, and 12 successive 10-min values of this parameter. The next 260 words constitute a 13- x 20-word array where the first column of the array contains orbit-averaged fluxes for all counting modes, and each of the next 12 columns contains 10-min averaged fluxes for these modes.

24-s and 10-min Averaged Particle Count Rates

Averaged count rate (24 s and 10 min) data for Apollo 15 and 16 are available on microfilm. These microfilm data are plots of the 24-s and 10-min particle fluxes on 35-mm microfilm provided by the experimenter. Each time interval is covered by 10 frames, each having 2 traces that represent all the counting modes of the experiment. Although some characters on the frames are illegible, the supporting documentation permits ready use of the plots. There are two types of film plots, one type presenting the finest time scale data at 2 h/frame, and the other presenting 10-min averages at 24 h/frame. For any one time, both types of plots are included (10 each). The 2-h averages of all counting modes plotted at 10 days/frame are identified in the data, "2-h Averaged Count Rates (Orbital Summary)," described in the following section.

2-h Averaged Count Rates (Orbital Summary)

These data are plots of particle fluxes on 35-mm microfilm provided by the experimenter. Each time interval is covered by 10 frames, each having 2 traces, representing all the counting modes of the experiment. Although some characters on the frames are illegible, the supporting documentation permits ready use of the plots. Each frame covers 10 days and contains 2-h averaged fluxes. Finer time scale flux plots are identified in the data, "24-s and 10-min Averaged Particle Count Rates," described in the preceding section.

BIAXIAL FLUXGATE MAGNETOMETER

The Apollo 15 and 16 biaxial fluxgate magnetometer experiments were boom-deployed on the lunar-orbiting subsatellites. One of the magnetometer axes lay along the satellite spin axis; the other was in the spin plane. A Sun pulse sector generator provided phase information needed to obtain the direction of the magnetic vector. The spin rate was 5.175 s. The dynamic ranges of the Apollo 15 instrument were ±50 and ±200 nT. The Apollo 16 instrument dynamic ranges were ±25 and ±100 nT. Three data modes were available: one real time and two stored modes. The real-time mode was available when the subsatellite was on the earthward side of the Moon. The sample rate was once per second in the spin plane and twice per second along the spin axis. The normal stored mode obtained a vector every 24 s. The fast stored mode recorded the same information every 12 s. The stored modes were available at any time. (See *Apollo Scientific Experiments Data Handbook*, 1974, for more details on this experiment.)

Data available from NSSDC are shown in Table 5-24 and are described in the following sections. The NSSDC ID numbers, necessary for ordering these data, are given in the Index to Available Data.

Table 5-24. Biaxial Fluxgate Magnetometer Experiment Data at NSSDC Vector Magnetic Field Measurements

Mission and Time Period	24-s Time Resolution on Magnetic Tapes	192-s Averaged Data Plots on Microfilm Reels	192-s Averaged Data Listings on Microfilm Reels
Apollo 15 Aug. 4, 1971 - Feb. 3, 1972	29	6	6
Apollo 16 Apr. 25, 1972 - May 29, 1972	9	1	1

24-s Biaxial Vector Magnetic Field Measurements

The Apollo 15 subsatellite magnetic tapes were generated by NASA/JSC for the experimenter and contain 24-s magnetic field data and engineering data every 192 s, the basic cycle time for the subsatellite. These data are on 7-track, 800-bpi, odd parity, magnetic tapes written on a Univac 1108 computer with 36-bit words.

Contained in the data are time, various data relevant to spacecraft position and housekeeping, and the magnetic field measurements transverse and parallel to the spacecraft spin axis that, together with the Sun pulse information, yield triaxial magnetic field measurements. These data are blocked with a maximum of 560 words per physical record. Times are in milliseconds.

Apollo 16 subsatellite data are also available on magnetic tape that was generated by the experimenter on an IBM 360/91 computer. This tape is a 9-track, 1600-bpi, odd parity, binary, multifile tape with 36-bit words.

Plots of Triaxial 192-s Averaged Magnetic Field Data

These plots are on 16-mm microfilm reels generated by NASA/JSC for the experimenter. There are two types of plots. The first (A) plots contain 192-s averaged magnetic components, X, Y, and Z, in spacecraft coordinates and total field magnitude plotted against time for one orbit per frame. Spacecraft coordinates have X and Y in the spin plane, with X along the projection of the Earth-Sun line. The Z direction lies along the spacecraft spin axis, which is nearly perpendicular to the ecliptic plane. No sensor drift corrections have been applied to the Z component of the data prior to plotting, but drifts are expected to be within +0.27 to -0.87 nT (gamma). Offset drifts are tabulated in the documentation, along with instructions on how to apply them. The second (B) plots contain engineering parameters, spin periods, and data from the lunar particle shadows and boundary layer experiment for the shielded and unshielded telescopes.

192-s Averaged Magnetic Field Vectors and Magnitude

These magnetic data are on 16-mm microfilm reels generated at NASA/JSC for the experimenter and contain 192-s averaged data presented as functions of time. These data listings contain X-, Y-, and Z-vector components in spacecraft coordinates where the X- and Y-axes lie in the spacecraft spin plane, with X along the projection of the Earth-Sun line. The Z-axis is along the spacecraft spin axis and is approximately along the northward normal to the ecliptic plane. Also listed are magnetic field magnitude and the shielded counts from the lunar particle shadows and boundary layer experiment data. Subsatellite state information is also tabulated.

REFERENCES/SOURCES

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Technical Information Service
American Institute of Aeronautics
and Astronautics
750 Third Avenue
New York, NY 10017

N-numbers refer to documents available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

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THE LUNA AND ZOND PROGRAMS

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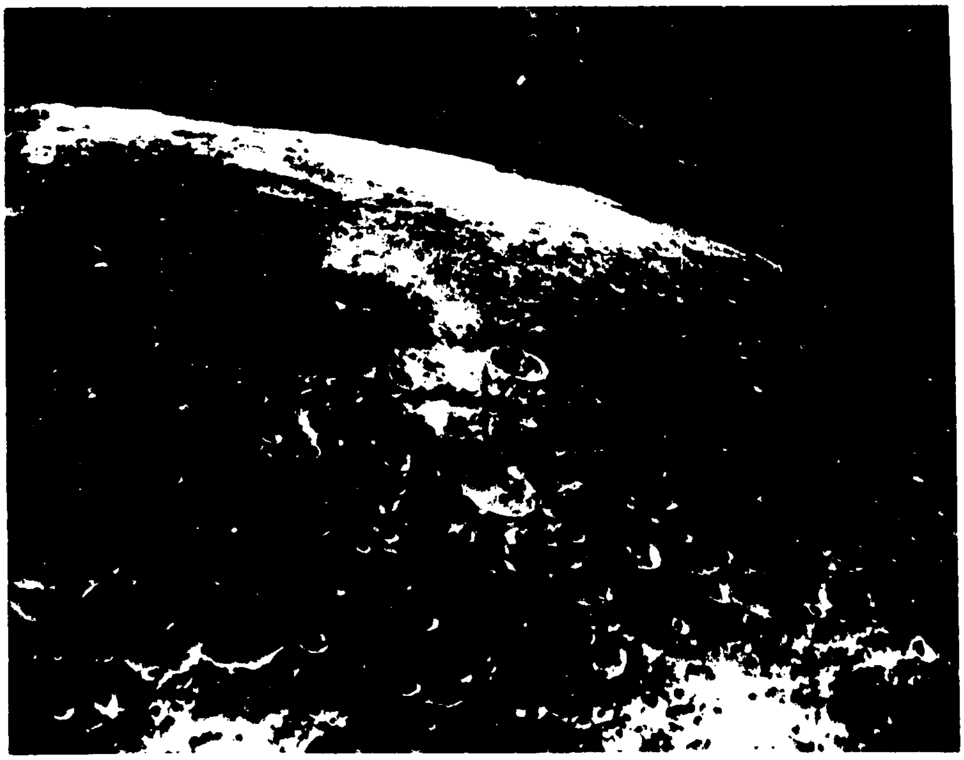
6 THE LUNA AND ZOND PROGRAMS



Zond 8 photograph taken during close flyby of the lunar farside west of Mare Orientale. Mare Orientale is seen on the limb at center, and the large "eared" crater is east of Ladygin. (Zond 8-17-401)

N77-32134

THE LUNA AND ZOND PROGRAMS

The Luna and Zond series of unmanned U.S.S.R. spacecraft were designed to investigate the Moon and its vicinity (*Govorchin*, 1965; *Parker*, 1969). With the launch of the first Luna in 1959, the U.S.S.R. lunar program began. Sixteen Luna spacecraft and, since 1965, six Zond spacecraft have obtained lunar data. (The first two Zond spacecraft were launched in 1964 to study Venus and Mars, respectively.)

These series have included flyby, lunar-orbiting, and soft-landing missions. A variety of experiments were carried out by these spacecraft including studies of magnetism, X-ray and gamma ray emissions, gravitational anomalies, and chemical composition. Soil samples, near- and farside photography (both color and black and white), and Earth-cloud photography were also acquired. Luna 17 and 23, launched in 1970 and 1974, respectively, carried automatic roving vehicles (Lunokhod 1 and 2) that traversed portions of the lunar surface. Lunokhod 1 roamed in Mare Imbrium near Sinus Iridum, and Lunokhod 2 roamed in the Crater Le Monnier at the eastern edge of Mare Serenitatis. The Luna 16, 20, and 24 missions soft-landed on the lunar surface, scooped up lunar material, and returned these samples to Earth. These three missions landed near Mare Crisium.

The few data acquired by NSSDC from the successful Soviet Union lunar missions are from Luna 3, 9, and 13 and from Zond 3, 6, 7, and 8. These missions are compared in Table 6-1 and 6-2. The Luna 3 and Zond 3 spacecraft were flyby missions (Figure 6-1) that continued into solar orbits. Zond 6 through 8 (Figure 6-1) flew around the Moon and returned to Earth. Zond 6 and 7 were retrieved in the Soviet Union and Zond 8 in the Indian Ocean. Luna 9 and 13 (Figure 6-2) were lunar landers that remained on the Moon.

NSSDC has acquired only small amounts of data from these missions, and these are exclusively photographic. The photographic samples received are in the form of paper prints. Some publications containing photographs, described in the following sections, are considered data by NSSDC because these are virtually all the U.S.S.R. data that are available for general use.

FLYBY PHOTOGRAPHY EXPERIMENTS

The purpose of the Luna 3, Zond 3, and Zond 6 through 8 flyby mission photography experiments was to obtain photographs of the lunar surface, particularly of the limb and farside regions. The Luna 3 spacecraft began the photographic coverage of the farside and Zond 3 completed it. Zond 8 obtained photographs of the Mare Orientale region eastward on the farside to 165°E.

Table 6-1. Luna and Zond Flyby Missions

Parameters	Mission Name				
	Luna 3	Zond 3	Zond 6*	Zond 7*	Zond 8*
Launch Date	Oct. 4, 1959	July 18, 1965	Nov. 10, 1968	Aug. 7, 1969	Oct. 20, 1970
Photograph Acquisition Date	Oct. 7, 1959	July 20, 1965	Nov. 14, 1968	Aug. 11, 1969	Oct. 24, 1970
Location of Photographs	16.9° - 17.3°Lat. 117.6° - 117.1°Long.	Unknown	17° - 180°W 80°N - 70°S	~ 30°Lat. ~ 40°Long.	17°W - 165°E 70°N - 90°S
Spacecraft Altitudes					
First Photographic Sequence altitude (km)	63,500 - 66,700	7,300 - 8,900	9,300 - 6,800	9,100 - 8,300	9,600 - 8,880
Second Photographic Sequence Altitude (km)			2,600 - 2,400	1,500 - 1,200	1,600 - 1,400
Number of Photographs					
First Photographic Sequence	Unknown	28 B/W	1 B/W	18 Color	38 B/W
Second Photographic Sequence			2 B/W	15 Color	70 B/W

*Returned to Earth and recovered.

Table 6-2. Luna Lander Missions
(for which NSSDC has data)

Parameters	Mission Name Luna 9	Luna 13
Launch Date	Jan. 31, 1966	Dec. 21, 1966
Landing Date	Feb. 3, 1966	Dec. 24, 1966
Landing Coordinates	64.5°W, 7°N	62.05°W, 18.87°N
Landing Area	Western edge of Oceanus Procellarum*	
Photo Acquisition Dates	Feb. 4-5, 1966	Dec. 25-28, 1966

*Luna 13 landed 300 km from Luna 9.

The cameras used were phototelevision types designed to photograph and transmit surface images. The Zond 3 camera lens had a focal length of 106.4 mm and an aperture of 13 mm. The 25.4-mm film used on Zond 3 had a halftone wedge impressed on the edge. The film was exposed through a shutter, passed along into a developing device, dried on a hot drum surrounded by a moisture absorbing device, then passed onto a holder. Here the film was scanned with a light spot of 20-μm diameter. The beam was collected by a condenser and entered a photomultiplier that produced an electrical signal proportional to the film wedge density. These signals were then transmitted by a narrow-beam parabolic antenna to a receiving station on Earth at 1100 lines/frame. The image signals received were recorded on magnetic tape, and the image was reconstructed on electric-chemical paper.

There were two transmission modes. The first was a rapid scan that was used for the 28 frames exposed. These were studied, and it was decided to transmit 14 of the images in the normal mode. These frames were enlarged by approximately a factor of 8, compared to the onboard frame size. Of the 28 exposed frames, 23 were of the lunar surface, 3 were exposed through ultraviolet light, and 2 were either not transmitted or did not include the lunar surface.

Similar methods were used by Luna 3, although camera parameters differed. The Luna 3 camera focal lengths were 200 and 500 mm; apertures were 1:56

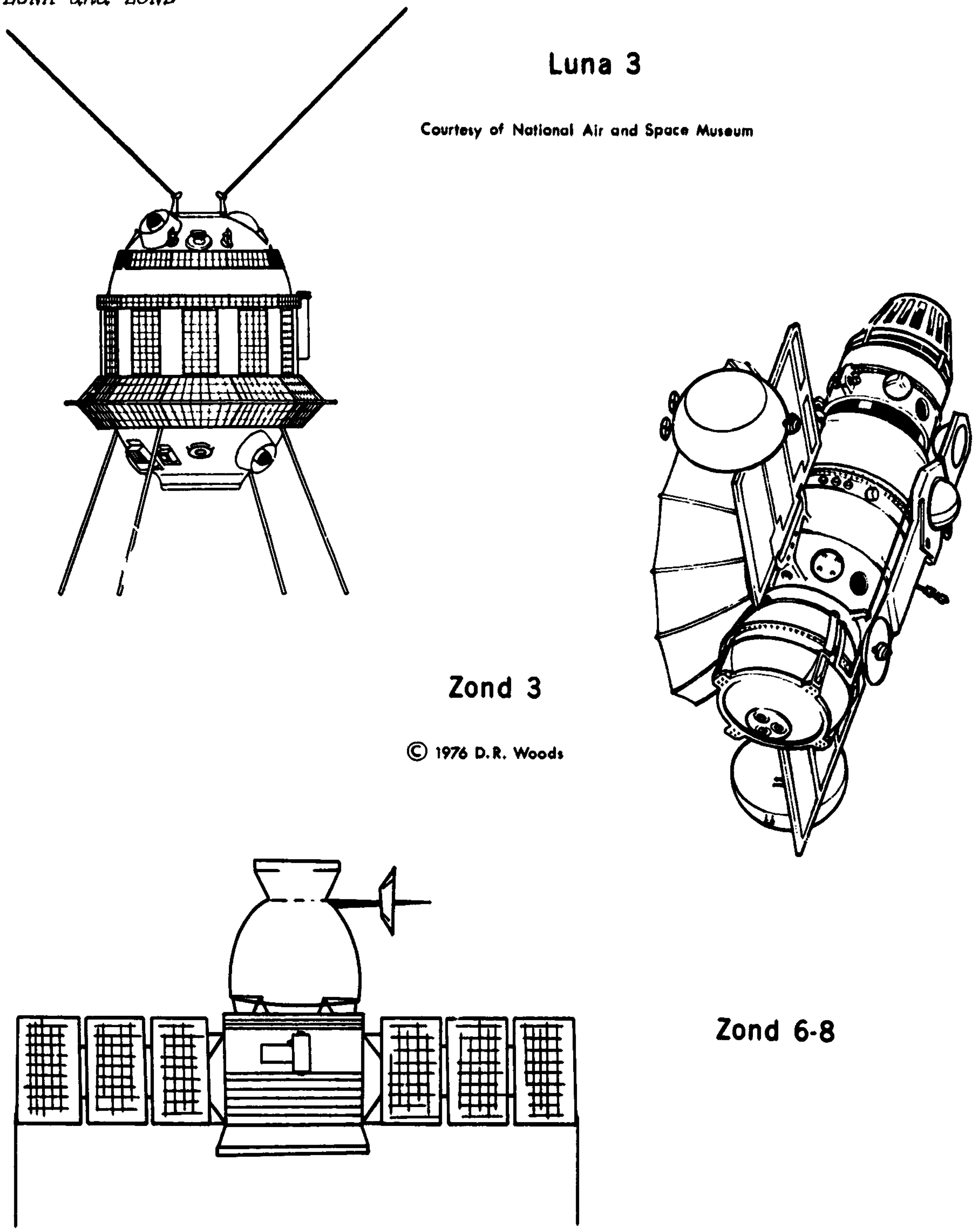


Figure 6-1. Luna and Zond flyby spacecraft.

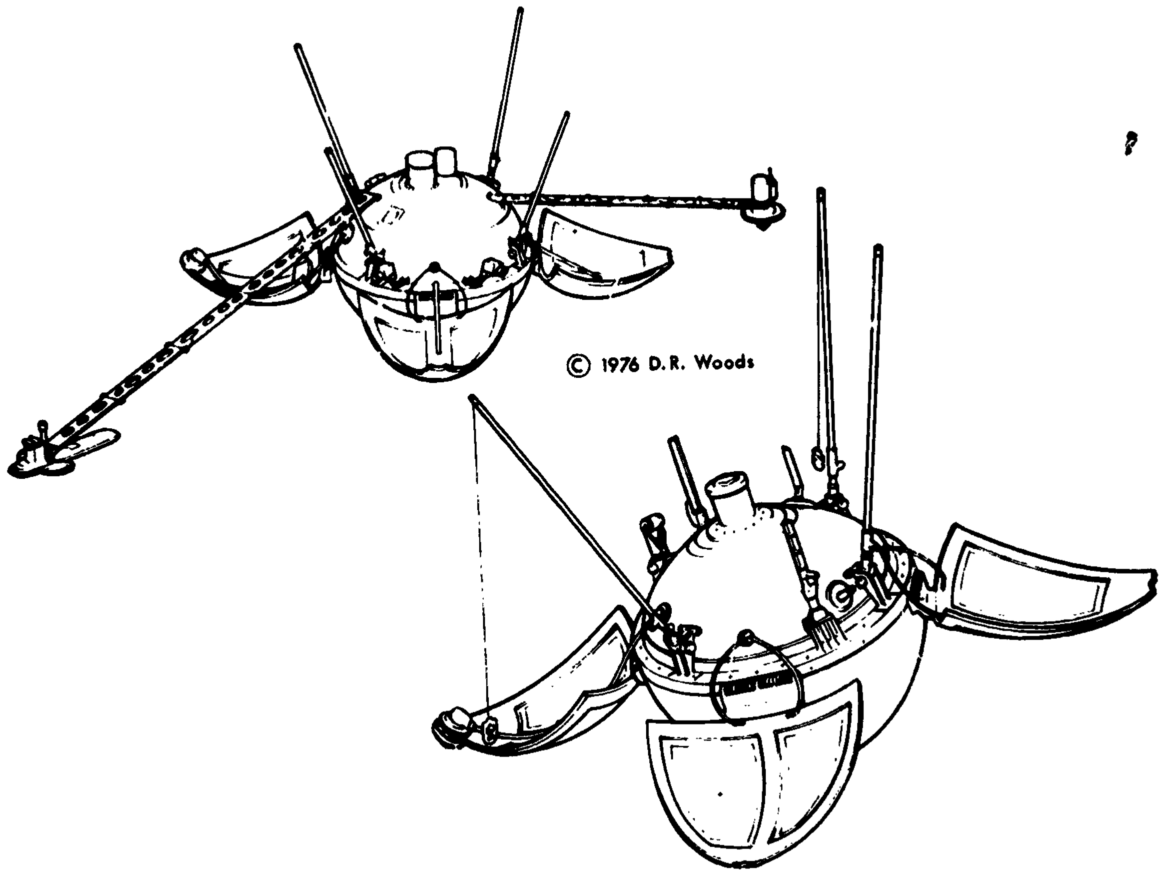


Figure 6-2. Luna lander spacecraft.

and 1:9.5, respectively; transmission lines were ≤ 1000 lines per frame; and film width was 35 mm.

The Zond 6 through 8 spacecraft obtained photographs as they flew around the Moon and then returned to Earth where the camera film was retrieved. Therefore, the retrieved photographs are free of noise that occurs during television data transmissions. Zond 6 carried a standard aerial camera that had a focal length of 400 mm, a frame size of 13 x 18 cm, and a resolution of 50 lines/mm. The Zond 7 photographic equipment was similar and obtained color as well as black and white photographs. Photographs were acquired of the lunar surface and of the Earth as it set beneath the lunar horizon. Photographs of the Earth were transmitted from Zond 8 during its flight to the Moon. Each of these spacecraft carried out two lunar photographic sequences: (1) photography of the lighted lunar disk during approach and (2) photography of the lunar farside during flight around the Moon.

Flyby Photographic Data

The data available from NSSDC are listed in Table 6-3 and are described in the following sections. NSSDC ID numbers, necessary for ordering these data, are listed in the Index to Available Data.

Table 6-3. Luna and Zond Flyby Photographic Data at NSSDC

Mission	Atlases on Microfiche	Photographs	Index
Luna 3	30 photographs* 3 photographs†		
Zond 3	23 photographs†		
Zond 6		1	X
Zond 7		2	X
Zond 8	18 photographs*	18	X

*Russian.
†English translation.

A *Data Announcement Bulletin, Status of Availability of Zond 8 (1970-088A) Lunar Photography* (NSSDC/WDC-A-R&S 76-01), was published in 1976 and describes nine of the available Zond 8 photographs. This DAB is listed on the order form.

Photographic Atlases

Three atlases have been published by the U.S.S.R. that contain flyby photography of the farside of the Moon:

- *Atlas of the Farside of the Moon*, containing 30 halftone paper prints from Luna 3.
- *Atlas of the Farside of the Moon Part 2*, containing 23 halftone paper prints (9 are rapid scan only; no UV) from Zond 3.
- *Atlas of the Farside of the Moon Part 3*, containing 18 halftone paper prints (9 disk and 9 closeup) from Zond 8.

These atlases contain discussions of the onboard phototelevision systems, cartographic information, and photometric characteristics of selected surface objects. Lunar topographic features and the terrain photographed are included in the first two volumes. Photographic maps of the lunar farside compiled from the Zond 3 photography are contained in Part 2 and Part 3. In Part 3, a discussion of the Zond 6 and 7 missions is included with the discussion of the Zond 8 mission.

In addition to these atlases, three Luna 3 photographs appear in *First Photographs of the Farside of the Moon*. This book also has brief discussions of the equipment on Luna 3, its flight, and lunar surface features.

These publications may be viewed at NSSDC or obtained on microfiche as indicated in Table 6-3. NSSDC has the original Russian language editions of these publications and an English translation of *Atlas of the Farside of the Moon Part 2* and *First Photographs of the Farside of the Moon* available for viewing. The microfiche version reduces the quality of the photographs.

Zond 6, 7, and 8 Photographs

One Zond 6, two Zond 7, and eighteen Zond 8 photographs are available from NSSDC and are stored as 10.2- x 12.7-cm (4- x 5-in.) negatives. NSSDC can provide negatives, positive transparencies, and slides as well as paper prints of varying sizes. The photographs are of the Mare Orientale region.

Nine of the Zond 8 photographs were announced in the DAB (NSSDC/WDC-A-R&S 76-01) described previously. No supporting data or indexes were received with these photographs, but feature identification was made at NSSDC and is contained in the DAB. The nine additional Zond 8 photographs and the three Zond 6 and 7 photographs were also identified at NSSDC, and an index (described in the following section) giving approximate locations and features will be provided with the photographs.

Z nd 6, 7, and 8 Indexes

An index and footprint map were supplied by the U.S.S.R. with the Zond 7 and 8 photographs. The index provides the photograph number and corner coordinates for the Zond 7 and Zond 8 photograph acquisition sessions. The footprint maps indicate corner coordinates. Because the individual photographs received are unnumbered, the indexes and footprint maps cannot be used for photograph selection but will be supplied with requested photographs.

Photographs received for the Zond 6, 7, and 8 missions have been identified and indexed by NSSDC. The NSSDC index contains an assigned number, approximate U.S. selenographic corner coordinates, major surface features photographed, possible corresponding U.S.S.R. index numbers, and photograph location of the Zond 8 photographs in the *Atlas of the Farside of the Moon Part 3* (available on microfiche). This index will be supplied with the Zond 6, 7, or 8 photographs.

LANDER PHOTOGRAPHY EXPERIMENTS

The purpose of the photography experiments on the Luna lander spacecraft was to obtain closeup, large-scale photographs of the lunar surface surrounding the spacecraft landing area on the Moon. The photographs provided information on the following surface characteristics.

- Crater density
- Crater size range
- Crater morphologies
- Crater ejecta (amount, distribution, and size)
- Surface mechanical properties (bearing strength, cohesion, compaction, etc.)

The objectives of the photographic experiment on Luna 9 and 13 included the determination and recognition of geologic and impact processes that produce lunar features. These combined studies helped to determine the feasibility of manned landings on the Moon.

The imaging systems for Luna 9 and 13 were identical, each having a panoramic television camera capable of a resolution to 1.5 mm. Scanning image transmission speed was 1 line/second. The camera was composed of a rotating mirror that reflected the surface image through a lens to the diaphragm forming an image element. The light flux was then received by a light receiver that converted it to an electrical signal determined by the brightness of the object. The signals were transmitted to Earth.

The signals received on Earth were registered on film and recorded on magnetic tape. The film was conducted to a drum-type phototelegraph in which one revolution of the drum corresponded to one line of the incoming image. There were 500 elements per line and 500 lines per picture (or 0.06° per TV element). Special devices insured synchronous and inphase operation of ground registration equipment.

Lander Photographic Data

The data available from NSSDC for Luna 9 and 13 are listed in Table 6-4. NSSDC data ID numbers necessary for ordering these data are listed in the Index to Available Data.

Table 6-4. Lander Photographic Data at NSSDC*

Mission	Panorama Number	Fragments	Full Panorama	Other Photographs
Luna 9	1	9	X	12 stereo pairs from the three panoramas
	2	6	X	
	3	7	X	
Luna 13	1	2		
	2	7	X	
	3	7	X	
	4	4		
	5	7	X	

*Halftone paper prints contained in books.

The photographs are contained in a two-volume set of books, *First Panoramas of the Lunar Surface*. Volume 1 contains photographs from Luna 9, and Volume 2 contains photographs from Luna 13.

Included in the first volume are also discussions of equipment, onboard systems, flight dynamics, results from studies of the panoramas of the lunar surface, mapping of the surroundings of the spacecraft, and morphology of the landing area. Panorama 3 and other photographs are presented throughout the text.

Volume 2 of the set contains panoramas and individual fragments of the lunar surface taken by Luna 13. Also included are discussions and descriptions of the spacecraft, flight conditions, scientific apparatus (i.e., the soil mechanics penetrometer and the radiation densitometer), results of scientific research with comparisions of the Luna 9 and 13 missions, photogrammetric properties of the lunar panorama, locality of Luna 13, its relief, stereo studies of the rocks, morphological characteristics of the landing site, and topography.

These books were published in the Russian language and may be viewed at NSSDC. There is an English translation available for Volume 1, and a microfiche version of this translation is available from NSSDC. An English translation of Volume 2 is available on microfiche, but the Russian language edition is only available for viewing at NSSDC. Note that the photographs will be degraded in microfiche copies of these books.

REFERENCES/SOURCES

The following citations are annotated with A- and N-numbers where applicable. An A-number indicates those documents available from:

Technical Information Service
American Institute of Aeronautics
and Astronautics
750 Third Avenue
New York, NY 10017

N-numbers refer to documents available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

Behm, H. J., "Results of the Ranger, Luna 9, and Surveyor 1 Missions," *J. Astronautical Sci.*, *14*, 101-111, May-June 1967. (A67-39309)

Cherkasov, I. I., A. L. Kenurdzhian, L. N. Mikhailov, and V. V. Mikheev, "Determination of the Density and Mechanical Strength of the Surface Layer of Lunar Soil at the Landing Site of the Luna 13 Probe," *Cosmic Res.*, *5*, 636-645, September-October 1967. (A68-28382)

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Gault, D. E., W. L. Quaide, V. R. Oberbeck, and H. J. Moore, "Luna 9 Photographs, Evidence for a Fragmental Surface Layer," *Science*, *153*, 985-988, August 1966. (A66-40017)

Govorchin, G. G., "Soviets in Space - An Historical Summary," *Spaceflight*, *7*, 74-82, May 1965. (A65-23459)

Gurshteyn, A. A., and K. B. Shingarev, *Soviet Space Probes Study the Moon*, NASA TT F-13959, February 1972. (N72-18844)

Hapke, B., "Surveyor 1 and Luna 9 Pictures and the Lunar Soil," *Icarus*, *6*, 254-269, March 1967. (A67-24607)

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Johnson, R. W., "Lunar Surface According to Luna 9 and Surveyor 1," *Astronautica Acta, 12*, 370-383, September-December 1966. (A67-22405)

Lebedinskiy, A. I., G. M. Aleshin, V. A. Iozenas, and V. A. Krasnopolskiy, "Lunar Ultraviolet Spectrum in the Range of 2850 - 3350 Angstrom Units According to the Data Obtained from the Zond 3 Automatic Space Probe," in *Moon and Planets*, 65-70, North Holland Pub. Co., Amsterdam, 1967. (A67-34141)

Lipsky, Y. N., "What Luna 9 Told Us About the Moon," *Sky and Telescope, 32*, 257-260, November 1966. (A67-10964)

Lipsky, Y. N., "Zond-3 Photographs of the Moon's Far Side," *Sky and Telescope*, 338-341, December 1965. (A65-34814)

Minchin, S. N., and A. T. Ulubekov, *Earth, Space, Moon*, NASA TT F-800, Washington, D. C., September 1974. (N75-10886)

Parker, P. J., "Russia's Moon Programme," *Spaceflight, 11*, 378-383, 395, November 1969.

Petrovich, G. V., *Soviet Encyclopedia of Spaceflight*, MIR Publ., Moscow, 1969.

Rodionov, B. N., I. V. Isavnina, Yu. F. Avdeev, and V. D. Blagov, "New Data on the Moon's Figure and Relief Based on Results from the Reduction of Zond-6 Photography," *Cosmic Res., 9*, 410-417, May-June 1971. (A72-17040)

Shoemaker, E., R. N. Batson, and K. B. Larson, "Appreciation of the Luna 9 Pictures," *Astronautics and Aeronautics, 4*, 40-50, May 1966. (A66-28741)

"Soviet Artificial Earth Satellites, Spaceprobes, and Spacecraft," Lockheed Missiles & Space Co., unnumbered, Palo Alto, California, 1970. (N71-17104)

Soviet Space Program 1966-70, Library of Congress, Congr. Res. Serv., unnumbered, Government Printing Office, Washington, D. C., December 1971.

Soviet Space Program 1971, Library of Congress, Congr. Res. Serv., unnumbered, Government Printing Office, Washington, D. C., April 1972.

Soviet Space Program 1971-75, Vols. I and II, Library of Congress, Congr. Res. Serv., unnumbered, Government Printing Office, Washington, D. C., August 1976.

Vinogradov, A., and Yu. Lipskii, "Soviet Lunar Spacecraft," *Pravda*, April 1968.

Watts, R. N., Jr., "The Soviet Lunar Rover," *Sky and Telescope*, *41*, 155-157, March 1971.

Woods, D. R., "A Review of the Soviet Lunar Exploration Program," *Spaceflight*, *18*, 273-290, July-August 1976. (A76-36320)

Zonnenshtral, G. A., and Iu. I. Pel'dman, "Specific Effective Scattering Area of the Lunar Surface Determined from Measurements by the Luna-9 and Luna-13 Automatic Stations," *Cosmic Res.*, *8*, 541-546, July-August 1970. (A71-23145)

APPENDIXES

APPENDIXES

APPENDIX 1 - NONSATELLITE DATA

GROUND-BASED LUNAR PHOTOGRAPHS

Table A1-1 provides a list of worldwide astronomical observatories that obtained and can supply ground-based lunar photographs. Note that these photographs are not available from NSSDC, and requests for photographs should be made to the appropriate institution listed. In addition to those observatories listed, other observatories that were believed to have lunar photographs (including Harvard and Leander-McCormick) were contacted; however, some known photographs are not locatable (e.g., W. H. Pickering's 51 x 61 cm (20 x 24 in.) that appear in his atlas).

The photography that is available includes whole-disk photographs at several phases and ages of the Moon as well as local features and regions of the Moon at high magnifications. Photograph originals range from 7.6 x 12.7 to 20.3 x 25.4 cm (3 x 5 to 8 x 10 in.) for all observatories. Photographs that are available and were also incorporated in published atlases are noted, and an incomplete list of lunar atlases is provided in the following section of this Appendix. Those observatories that publish catalogs are noted.

In some cases, such as the Pic du Midi photographs archived at the Paris Observatory, plates may be viewed at the Observatory. A few (~ 100) of these are stored at the University of Manchester, England. The Paris Observatory at Meudon established the Planetary Photographs Center of the International Astronomical Union in 1961. Facilities and equipment for study and reproduction of the original plates and negatives are provided.

GROUND-BASED PHOTOGRAPHIC LUNAR ATLASES

The following list of lunar atlases includes those photographic atlases comprised of ground-based lunar photographs. Atlases comprised of satellite lunar photographs are not included here, but appear in the References/Sources sections of the *Catalog* or were described as data available from NSSDC.

The list excludes atlases comprised solely of charts and maps of the Moon, although these forms may be included with the ground-based photographic atlases listed. In addition, the Library of Congress shelf number has been included following the references in parentheses where possible.

Table A1-1. Ground-Based Photography of the Moon

Observatory or Source	Photographs Available* (Observatory)	Telescope Type† cm (in.)	Dates Acquired	Remarks§
Defense Mapping Agency Aerospace Center St. Louis AFS St. Louis, MO 63118	12[1] (U.S. Naval Obs.) 6,000[2] (Pic du Midi)	155 (61) L 61 (24) R	1965-1968 1943-1949	Additional U.S. Naval Observatory photographs may become available.
Lick Observatory** University of California Santa Cruz, CA 95064	32[1]	91 (36) R 305 (120) L	1930s-1940s 1960s	Best in *Kuiper et al.*, 1960.
Lunar and Planetary Laboratory University of Arizona Tucson, AZ 85721	~ 800[1] (Yerkes) ~ 400[3] (McDonald) ~ 4,400[3] (Catalina)	102 (40) R 208 (82) L 155 (61) L	1959-1961 1956-1963 1965-1967	*Kuiper et al.*, 1960. *Kuiper et al.*, 1960. *Kuiper et al.*, 1967. Some also from Mt. Wilson, Lick, and early Pic du Midi - not suitable for reproduction.
McDonald Observatory University of Texas P. O. Box 1337 Fort Davis, TX 79734	> 42[4]	208 (82) L	~ 1950s	Photographs not available; some in *Kuiper et al.*, 1960.
Mount Palomar Mount Wilson Hale Observatories** 813 Santa Barbara Street Pasadena, CA 91101	2[1] 14[1]	50 (200) L 254 (100) L	1950s ~ 1920s	Original plates archived at Mt. Wilson; *Kuiper et al.*, 1960. Positive copies may be available from Lunar and Planetary Laboratory.
Paris Observatory and Meudon Observatory Observatoire de Paris** Section d'Astrophysique 92190 Meudon, France	> 2,000[1] 52[3] > 100 (Pic du Midi) some	61 (24) R 61 (24) R 61 (24) R 107 (42) L 84 (33) R	1894-1909 unknown 1943-1949 < 1890	Best in *Loewy and Puiseux*, 1896-1909; *Le Morvan*, 1914-1921; *Weimer*, 1952. Best in *de Callataÿ*, 1964.
Pic du Midi Observatory 65 Bagnères de Bigorre France	> 100,000[2] 100[1]	61 (24) R 61 (24) R	1960s 1942-1950s	Used for lunar aeronautical charts. Some in *Kuiper et al.*, 1960; 1967. Some available from Manchester Observatory, England; Meudon Observatory; and the Defense Mapping Agency. None available from Pic du Midi.
U.S. Naval Observatory Washington, D.C. 20390	~ 500[5] 24[1]	13 (5) R 155 (61) L	1947-1956 1965-1966, 1974-1975	Includes Watts' limb photographs. *Kuiper et al.*, 1967. Some available from U.S. Naval Observatory; some available from Defense Mapping Agency.
Yerkes Observatory** University of Chicago Williams Bay, WI 53191	18[1] 9[6] 16[7]	102 (40) R 30 (12) R 25 (10) R	~ 1920s-1930s ~ 1920s-1930s 1900-1920s	Best in *Kuiper et al.*, 1960; 1967.

*Frame or plate size: [1]20.3 x 25.4 cm (8 x 10 in.); [2]23 x 23 cm (9 x 9 in.); [3]12.7 x 17.8 cm (5 x 7 in.); [4]10.2 x 12.7 cm to 20.3 x 25.4 cm (4 x 5 in. to 8 x 10 in.); [5]12.7 x 21.6 cm (5 x 8.5 in.); [6]15.2 x 15.2 cm to 20.3 x 25.4 cm (6 x 6 in. to 8 x 10 in.); [7]7.6 x 12.7 cm to 20.3 x 25.4 cm (3 x 5 in. to 8 x 10 in.).
†L = reflector; R = refractor.
§See atlas references in text.
**Catalog available.

Alter, D. (ed.), *Lunar Atlas*, Space Sciences Labs., N. American Aviation, Inc., Dover Pub., New York, 1968. (QB595.N63)

Alter, D., *Pictorial Guide to the Moon*, 3rd ed., Illus., Thomas Y. Crowell, New York, 1973. (QB595.A56)

de Calatay, V., *Atlas de la Lune*, (trans. by R. G. Lascelles), St. Martin's Press, New York, 1964. (QB595.C313)

Firsoff, V. A., *Moon Atlas*, Hutchinson, London, 1961. (QB595.F52)

Kopal, Z., *New Photographic Atlas of the Moon*, Taplinger Press, New York, 1970. (QB595.K83N53)

Kopal, Z., J. Klepesta, and T. W. Rackman (eds.), *Photographic Atlas of the Moon*, Academic Press, Inc., New York, 1965. (QB595.K83)

Krieger, I. N., *Mond-Atlas, Neue Folge (Atlas of the Moon, New Series)*, Leipzig, Trieste, Vienna, 1898-1917.

Kuiper, G. P., *Orthographic Atlas of the Moon* (Suppl. No. 1 to the *Photographic Lunar Atlas*, Edition A showing the Standard Orthographic Coordinate Grid), University of Arizona Press, Tucson, Arizona, 1960. (QB595.A73 No. 1)

Kuiper, G. P., *Orthographic Atlas of the Moon* (Suppl. No. 1 to the *Photographic Lunar Atlas*, Edition B showing the Standard Orthographic Coordinate Grid and the Mean Latitude-Longitude Grid), University of Arizona Press, Tucson, Arizona, 1961. (QB595.K96)

Kuiper, G. P., D. W. G. Arthur, E. Moore, J. W. Tapscott, and E. A. Whitaker, *Photographic Lunar Atlas* (Based on Photographs Taken at the Mt. Wilson, Lick, Pic du Midi, McDonald, and Yerkes Observatories), University of Chicago Press, Chicago, Illinois, 1960. (QB595.U5)

Kuiper. G. P., E. A. Whitaker, R. G. Strom, J. W. Fountain, and S. M. Larsen, *Consolidated Lunar Atlas* (Suppl. Nos. 3 and 4 to the *Photographic Lunar Atlas*, Using Photographs from the U. of Ariz. 61-in. reflector and the Naval Observatory 61-in. reflector at Flagstaff), Lunar Planetary Laboratory, University of Arizona, Tucson, Arizona, 1967. (QB595.K96)

le Morvan, *Carte Photographique et Systêmatique de la Lune*, Paris Observatory, Paris, France, 1914-1921.

Loewy, M., and P. Puiseux, *Atlas Photographique de la Lune*, Paris Observatory (published in *Bulletin de la Sociêtê Belge d'Astronomie*), Paris, France, 1896-1909.

Miyamoto, S., and A. Hattori, (eds.), *Photographic Atlas of the Moon, Second Edition 1964*, Contributions from the Institute of Astrophysics and Kwasan Observatory, University of Kyoto, No. 137, Japan, 1964.

Pickering, W. H., *The Moon*, Doubleday, Page, and Co., New York, 1903. (QB581.P6)

Pickering, W. H., *Photographic Atlas of the Moon*, *Annals of Harvard College Observatory*, *51*, Cambridge, Massachusetts, 1903. (QB4.H3300151)

Weimer, Th., *Atlas de Profils Lunaires*, Paris Observatory, Paris, France, 1952. (QB399.W4)

Weinek, L., and I. N. Krieger, *Paris Atlas of the Moon*, Paris, France, 1912.

Whitaker, E. A., G. P. Kuiper, et al., *The Rectified Lunar Atlas* (Suppl. No. 2 to the *Photographic Lunar Atlas*), University of Arizona Press, Tucson, Arizona, 1963. (QB595.A73 No. 3)

LUNAR MAPS

Lunar maps that were prepared by the Defense Mapping Agency and are now out of stock can be obtained, in reduced form, from NSSDC. The original maps were prepared from lunar mission photography by the Defense Mapping Agency Topographic Center for distribution and were described and cataloged in the *Lunar Cartographic Dossier* (L. A. Schimerman, ed., 1973). The maps range in scale from 1:10,000,000 to 1:1000.

The Defense Mapping Agency Aerospace Center (DMAAC) prepared 70-mm color transparencies of maps that are now out of stock. These transparencies are stored at NSSDC for request purposes.

NSSDC can supply black and white paper print enlargements in various sizes up to 51 x 61 cm (20 x 24 in.). However, resolution of large terrain features and printed matter is fair to poor, while smaller items are illegible. Scientific use will be limited. Requests directed to the distribution agencies for out-of-stock maps will be forwarded automatically to NSSDC.

Most maps held at NSSDC are described in the *Lunar Cartographic Dossier*. This document was prepared by and is available from:

Defense Mapping Agency Aerospace Center
St. Louis Air Force Station
St. Louis, MO 63118

APPENDIX 2 - U.S. PRINCIPAL INVESTIGATORS WITH DATA AT NSSDC

RANGER PROGRAM
Television Experiment: R. L. Heacock (G. P. Kuiper, deceased)

SURVEYOR PROGRAM
Alpha-Scattering Surface Analyzer Experiment: A. Turkevich
Soil Mechanics Surface Sampler: R. F. Scott (Surveyor 7); E. M. Shoemaker (Surveyor 3)
Television Experiment: E. M. Shoemaker

LUNAR ORBITER PROGRAM
Lunar Photographic Studies: L. J. Kosofsky
Meteoroid Experiment: C. A. Gurtler
Selenodesy Experiment: W. H. Michael, Jr.

APOLLO PROGRAM
Active Seismic: R. L. Kovach
Alpha Particle Spectrometer: P. Gorenstein
Atmospheric Composition Experiment: J. H. Hoffman
Biaxial Fluxgate Magnetometer: P. J. Coleman
Bistatic Radar: T. H. Howard
Charged Particle Lunar Environment Experiment: D. L. Reasoner
Closeup Stereoscopic Camera: T. E. Gold (Apollo 11, 12); R. J. Allenby (Apollo 14)
Cold Cathode Ion Gage: F. S. Johnson
Contamination Photography: G. A. Gary
Cosmic Ray Detector: R. L. Fleischer
Far Ultraviolet Spectrometer: W. G. Fastie
Far UV Camera/Spectrograph: G. R. Carruthers
Gamma Ray Spectrometer: J. R. Arnold
Gegenschein: L. Dunkelman
Hasselblad Multispectral Photography: A. F. H. Goetz
Hasselblad 70-mm Photography: R. J. Allenby (Apollo 8, 10-14); F. J. Doyle (Apollo 15, 16, 17)
Heat Flow Experiment: M. G. Langseth
Hycon Camera: Mapping Sciences Laboratory, NASA/JSC
Laser Altimeter (Mapping Camera System): W. M. Kaula; W. L. Sjogren
Laser Ranging Retroreflector: C. O. Alley; J. Faller
Lunar Dust Detector: J. R. Bates
Lunar Field Geology: W. R. Muehlberger (Apollo 16); E. M. Shoemaker (Apollo 11, 12); G. Swann (Apollo 14, 15, 17)
Lunar Particle Shadows and Boundary Layer Experiment: K. A. Anderson
Lunar Portable Magnetometers: P. Dyal

Lunar Sounder Experiment: R. Phillips
Lunar Surface Cosmic Ray Experiment: R. M. Walker
Lunar Surface Magnetometers: P. Dyal (Apollo 15, 16); C. P. Sonett (Apollo 12)
Mapping Camera System: F. J. Doyle
Mass Spectrometer: J. H. Hoffman
Maurer Camera: R. J. Allenby (Apollo 8, 10-14); F. J. Doyle (Apollo 15, 16, 17)
Neutron Probe: D. S. Burnett
Nikon Camera: F. J. Doyle (Apollo 16); L. Dunkelman (Apollo 15); R. Musgrove (Apollo 17)
Panoramic Camera: F. J. Doyle
Passive Seismic Experiment: G. V. Latham
S-Band Transponder: W. L. Sjogren
Seismic Profiling: R. L. Kovach
Soil Mechanics Experiment: J. K. Mitchell
Solar Wind Spectrometer: C. W. Snyder
Stellar Camera (Mapping Camera System): F. J. Doyle
Suprathermal Ion Detector: J. W. Freeman
Surface Electrical Properties Experiment: M. G. Simmons
Traverse Gravimeter Experiment: M. Talwani
TV Kinescope Photography: F. J. Doyle
X-Ray Fluorescence: I. Adler

APPENDIX 3 - ACRONYMS AND ABBREVIATIONS

ALSD	Apollo lunar surface drill
ALSE	Apollo lunar sounder experiment
ALSEP	Apollo lunar surface experiments package
AMS	Army Map Service (now Defense Mapping Agency Topographic Center)
APE	Apollo photographic evaluation (data)
ASE	active seismic experiment
BCD	binary coded decimal
bpi	bits per inch
B/W	black and white
Cal Tech	California Institute of Technology
CCGE	cold cathode gage experiment
CDR	commander
CM	Command Module
CMP	Command Module pilot
CRD	cosmic ray detector
CSAR	coherent synthetic aperture radar
CSM	Command and Service Module
DAB	Data Announcement Bulletin
DUN	Data Users Note
D&R	Deblock and Register (program)
EASEP	early Apollo surface experiments package
EROS	Earth Resources Observation Systems
EVA	extravehicular activity
f	relative aperture
F	full
FOV	field of view
fps	frames per second
FTSP	fine time scale parameters
GET	ground elapsed time
GMT	Greenwich mean time
GRE	ground reconstruction equipment
HF	high frequency
HR	high resolution

ID	identification
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center (formerly Manned Spacecraft Center)
LAC	lunar aeronautical charts
LaRC	Langley Research Center (formerly LRC)
LM	Lunar Module
LMP	Lunar Module pilot
LP	long period
LPM	lunar portable magnetometer
LRRR	laser ranging retroreflector
LRV	lunar roving vehicle
LSCR	lunar surface cosmic ray
LSM	lunar surface magnetometer
LSPE	lunar seismic profiling experiment
MCS	mapping camera system
MET	modularized equipment transporter
MR	medium resolution
MSC	Manned Spacecraft Center (now Johnson Space Center)
NASA	National Aeronautics and Space Administration
NSDF	Nonsatellite Data File
NSSDC	National Space Science Data Center
NTIS	National Technical Information Service
ODG	Orbit Data Generator (program)
ODP	Orbit Determination Program
P	partial
PSE	passive seismic experiment
rms	root mean square
SEP	surface electrical properties
SIDE	suprathermal ion detector experiment
SIM	scientific instrument module
SM	Service Module
SP	short period
SS	subsatellite
SWRF	Sine Wave Response Filter (program)
TDP	Tracking Data Processor (program)
TID	total ion detector
TV	television

u	unified atomic mass unit
U.S.S.R.	Union of Soviet Socialist Republics
UT	universal time
UV	ultraviolet
UVS	UV spectrometer
VHF	very high frequency
V/H	velocity-to-height (ratio)
WDC-A-R&S	World Data Center A for Rockets and Satellites

APPENDIX 4 - NSSDC FACILITIES AND ORDERING PROCEDURES

NSSDC PURPOSE AND ORGANIZATION

The National Space Science Data Center (NSSDC) was established by the National Aeronautics and Space Administration (NASA) to provide data and information from space science experiments in support of additional studies beyond those performed by principal investigators. Available lunar data in all disciplines are announced in this *Catalog*. Data available from NSSDC in other disciplines (see inside front cover) comprise additional published catalogs or catalogs to be published in the near future. In addition to its main function of providing selected data and supporting information for further analysis of space science flight experiments, NSSDC produces other publications. Among these are a report on active and planned spacecraft and experiments and various users guides.

Virtually all the data available at or through NSSDC result from individual experiments carried on board individual spacecraft. The Data Center has developed an information system utilizing spacecraft/experiment/data identification hierarchy. This *Catalog* is based on this information system, and additional program information has been provided.

NSSDC FACILITIES AND SERVICES

NSSDC provides facilities for reproduction of data and for onsite data use. Resident and visiting researchers are invited to study the data while at the Data Center. The Data Center staff will assist users with additional data searches and with the use of equipment. In addition to satellite data, the Data Center maintains some supporting information and other supporting data that may be related to the needs of researchers.

DATA AVAILABILITY, COSTS, AND ORDERING PROCEDURES

The services provided by NSSDC are available to any individual or organization resident in the United States and to researchers outside the United States through the World Data Center A for Rockets and Satellites (WDC-A-R&S). Normally a charge is made for the requested data to cover the cost of reproduction and the processing of the request. The researcher will be notified of the charge, and payment must be received prior to processing the request. However, as resources permit, the Director of NSSDC/WDC-A-R&S may waive the charge for modest amounts of data when they are to be used for scientific studies or for specific educational purposes and when they are requested by an individual affiliated with: (1) NASA installations, NASA contractors, or NASA grantees; (2) other U.S. Government agencies, their contractors, or their grantees; (3) universities or colleges; (4) state or local governments; or (5) nonprofit organizations.

A researcher may obtain data described in this *Catalog* by a letter or telephone request, an onsite visit, or the NSSDC/WDC-A-R&S data request form provided specifically for lunar data. This form enables a requester to order (1) documentation that will facilitate ordering specific data and (2) specific data where definitive information can be obtained from this *Catalog*. Anyone who wishes to obtain data for a scientific study should specify the NSSDC identification number (provided in the Index to Available Data), the common name of the satellite and the experiment, the form of the data, and the timespan (or location, when appropriate) of interest. A researcher should also specify why the data are needed, the subject of his work, his affiliation, and any Government contracts he may have for performing his study.

NSSDC would also appreciate receiving copies of all publications resulting from studies in which data supplied by NSSDC have been used. It is further requested that NSSDC be acknowledged as a source of the data in all publications resulting from use of the data provided.

Data can be provided in a format or medium other than that noted in the data descriptions. For example, magnetic tapes can be reformatted, computer printout or microfilmed listings can be reproduced from magnetic tape, enlarged paper prints are available from data on photographic film and microfilm, etc. The Data Center will provide the requester with an estimate of the response time and, when appropriate, the charge for such requests. When requesting data on magnetic tape, the user should specify whether he will supply new tapes prior to the processing, return the original NSSDC tapes after the data have been copied, or pay for new tapes.

The Data Center's address for requests is:

National Space Science Data Center
Code 601.4
Goddard Space Flight Center
Greenbelt, Maryland 20771
Phone: (301) 982-6695

Researchers who reside outside the U.S. should direct requests for data to:

World Data Center A for Rockets and Satellites
Code 601
Goddard Space Flight Center
Greenbelt, Maryland 20771 U.S.A.
Phone (301) 982-6695

Because the World Data Center A for Rockets and Satellites (WDC-A-R&S) also maintains listings of rocket experiments, requests for information concerning rocket launchings and experiments flown may be directed to this institution.

INDEXES

INDEXES

INDEX TO U.S. PRINCIPAL INVESTIGATORS

*Mr. Doyle was the chairman of the CSM Orbital Science Photographic Team.

*Retired.

*Deceased, see Heacock.

INDEX TO AVAILABLE DATA

*This number refers to the NSSDC data identification and must be used when requesting data.