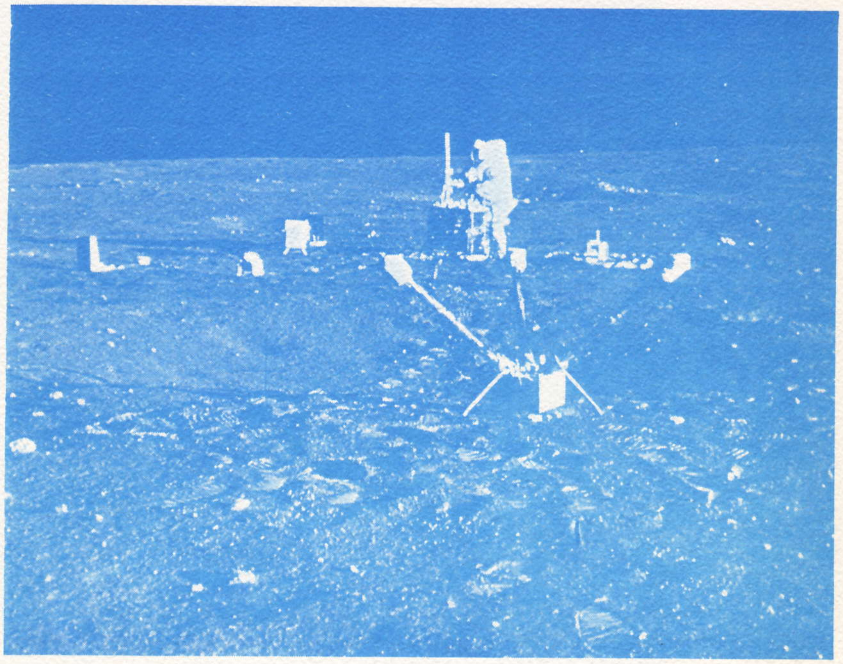
Apollo Lunar Surface Experiments Package (ALSEP)

THREE YEARS OF LUNAR SCIENCE

ALSEP SYSTEM

The Apollo Lunar Surface Experiments Package (ALSEP) is a system of scientific instruments that is carried to the moon on an Apollo spacecraft. The Apollo crew plays a key role in the emplacement and initial operation of ALSEP on the lunar surface. Using a self-contained power supply and communications equipment, each ALSEP collects, and transmits to earth, scientific and engineering data for extended periods following departure of the crew.



Apollo 12 ALSEP on the Moon

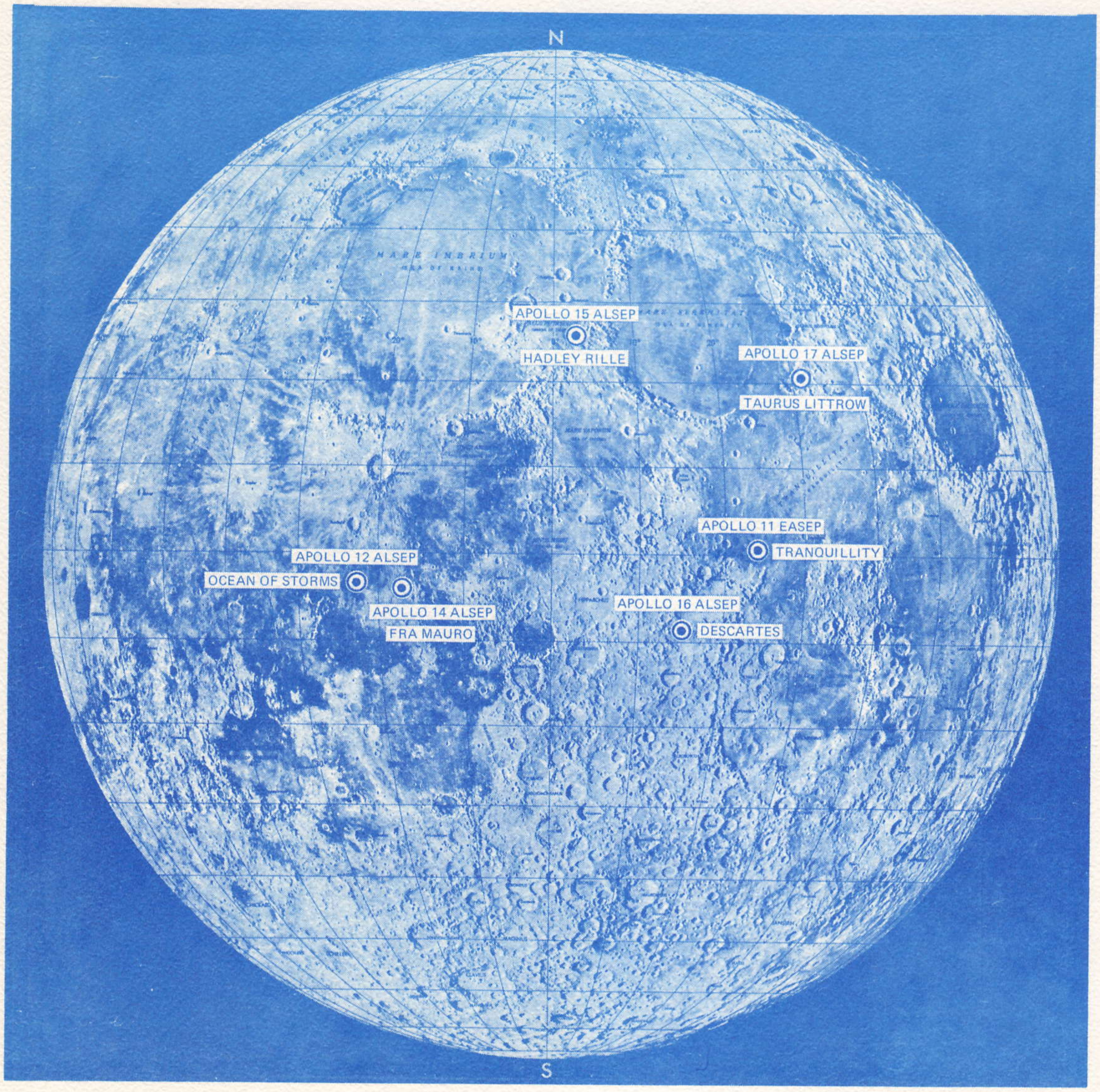
TRANQUILLITY TO DESCARTES AND BEYOND

APOLLO MISSION	11	12	14	15	16
LUNAR LOCATION	TRANQUILLITY	OCEAN OF STORMS	FRA MAURO	HADLEY	DESCARTES
DEPLOYMENT DATE	JULY 20, 1969	NOV 19, 1969	FEB 5, 1971	JUL 31, 1971	APRIL 21, 1972
DESIGN LIFE (DAYS)	14	365	365	365	365
OPERATING TIME (DAYS)*	71	1,096	653	477	212

*As of 19 November 1972

Bendix Aerospace Systems Division

ALSEP FORMS LUNAR SCIENCE NETWORK



LUNAR SCIENCE DATA FROM ALSEP INSTRUMENTS

The Apollo 12 ALSEP continues to transmit scientific and engineering data to earth after more than 3 years of operation on the lunar surface. Establishment of the Apollo 12 scientific station on the lunar surface November 19, 1969, provided man with the first long-term, on-site laboratory on another planet. Subsequent ALSEPs—i.e., Apollo 14, February 5, 1971; Apollo 15, July 31, 1971; and Apollo 16, April 21, 1972—established an ALSEP network of four sites simultaneously collecting and transmitting scientific data. This ALSEP network provides a wealth of scientific data for the continuing investigation of the moon-earth relationship.

The four stations have accepted and executed more than 38,000 commands from earth and returned 23 billion data measurements. The ALSEP experiments investigate the evolution of the moon and the solar system through instruments such as seismometers, magnetometers, temperature probes, and ion detectors. Establishment of a network of instruments with successive lunar landings enables the definition of the location, velocity, and intensity of lunar events.

APOLLO MISSION ASSIGNMENTS

Because of power and weight limitations, no single flight can carry all the experiments. A different combination has been assigned to each of the Apollo flights.

ALSEP EXPERIMENT / APOLLO / LUNAR LOCATION	11 23.4°E 0.7°N	12 23.5°W 3.0°S	13	14 17.5°W 3.7°S	15 3.7°E 26.1° N	16 15.5°E 9.0°S	17 30.8°E 20.2°N
PASSIVE SEISMIC EXPERIMENT	●	●	●	●	●	●	
ACTIVE SEISMIC EXPERIMENT				●		●	
SUPRATHERMAL ION DETECTOR		●		●	●		
COLD CATHODE GAGE		●	●	●	●		
SOLAR WIND SPECTROMETER		●			●		
CHARGED PARTICLE EXPERIMENT			●	●			
LUNAR SURFACE MAGNETOMETER		●			●	●	
HEAT FLOW EXPERIMENT			●		●	●	●
LASER RANGING RETRO-REFLECTOR	●			●	●		
LUNAR SEISMIC PROFILING							●
LUNAR MASS SPECTROMETER							●
EJECTA AND METEORITES							●
LUNAR SURFACE GRAVIMETER							●

MOONQUAKES AND METEORITES

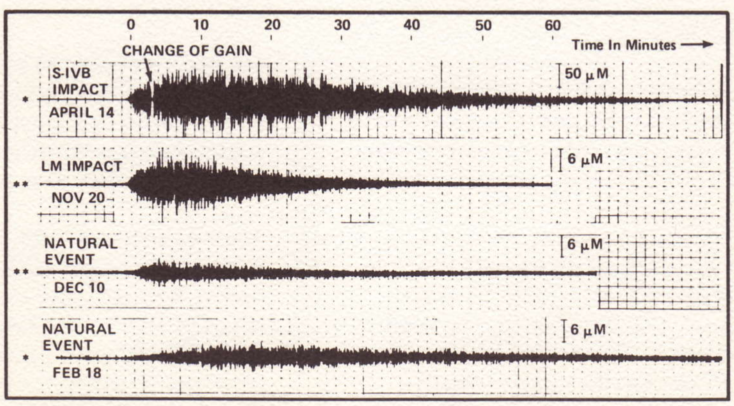
Passive Seismic Experiment

The four ALSEP Passive Seismic Experiments (PSE) provide information on the moon's internal composition by monitoring natural and manmade seismic events. The Apollo 12, 14, 15, and 16 stations, separated by as much as 1,100 kilometers (km), permit locating seismic events, such as moonquakes that occur with regularity when the moon is at apogee and perigee of its orbit about the earth. These orbit positions correlate with maximum lunar tides, and the quakes represent either a release of tidal energy or the release of internally generated stresses. The epicenters of the majority of these moonquakes are located approximately 600 km south-southwest of the Apollo 12 ALSEP, and the depths of focus are approximately 850 km—deeper than any known earthquake.

In addition to periodic moonquakes, quakes resulting from meteorite impacts are recorded. One impact occurred 145 km north of the Apollo 14 station and was the largest impact yet recorded. Analysis of this single event recorded by the four seismometers has greatly improved the understanding of the structure under the lunar crust; evidence of a lunar crust and mantle has been discovered—in the lunar highland region the crust appears to be 60 km thick.

Active Seismic Experiment

In addition to the PSE, two Active Seismic Experiments (ASE) were deployed—one at the Apollo 14 site and one at the Apollo 16 site. The purpose of the ASE is to generate and monitor seismic waves for use in studying the lunar near-surface structure. The ASE generates seismic energy in two ways: (1) real-time detonation of small explosive devices by an astronaut and (2) post-mission launching of grenades upon command from earth. Analysis of some seismic signals recorded by the ASE indicates that there are major regional differences in the near-surface acoustical properties of the moon. Seismic velocities indicate a surficial layer about 12 meters (m) thick with an underlying structure approximately 70 m thick.



*1970
**1969

Typical Seismic Data

MAGNETISM ON THE MOON

Lunar Surface Magnetometer

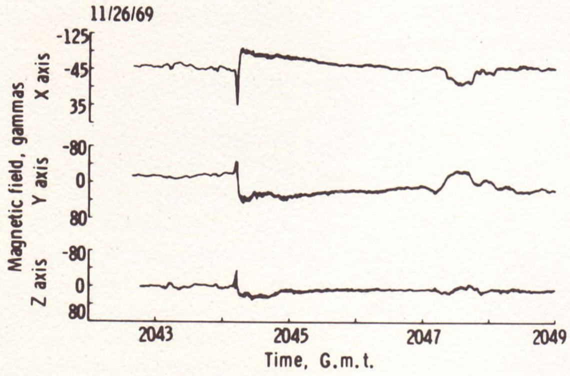
The ALSEP Lunar Surface Magnetometer and another experiment, the Lunar Portable Magnetometer, have been deployed on the lunar surface to permit study of intrinsic remanent lunar magnetic fields and the global magnetic response of the moon to large-scale solar and terrestrial magnetic fields.

A study of the interaction between a planet's magnetic field and the hot ionized gas emanating from the sun can augment knowledge concerning atmospheric accretion, radiation belts, and absorbed gases during the evolutionary phase of that planet.

The magnetic field at the earth's equator is approximately 35,000 gammas. Steady remanent fields (in gammas) measured at the various lunar sites are as follows: 38 at the location of Apollo 12; 103 and 43 at two locations near Apollo 14; 6 at the location of Apollo 15; and 121 to 313 at various locations near Apollo 16. The lunar values are attributed to remanent magnetization in the nearby sub-surface material.

The remanent fields could be due to a variety of types of sources, including possible nearby platelike regions that originally were uniformly magnetized but subsequently have been changed by some mechanism such as meteorite shock impact. The lunar surface steady field varies widely with location on the moon as evidenced by measurements differing by nearly two orders of magnitude. Magnetic concentrations (magcons) evidently exist at widely separated regions of the moon.

Electrical conductivity of the lunar interior has been determined from magnetic field step-transient measurements. The data fit a spherically symmetric three-layer lunar model having a thin outer crust of very low electrical conductivity. Since the conductivity is a function of temperature, and assuming that the lunar material is peridotite, the temperature profile rises sharply to a value between 850 and 1,050°K at a depth of approximately 90 km, then increases gradually to a value between 1,200 and 1,500°K at approximately 1,000 km, and may be above 1,500°K at greater depths.



Magnetometer Data Crossing Bow Shock

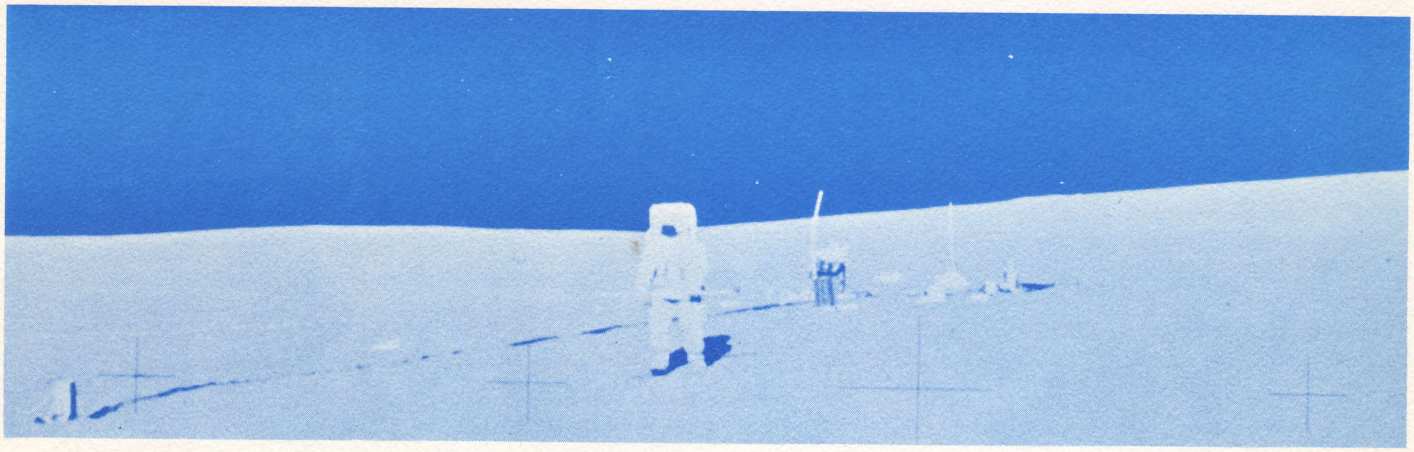
PRECISE DISTANCE: EARTH-TO-MOON

Laser Ranging Retro-Reflector

Laser Ranging Retro-Reflectors (LRRR) deployed on the lunar surface on the Apollo 11, 14, and 15 missions serve as reference points in measuring precise ranges between the array and points on earth using the technique of short-pulse laser ranging.

The Apollo 11 and 14 retro-reflectors are both near the equator, but are well separated; the Apollo 15 retro-reflector completes a triangular network for precision ranging by earth-based lasers. The Apollo 15 array is sufficiently far north of the Apollo 11 and 14 retro-reflectors to form a large triangular network. The Apollo 15 LRRR has 300 retro-reflectors, compared to 100 on the Apollo 11 and 14 arrays, and therefore has higher signal return. This network of retro-reflectors permits measurement of the earth-moon separation (240,000 statute miles) with an accuracy of 6 in., which will be reduced to 1.5 in. as more data are collected.

The measurements will reveal extremely small variations in the orbits of the earth and the moon. Scientists are now able to see more accurately how the earth wobbles about its polar axis. The increased accuracy may also permit direct study of continental drift. Astronomical, geophysical, and general relativity experiments planned for the future will require the accumulation of data from the LRRR network over a period of years.



Apollo 14 ALSEP on the Moon

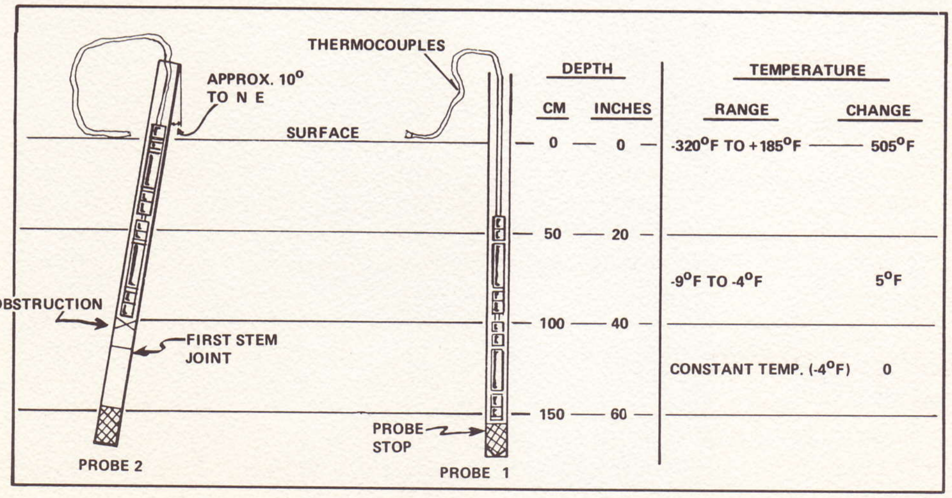
HIGH HEAT FLOW FROM MOON

Lunar Heat Flow Experiment

Moon temperatures are being monitored by the Lunar Heat Flow Experiment inserted into the lunar surface by the Apollo 15 crew. Thermal conductivity and temperatures within the lunar subsurface material are measured to determine the rate at which heat is flowing out of the moon. This heat loss is directly related to the rate of internal heat production and to the internal temperature profile.

Preliminary analysis of this instrument's measurements shows that the heat flow from beneath the Apollo 15 site is 0.8×10^{-6} cal/cm^2-sec. Although approximately half as much as the average value at the earth's surface, it is approximately three times the value expected. If the measured value is representative of the entire moon, assuming a uniform sphere with constant internal heat generation, then the lunar material is far more radioactive than previously expected–far more than the ordinary chrondites and carbonaceous chrondites which have formed the bases of standard models of the earth and moon to date.

Conductivity measurements of 1.4×10^{-4} and 2.5×10^{-4} W/cm^2-$^\circ$K were obtained in the subsurface material. These values are a factor of 7 to 10 above the conductivity of the surface layer, thus indicating that conductivity increases with depth. The temperature profile as obtained from the two probes shows 253.1°K and 250.7°K at 1.0 m below the surface, about 35°K above the mean surface temperature, and a temperature increasing with depth at a rate of 1.75°K/meter from a depth of 1.0 m down to 1.5 m.

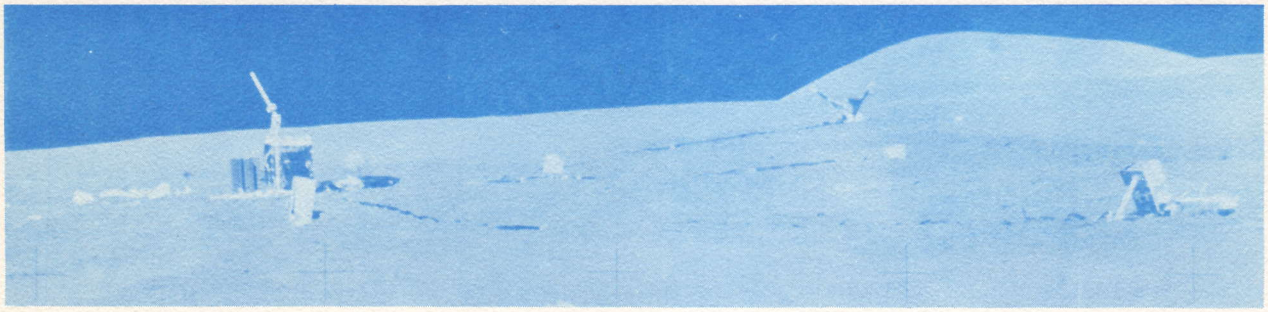


Apollo 15 ALSEP Heat Flow Experiment

LUNAR ATMOSPHERE

Gas Molecules at the Lunar Surface

The thin concentration of gases on the moon is supplied by a number of interacting processes. One of these originates in the solar wind, or plasma, which is the outside layer of atmosphere on the sun (often called the corona). The plasma is completely ionized and expands into space at hypersonic velocities in all directions. As these ions reach the moon, some attract free electrons and become gas molecules. Some strike the lunar surface material, releasing secondary constituents which may also form molecules. In addition to the solar wind processes, lunar gases are generated by natural and man-made sources; e.g., the continued release of molecules from the moon's interior through the lunar crust and venting and outgassing from the lunar module and other space gear. These accumulation processes are offset by gas molecule losses. Some of the molecules become ionized, producing charged particles, i.e., electrons and protons. Because of the moon's low gravity field, many of the remaining gas molecules quickly escape into space and only a few are held in the layer of lunar atmosphere. The relative rates of accumulation and loss determine the amount of gas present at any given time.

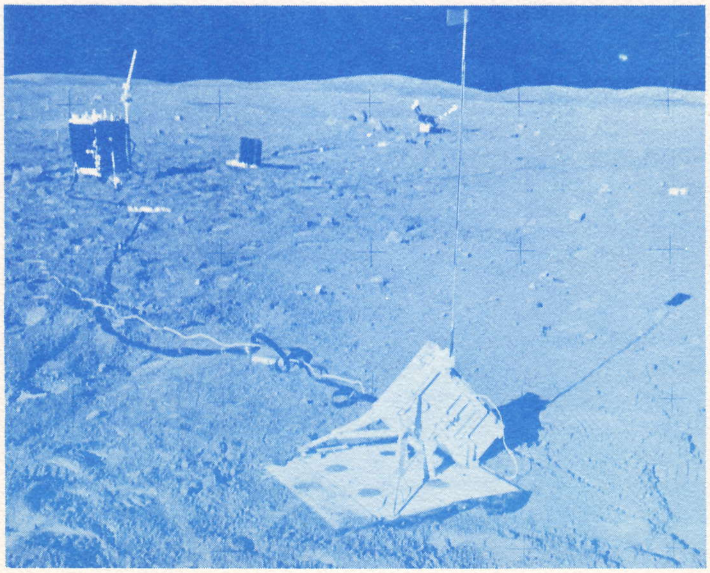


Apollo 15 ALSEP on the Moon

Cold Cathode Gage Experiment

The Cold Cathode Gage Experiment (CCGE) determines the density of the tenuous atmosphere at the lunar surface by measuring the number of neutral gas particles in a unit volume.

Data from the Apollo 12, 14, and 15 CCGE instruments show that the gas concentrations observed during the lunar days appear to be due overwhelmingly to contaminants released by the lunar module and its associated equipment. However, the concentrations observed during the lunar nights, typically less than 2×10^5 particles/cm^3, are lower even than those expected from just the neon component of the solar wind alone. Contaminant gases from spacecraft equipment remain adsorbed at the low nighttime temperatures—the lunar surface itself is not saturated with neon—apparently the rate of neon release from the surface is much slower than the rate of neon implantation.



Apollo 16 ALSEP
on the Moon

CHARGED PARTICLE INTERACTIONS WITH THE MOON

Solar Wind – Geomagnetosphere – Electrons and Ions

The solar wind has magnetic fields associated with the stream of ionized gas emanating from the sun into free space. The earth, with its magnetic field, interacts with the solar wind to form a magnetic bow shock and downstream wake which contains the geomagnetic tail. Each lunar orbit of 29.5 earth days takes the ALSEP experiments through the undisturbed region of free space, where solar wind effects predominate, and through the wake where geomagnetosphere effects are most significant. The moon interacts with the solar wind and geomagnetosphere to modify the electric and magnetic fields. ALSEP experiments monitor the effects of the resulting fields, near the lunar surface, on the motions and energies of charged particles – electrons and positive ions, or protons – arriving from space or generated at the moon's surface.

Solar Wind Spectrometer

The two Solar Wind Spectrometer Experiments, deployed 1,100 km apart on the Apollo 12 and 15 missions, measure the interaction between the moon and the solar wind by sensing the flow direction and energies of both electrons and positive ions. Solar wind plasma, magnetosphere plasma, and magnetopause crossings have been observed by both instruments which show good agreement between these observations; for example, simultaneous (within 15 seconds) changes in proton densities and velocities are detected at both sites. As first measured with the Apollo 12 instrument, the solar plasma detected at the lunar surface is indistinguishable from the solar plasma some distance out from the surface as monitored by orbiting instruments. This was true whether the moon was outside or inside the magnetic bow shock of the earth.

Charged Particle Lunar Environment Experiment

The Charged Particle Lunar Environment Experiment of Apollo 14 measures the ambient fluxes of charged particles, both electrons and ions, with energies in the range of 50 to 50,000 electron volts (eV). One of the most stable features is the presence of low-energy electrons whenever the landing site is illuminated by the sun. The variation in the low-energy electron flux during the lunar eclipse of February 10, 1971, provided strong evidence that the electrons are photoelectrons liberated from the lunar surface. Another characteristic is the rapid variation of solar wind flux (with time periods of approximately 10 seconds), both when the moon is in interplanetary space and when it is immersed in the geomagnetic tail of the earth. Passage of the moon through the magnetopause and geomagnetic tail has revealed some particularly interesting data including: rapidly fluctuating low-energy (50- to 200-eV) electrons, fluxes of medium-energy electrons lasting from a few minutes to tens of minutes, and electrons that have energy spectra remarkably similar to those observed above terrestrial auroras. If it is confirmed that these are auroral particles penetrating far into the geomagnetic tail, a revision of theories on magnetospheric topology would be required.

After impact of the Apollo 14 lunar module ascent stage, two plasma clouds were observed just seconds apart. They were traveling at approximately 1 km/sec and had diameters of 14 and 7 km.

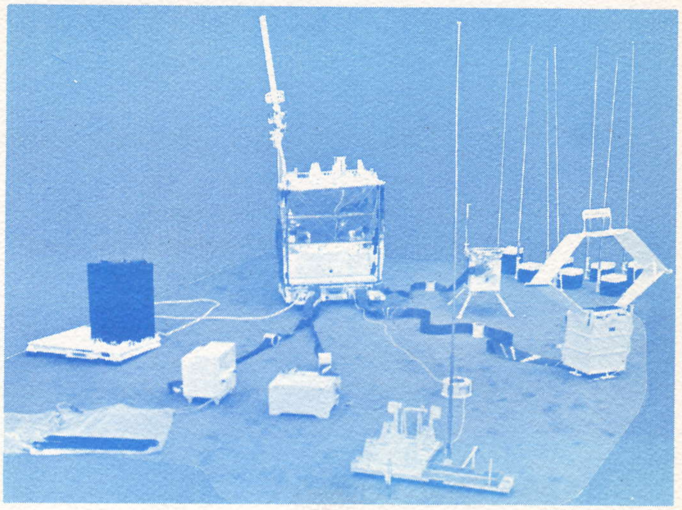
Suprathermal Ion Detector

The network of three Suprathermal Ion Detectors (Apollo 12, 14, and 15) continues to provide information on the energy and mass spectra of positive ions close to the lunar surface. Evidence of prompt ionization and acceleration of gases generated at the moon has been found in data from the Apollo 12 and 14 instruments. The combination of three instruments provides for precise determination of the dimensions and motions of ion clouds moving across the lunar surface.

An example of significant results is the detection of water vapor in the lunar exosphere by the Apollo 14 instrument. A few kilograms of water from some unknown depth below the surface are believed to have been liberated by seismic activity, and vaporized instantly upon exposure to the lunar atmosphere. The vapor was then dispersed over a wide area; some fraction of it became ionized and these ions were detected.

SCIENTIFIC EXPLORATION GOES FORWARD

The ALSEP to be carried on Apollo 17, the last planned Apollo mission, is designed to operate for 2 years. Earlier ALSEP systems were designed to function for a minimum of 1 year. The Apollo 17 scientific experiments will complement those already operating on the lunar surface. In addition, another Heat Flow Experiment will be flown to supplement the one delivered by Apollo 15. The four new experiments are described below.



Apollo 17 ALSEP Prepared for 1972 Flight to the Moon

Lunar Surface Gravimeter Experiment

The Lunar Surface Gravimeter Experiment uses a spring-mass suspension (of the zero-length type) to sense changes in the vertical component of lunar gravity. With a sensitivity of one part in 10 billion, and operating in the moon's environment of low natural seismic activity, it is expected to provide data which cannot be obtained in the earth's noisy environment. The instrument will allow searching for gravitational forces radiating from cosmic sources. If gravitational waves are found, it will be the first confirmation of Einstein's theoretical prediction that gravity propagates as waves. The gravimeter will also measure seismic disturbances produced by moonquakes and the lunar surface deformations associated with tidal forces to add new information on the moon's internal structure.

Lunar Mass Spectrometer

The Lunar Mass Spectrometer, also called the Lunar Atmospheric Composition Experiment, uses a magnetic-deflection mass spectrometer to identify the constituent components of the minute quantities of gas surrounding the moon, and to determine their relative abundance. The results will provide clues to the origin of the lunar exosphere, including, for example, the possibility of volcanic activity if traces of carbon monoxide and sulfur dioxide are discovered.

Lunar Seismic Profiling Experiment

The Lunar Seismic Profiling Experiment is an advanced version of the earlier Active Seismic Experiment. It uses four sensors, called geophones, to detect seismic waves generated by the detonation of eight explosive charges. The weight of these charges varies from 1/8 to 6 pounds—the charge material is approximately equivalent to TNT. These charges will be placed on the lunar surface at distances of 0.5 to 3.5 km from the geophones and later detonated at predetermined times, after departure of the Apollo crew. Analysis of the results will reveal the internal lunar structure, such as layering, to a depth of 3 to 4 km.

Lunar Ejecta and Meteorites Experiment

The Lunar Ejecta and Meteorites Experiment uses three separate detectors that will be oriented on the moon to face up, east, and west. The east and upward facing detectors measure energy, speed, and direction of dust particles while the west facing detector measures energy only. Dust particles weighing as little as a millionth of a milligram will be analyzed: for time-dependent variations in properties of cosmic dust impacting the lunar surface, for quantity and characteristics of dust ejected from the surface by meteorite impacts, and for the nature of streams of meteorites drifting through the solar system.

ALSEP AND THE FUTURE

The continuing output of ALSEP data on the lunar exosphere, surface mantle, and whole body properties is steadily improving our understanding of the earth-moon relationship and the entire solar system. Systematic scientific data collection on the moon, through long-term ALSEP operation, will extend far into the future.

Apollo Lunar Surface Experiments Packages have been developed by the Aerospace Systems Division of The Bendix Corporation under the direction of the National Aeronautics and Space Administration, Manned Spacecraft Center.

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