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JULY 19 - 31, 1965

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Scientific and Technical Information Division 1965
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

LIST OF ABBREVIATIONS

AES Apollo Extension System—A more versatile phase of the early Apollo missions which permits longer stay times, greater exploration capabilities, and will operate in the 1970–1974 time period.

ESS Emplaced Scientific Station—A geophysical observatory containing a complex of instruments similar to the LSEP but of larger size.

LEM Lunar Excursion Module—Vehicle for transporting the astronauts from lunar orbit to the Moon's surface.

CM Command Module—The spacecraft command center which will remain in orbit after LEM is deorbited to the surface and perform all command decisions.

LSEP Lunar Surface Experiment Package—A package of geophysical instruments to be carried on early Apollo manned lunar flights which will be emplaced by the astronauts on the lunar surface and left there to record and transmit to Earth lunar geophysical data for periods up to 1 year.

LSSM Local Scientific Survey Module—A lunar surface roving vehicle capable of carrying one or two suited astronauts and a scientific payload up to 600 pounds, with an operational range up to 8 kilometers.

LFV Lunar Flying Vehicle—A one-man rocket-propelled flying craft for studying areas inaccessible to the LSSM.

LSRL Lunar Sample Receiving Laboratory—Earth-based facility for storage and preliminary study of returned lunar samples.

MSC Manned Spacecraft Center

MSFC Marshall Space Flight Center

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FOREWORD

From July 19 through July 31, 1965, the National Aeronautics and Space Administration conducted a Lunar Exploration and Science Conference at the Lawrence High School in Falmouth, Massachusetts. The conference was held immediately after completion of the Space Science Summer Study conducted at Woods Hole, Massachusetts, for NASA by the National Academy of Sciences. The Lunar Conference was under the auspices of the Manned Space Science Coordinating Committee appointed by Homer E. Newell, the Associate Administrator for the Office of Space Science and Applications (OSSA). This Coordinating Committee was established to advise Willis B. Foster, Director of the Manned Space Science Program of the Office of Space Science and Applications, and consists of one member from each of the Subcommittees of the Space Science Steering Committee and the Chairmen of seven discipline-oriented Working Groups. The Chairman of the Coordinating Committee is Richard J. Allenby, Deputy Director, Manned Space Science Programs, who also acted as conference chairman. The conference secretary was Jay Holmes, Field Center Development, Office of Manned Space Flight. The function of the Working Groups and the Coordinating Committee is to advise NASA on a sound, feasible, scientific exploration program for the Moon.

The Chairmen and Secretaries of the Working Groups of the Manned Space Science Coordinating Committee are as follows:

GEODESY/CARTOGRAPHY: Chairman, Hellmut Schmid, U.S. Coast and Geodetic Survey, Rockville, Maryland; secretary, James Sasser, Manned Spacecraft Center, NASA, Houston, Texas.

GEOLOGY: Chairman, Eugene M. Shoemaker, U.S. Geological Survey, Flagstaff, Arizona; secretary, Donald Beattie, Advanced Manned Missions Program Office, Office of Manned Space Flight, NASA Headquarters.

GEOPHYSICS: Chairman, Frank Press, Massachusetts Institute of Technology, Cambridge, Massachusetts; secretary, Edward Davin, Manned Space Science Programs, Office of Space Science and Applications, NASA Headquarters.

BIOSCIENCE: Chairman, Melvin Calvin, University of California, Berkeley, California; secretary, Siegfried Gerathewohl, Manned Space Science Programs, Office of Space Science and Applications, NASA Headquarters.

GEOCHEMISTRY: Chairman, James Arnold, Scripps Oceanographic Institute, La Jolla, California; secretary, Paul Lowman, Goddard Space Flight Center, NASA, Greenbelt, Maryland.

PARTICLES AND FIELDS: Chairman, Wilmot Hess, Goddard Space Flight Center, NASA, Greenbelt, Maryland; secretary, Jacob Trombka, Manned Space Science Programs, Office of Space Science and Applications, NASA Headquarters.

LUNAR ATMOSPHERES: Chairman, Francis S. Johnson, Southwest Research Institute, San Antonio, Texas; secretary, Dallas Evans, Manned Spacecraft Center, NASA, Houston, Texas.

In addition to the above seven working groups a special Astronomy Study Group was convened under the chairmanship of Nancy Roman, Physics and Astronomy Programs, OSSA. This group furnished the recommendations relating to astronomy on the lunar surface.

The first six Working Groups met at the summer conference, while the seventh Working Group, Lunar Atmospheres, decided that the recommendations set forth by the Apollo Science Team were sufficient and therefore did not convene. Curtis Michel, Associate Professor of Space Science, Rice University, Houston, Texas (now of the Astronaut Office, Manned Spacecraft Center, NASA, Houston, Texas) attended the conference as an observer for the Atmospheres Working Group.

The recommended program covers a 10-year period beginning with the first Apollo flights. Emphasis was placed on manned exploration, but consideration was also given to the scientific contributions that could be made by unmanned vehicles during this period.

The report is composed of two main sections. The first section outlines the conference results according to: (1) mission, and (2) scientific discipline. The second section contains the complete report of each of the working groups including the Lunar Atmospheres Apollo Science Team Report and the Astronomy Study Group Report. It is hoped that the summary will serve for those desiring only a brief résumé of the results, while those seeking greater detail can consult the individual reports of the Working Groups.

It must be emphasized that this report represents the opinions and conclusions of the Working Groups and does not constitute official NASA policy. The report does, however, represent the current thinking of some of the outstanding lunar scientists in the United States, and NASA plans to make every effort to implement those parts of the recommended program which appear feasible within available resources.

Finally, this report cannot be, nor is it intended to be, a final or complete document on the subject. Further meetings of the Working Groups and the Coordinating Committee are planned, and additional reports will be issued in the future. Hopefully, one of the valuable results of this document will be to stimulate additional outstanding university and industrial scientists to participate in the lunar exploration program.

Grateful appreciation is acknowledged to the Working Group members and observers who participated in this endeavor, and especially to the Chairmen of the Working Groups whose diligent efforts have facilitated the publication of this report.

RICHARD J. ALLENBY, Chairman
Manned Space Science Coordinating Committee

MISSION AND DISCIPLINE

SUMMARY

MISSION SUMMARY

INTRODUCTION

In this chapter the major recommendations of the Working Groups are arranged by missions or programs. The suggested priorities, instrument allocations, and mission characteristics for various vehicles are indicated briefly. For information concerning details of the requirements, reasons for the recommendations, and additional equipment items, the working group reports should be consulted.

Although there was some overlap, most of the recommendations could be divided into these missions: Apollo, Lunar Orbiter, Apollo Extension System-Manned Lunar Orbiter (AES-MLO), Apollo Extension System-Manned Lunar Surface (AES-MLS) and Post-AES. For the Lunar Orbiters, the Groups in some cases did not explicitly distinguish between the Apollo Orbiter, the AES Manned Lunar Orbiter (AES-MLO), and the unmanned Lunar Orbiter. As the scientific instruments and space vehicle characteristics and availability become more clearly defined, the assignment of experiments will become clearer.

OVERALL PROGRAM

The plans and recommendations of the 1965 Lunar Exploration Summer Conference are based on a 10-year program of exploration, beginning with the first manned lunar landing in the Apollo program. The recommendations of this conference are limited to the 10-year period following the first Apollo lunar landings because a decade seems to be the approximate maximum time for which developments can be meaningfully forecast. In addition, the long lead times involved in the development of equipment for use in space flight require that recommendations be made to cover this period of time. In carrying out these recommendations, it will be necessary for the National Aeronautics and Space Administration to conduct its programs in a way that permits a maximum degree of flexibility to meet changing requirements.

The need for flexibility is also important for determining the rate at which missions should be conducted during this ten-year period. It is clearly desirable to schedule flight missions to provide adequate time between missions to react to the findings of one mission by modifying experiments for a later mission. One method of accomplishing this is through the modular construction of individual experiments. It is also desirable to program certain types of experiments so that the time of the operation of the devices used on one mission will overlap with the operating time of devices operated on a subsequent mission. This will provide not only scientific continuity in the experiments, but also simultaneous data from a multiplicity of lunar locations.

In addition, overall program planning considerations dictate the scheduling of missions at relatively close intervals. It is clearly desirable to maintain a certain degree of program momentum, both for psychological reasons and to make certain that the project personnel analyzing the results are provided with definite goals over a relatively long period of time.

On consideration of all of these factors, it was the feeling of the Working Groups that the National Aeronautics and Space Administration should schedule lunar surface missions at a minimum rate of one per year or possibly two through 1974. Lunar orbital missions should be conducted at the rate of one per year. Since many of the lunar surface missions will require two flights each, three to five Apollo/Saturn V vehicles are required annually.

Present indications are that lunar exploration should continue at the same rate in the latter half of the 1970's. However, there seems to be no need now to plan the flight mission assignment schedule for that period of time.

THE EARLY APOLLO MISSIONS

It is assumed that at least the first missions, with durations limited to a day or two and with exploration limited to an area close to the point of landing, will be dominated by operational considerations. Since the highest mission priority is assigned to the safety of the astronauts, the bulk of their time and attention will be devoted to perfecting the procedures of flight. In the relatively short duration of these early missions, the time assigned to scientific lunar exploration as such will be limited.

All experiments should be designed to conserve the astronauts' time, the most valuable scientific commodity on the early missions.

As flight procedures and techniques are perfected, and as improved flight equipment becomes available, plans should be made to gradually increase the duration of stays on the Moon, the distance traveled from the point of landing, and the proportion of the astronauts' time devoted to lunar exploration. A judicious use of "manned" and "unmanned" spacecraft will be required to obtain maximum coverage. Recommendations were made by some groups concerning the specific instrumentation to be carried on each of the first three landings.

Training of the astronauts in sampling techniques and field geology is of the utmost importance to insure the intelligent collection of samples. To assure collection of sterile samples, training is required for the astronauts in the nature of contaminants, transfer of contaminants, aseptic transfer procedures and chemical cleanliness.

Priorities for Experiments

The highest priority activity for the early Apollo landings is to return the greatest number and variety of samples as is feasible. It is desirable that all samples be kept sterile and free of chemical contaminants from such sources as the LEM fuels, the LEM atmosphere or the outgassing or leakage of the astronaut's suit. A variety of easily obtainable samples should be collected, ranging from dust to rock sizes. These samples should be taken as far from the LEM as possible. Both surface and subsurface samples are required. In the event of a semi-aborted or shortened stay on the lunar surface, the astronaut's first scientific duty is the collection of as many samples as possible, without regard to sterility.

The second priority for the Early Apollo is the emplacement of the Lunar Surface Experiment Package (LSEP) by the astronauts. This should be emplaced to attain optimum operating conditions. Next in priority are the lunar geological traverses by the astronauts. If feasible these should be accurately controlled with automatic procedures and monitoring. The description of topographic and geologic relations along the traverse lines should be supplemented by stereoscopic photographs.

Of concern to the successful performance of these scientific experiments is the existence of radioactive sources in the spacecraft. Many planned experiments could be affected by this radioactivity. Four serious sources of radioactivity have so far been identified on the spacecraft and its instrumentation: (1) Magnesium-thorium alloys used in structural members of the spacecraft. This is a rich but variable source of gamma radiation; (2) Promethium activated luminous dials in the Command Module could be a considerable source of gamma radiation; (3) Cobalt 60 used in the fuel gauging system in the reaction control system aboard the Service Module and the LEM; and (4) The radioisotope thermal generator (RTG) used as a power source for the LSEP system.

Recommendations were suggested for reducing as much as possible existing radioactive sources and to evaluate future possible sources. These recommendations are that: (1) A combined scientific and technical review of the presently authorized sources be made to determine which sources can be eliminated from the spacecraft and which are operationally necessary; (2) A complete radiation survey of the spacecraft mockup be made to determine where other sources may exist; (3) Specifications be set for radioactive interference (RAI) similar to those which are set for radio frequency interference (RFI); (4) All experimenters should determine the radiation tolerances acceptable to their experiments; and (5) Alternate experiments and alternate developments should be included or considered if significant interference by radioactive sources cannot be eliminated.

Equipment Requirements

The working groups were asked to consider equipment priority beginning with the most important. Weights assigned are the absolute minimum needed to accomplish the task. In some cases (i.e., sample tools), added weight and complexity would be desirable if weight and space are available. This priority list is as follows:

1. Sample containers (10 lb) should keep samples sterile and chemically clean. Stainless steel is acceptable. More studies should be completed relative to the use of teflon in the lunar environment.

2. Sampling tools (10 lb) should be easily operable, light and simple; e.g., space hardened rock hammer, rubber mallet, sun compass.

3. Aseptic sample collection tool (10 lb).

4. Photography (7 lb)—A stereoscopic camera with several filters and polarizing lenses.

5. LSEP experiments—Suggested experiments in order of priority are: a passive seismograph (25 lb); a magnetometer/particle detector (13 lb) and a heat flow measurement device (15 lb); an active seismograph experiment (7-20 lb); an atmosphere measurement device (10 lb); a micrometeoroid detector (15 lb). The gravimeter should be considered for AES because of its weight and development complexities.

Preliminary Studies

Studies and tests should be started immediately to determine the amounts and effects of the outgassing of the astronauts' suits and the escape of the atmosphere from the LEM. Sterilization of the escaping atmosphere from the LEM should be considered. Analyses of the possible contaminants in the LEM fuel and the effects on sample collection should be undertaken.

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Sample Investigations

Upon return of the lunar samples to Earth, they will be prepared at a Lunar Sample Receiving Laboratory (LSRL) for distribution. Here they will be logged in, cataloged, checked for outgassing, measured for low level radiation, and examined for pathogenic agents. Only those tests which must be done immediately will be conducted at the LSRL. The portion of samples to be distributed will be packaged and initial distribution to the selected scientific investigators will be made.

EARLY LUNAR ORBITERS

In the time period prior to the end of the decade two classes of missions are scheduled.

Unmanned Missions

These missions will begin in the time period of 1966-1967. The primary function for the approved missions is site selection and hence, low altitude orbiters are desirable. However, should particles and field experiments be included on later flights, altitudes of 150 to 2000 km are required. Following are some specific recommendations for inclusion on these flights:

1. Cartography. Stereophotogrammetric analysis of the photography obtained by the first block of Lunar Orbiters should be carried out in order to obtain information regarding the character of lunar topography and to gain experience in analyzing lunar photography. It is recommended that later first block Lunar Orbiters, or any second block, be placed in orbits of different inclinations, with priority for a polar orbit.

2. Particles and Fields. A 3-axis magnetometer and particle package to study day-night changes in particle and field environment should be included. For these experiments the spacecraft should be radioactively and magnetically clean.

3. Lunar Atmospheres. Pressure, flux and mass measurements for determination of neutral and ionic constituents should be conducted. This is advantageous for early flights because of the uncontaminated state of the atmosphere.

Manned Missions

Consideration should be given to the inclusion of simple diagnostic experiments to be conducted from the orbiting Command/ Service Module (CSM) in conjunction with Apollo experiments on the lunar surface.

AES MANNED LUNAR ORBITER (AES-MLO)

Role of AES-MLO

Since less than 1 percent of the lunar surface will be visited in the near future, a major source of scientific knowledge will come from orbiting spacecraft. Extensive information can be easily obtained for the following reasons:

1. Variation of orbital inclinations will permit mapping of the entire lunar surface.

2. Absence of atmosphere allows all regions of electromagnetic spectrum to be accessible.

Thus, Manned Lunar Orbiters can provide useful additions to the subsurface information obtained from geophysical studies and to the local studies from fixed and traversing surface experiments. Because of the orbiter's nature, however, they cannot provide information with the same precision and detail as the surface instruments. Orbital investigations offer the potential of identifying local areas of the lunar surface with unusual properties which might be of interest for future manned exploration.

It is recommended that one orbiter carrying the remote sensing package be flown prior to the first AES landings. Polar orbiters are desirable at the earliest time for total coverage of the lunar surface by remote sensors. In the first phase of lunar exploration (complete orbital survey), five or six missions are believed to be appropriate. Subsequently, AES-MLOs will be necessary to support and supplement the AES surface operations, as well as to monitor lunar activity. Launch rates should be approximately one a year.

A systematic program of geologic mapping using orbital data is recommended with the preparation of geologic maps at the following scales:

1. 1:2 500 000. Synoptic map for general planning and collating of a wide variety of data about the gross features of the Moon.

2. 1:1 000 000. Complete synoptic geologic mapping.

3. 1:250 000. Total coverage of the lunar surface. This is a long-range goal.

4. 1:100 000; 1:25 000. Special purpose, directed toward solution of selected topical problems.

Photography Equipment

For complete photographic coverage of the lunar surface the lunar Orbital Camera System should include the following camera subsystems:

1. Metric (Mapping) Camera Subsystem. Designed for use in determining the lunar figure and mapping of the lunar surface.

2. High Resolution Twin Convergent Panoramic Camera Subsystem. Designed for photography of highest resolution in keeping with coverage of large areas.

3. Ultrahigh Resolution Camera Subsystem. Designed to produce photography of extremely high resolution and multispectral response of limited areas.

4. Multiband Synoptic Camera Subsystem. A means for obtaining large areas of multispectral photographic coverage of the reflective properties of the lunar surface in the visible and near visible portion of the spectrum.

Remote Sensors

Imaging sensors will provide information about surface structure and composition from depths of microns to a few meters. Imaging instruments, including UV imagers, IR imagers, and high-resolution radars have proven value for surface and near-surface structure and composition studies and for the study of thermal anomalies. Coverage of the entire Moon with these instruments is recommended at an early date.

Nonimaging remote sensors, such as the passive microwave, radar scatterometer, IR, X-ray, gamma-ray, and alpha-particle emission are recommended for inclusion in lunar orbital payloads pending the results of current remote sensor feasibility studies. The characteristics of these instruments are tabulated under the Geochemistry Group Report.

Atmospheres, Particles and Fields Equipment

Atmospheric and ionospheric variability surveys should be conducted. The recommended characteristics of the ion and neutral mass spectrometers are described in the Group Report. Ion traps, solar wind detectors, and pressure gauges can be adapted from the unmanned programs.

Other experiments include the determination of the cosmic-ray albedo, the study of solar and lower-energy galactic cosmic rays (particle telescope), and the search for water using a neutron instrument to detect the hydrogen content of the surface.

Instruments for Subsurface Analysis

There are three orbital instruments that have the potential of obtaining valuable data from depths of kilometers and beyond. The first of these is a magnetometer which will yield important information on the geology of the lunar crust. Second is a gravity gradiometer yielding details of the variations in the lunar gravitational field. The third is the electromagnetic pulse probe which has the potential for probing to depth and differentiating the various layers present.

AES MANNED LUNAR SURFACE (AES-MLS)

The AES-MLS is essentially a continuation of the early Apollo missions characterized by longer stay time and larger scientific payloads.

It is suggested that this program can be usefully exploited in five or six missions, extending through 1974. The scientific requirements of this series include stay times up to 14 days and traverses up to 15 km from point of landing.

The longer stay time will probably permit the collection of more material than can be returned to Earth. Hence aids to the selection of samples in the field or prior to return should be provided by analytical equipment which will also measure sample characteristics which may be altered by return or packaging. Sample return is still the most significant achievement in these missions. Local mapping should also have a high priority so that sample location is accurately tied to the local geology.

The capability to off load several LSEP's during each AES mission is also an important aspect. In this way a small array of stations (LSEP's) could be set into operation, giving important information for revealing the internal properties of the Moon.

The Moon should provide a unique base for astronomers because of its useful environmental characteristics, the most important being the lack of an appreciable atmosphere. However, exhaustive studies of the complete lunar environment are necessary before engineering design can be started.

The primary objective of analytical devices used on the lunar surface should be to extend the power of the observer to differentiate materials which have similar characteristics. The optimum sample return capability would be between 200 and 250 kg (450-600 lb) per mission. The following basic types of equipment are required for this phase of lunar exploration:

1. Automatic position recording systems. Essential for tracking and recording movements of the astronaut, and the roving vehicle, and knowing the orientation of the camera. The system would automatically telemeter this information back to Earth or to the LEM.

2. Local Scientific Survey Module (LSSM). This surface roving vehicle should have the capability of carrying either one or two suited astronauts and a scientific payload of at least 600 lb. Operational range of 8 km radius is a minimum, and 15 km would be more useful. Remote control of the LSSM would also be advantageous both before and after the arrival of the astronauts.

3. Lunar Flying Vehicle (LFV). A LFV would be useful for extending the operational range of the AES and for studying features inaccessible to the LSSM due to topography. It should be able to carry at least a 300 lb scientific payload over a distance of 15 km. Continued study should determine how effectively it can be employed in surface operation.

4. Lunar Drills. The development of a 1 inch drill capable of penetrating to a depth of 3 meters in either rubble or solid rock is recommended. It should be operable from a roving vehicle. It is necessary for lunar heat flow studies and for obtaining biological samples.

Because of the liberal weight allowance for equipment delivered to the Moon's surface most Working Groups indicated a wide variety of experiments desired for inclusion in the program. Equipment and experiments include instrumentation for performing gravity surveys, active seismic surveys, magnetic measurements, radioactivity measurements, environmental measurements, and in general instrumentation and supporting equipment for conducting geological-geophysical surveys on the lunar surface.

To obtain maximum output of scientific information from these experiments, astronauts should be given scientific training in specific rather than general areas. The greatest need is for trained geologists; however, specialized training will be required in physics, meteorology, chemistry and other fields.

POST-AES

The AES should be followed by a program including long distance travel, up to 800 km and fixed site investigation from 2 months to 1 year. These missions should commence about 1975 and proceed at a rate of one per year through 1980. Additional orbital flights also appear desirable during this period so as to conduct simultaneous orbital and surface missions.

A long-range laboratory vehicle for geological and geophysical exploration is required to permit the collection of data to form a broad regional integrated picture of the surface geology and crustal structure. These data will also be essential as a basis for interpretation of the imagery and measurements obtained from the remote sensing orbital vehicle and also to substantiate other investigations.

A series of traverses along the equatorial belt is suggested, requiring a vehicle with the following characteristics:

1. A minimum range of 800 km.

2. Shelter for a three-man crew.

3. Mission duration capability of up to 2 months.

4. Not be constrained to return to starting point.

A Lunar Base is a surface complex which will allow longer stay time, possibly up to a year, than is presently envisioned by the AES concept. Primary needs for a base are visualized to be:

1. The measurement of presently occurring time varying phenomena—many are geophysical in nature.

2. The study of lunar surface processes.

3. Deep drilling studies—most important for information on early history, crustal composition, and surface properties of the past. Depth to be reached should probably exceed 300 meters.

4. Detailed study of a critical field area.

5. Construction and manning of large radio and optical telescopes, yet to be defined.

DISCIPLINE SUMMARY

GEODESY/CARTOGRAPHY

Introduction

The Geodesy/Cartography Working Group consider as its area of interest those scientific experiments that provide quantitative geodetic and cartographic information during the various phases of the lunar exploration program. This information will support geological, geophysical and other scientific experiments by providing a means of correlating the theoretical and experimental results with geodetic and/or cartographic parameters.

The following tasks appear to the Working Group as essential steps in a lunar geodetic-cartographic program:

1. Establishment of a selenocentric coordinate system oriented with respect to the Right Ascension-Declination System.

2. Measurement in sufficient detail of the gravitational field of the Moon.

3. Derivation of a reference figure with respect to a point representative of the center of mass of the Moon.

4. Establishment of a three-dimensional geodetic control system over the entire surface of the Moon in terms of latitude, longitude, and height above the chosen reference figure.

5. Establishment of systems for the collection of raw data for completion of topographic maps at various scales by photogrammetric methods.

6. Establishment of techniques and instruments for the reduction of acquired data, and presentation of these data in a useful form.

7. Establishment of additional geodetic measurements to provide complementary results for analyzing in depth such phenomena as rotation and physical libration of the Moon, and lunar tides.

8. Establishment of specific research and development programs which show promise of effecting significant improvements in knowledge of lunar geodetic parameters.

The Working Group considered the overall feasibility of a lunar geodetic-cartographic program, and its evolutionary aspects in terms of the results which can be expected during the progress of the Lunar Orbiter, early Apollo, and AES programs. The general consensus of the Working Group is that extensive lunar geodetic surface operations have limited significance so long as they can only be carried out at a few, and probably unfavorably distributed, landing sites. However, valuable geodetic information can be gathered by photographing the star background. This suggests the development of special camera systems as indicated in Recommendation 6.

It was also concluded that better knowledge of the size and shape of the Moon is necessary to attain the full scientific value of geodetic-geophysical measurements.

The following recommendations reflect those areas considered by the Working Group, but are not necessarily indicative of all areas discussed.

Recommendation 1: Geodetic/Cartographic Camera Systems for AES.

The Working Group considered requirements for photographic systems capable of producing a significant increase in knowledge of lunar geodesy and cartography.

1. The general content of the "Proposal for AES Lunar Orbital Flight Experiment in Relation to the Acquisition of Multipurpose Photography" was endorsed. It is urged that an intensive study be undertaken to determine the design parameters of optimum camera systems for lunar geodesy and cartography, in order to have systems available for inclusion on the AES missions.

2. First priority should be given to the development of a metric camera system capable of producing, by photogrammetric triangulation, a standard error of 10 meters in the three coordinates of spacecraft camera exposure stations and in the network of photo-identifiable points on the lunar surface.

3. The basic cartographic camera system should be designed on the conventional configuration of 6-inch focal length and 9×9 inch format in order to produce photography having the widest use among the scientific community.

4. The basic cartographic camera should be directly coupled with a stellar camera from which the angular orientation can be determined to a few seconds of arc.

5. In order to utilize stellar data it is essential that precise time be available on the spacecraft and recorded in synchronism with each cartographic and stellar exposure. A precision of one millisecond is required.

6. Precise altimetry, one part in 200 000, is essential to control the scale of the photogrammetric triangulation, and the subsequent determination of the variations of the lunar topography.

7. In design of the photogrammetric system, serious consideration should be given to the current state of knowledge of

lunar photometry and its effect on angular coverage, stereoscopic fusion, etc.

8. Suitable programs for rapid, efficient and vigorous reduction of photogrammetric triangulation should be developed.

9. Second priority should be assigned to the development of a high resolution convergent panoramic camera system.

10. The usefulness of ultra-high resolution, synoptic and multispectral photography for other disciplines is endorsed for AES missions. Such instruments may be helpful to cartographic keying by resolving uncertainties in classification of regions according to their surface characteristics.

Recommendation 2: Apollo Mapping and Survey Camera Systems (M&SS).

The primary mission of this system is for selection of lunar landing sites. However, the working group is concerned that the system may possibly be considered for later AES missions. The task of establishing photogrammetrically a basic geodetic control net on the surface of the Moon, and simultaneously determining the geometry of the orbit to the accuracy necessary for analysis of the lunar gravitational field would make inadvisable the use of this system.

The Working Group recommends that for AES missions a Geodetic/Cartographic Camera System, described above, be developed in addition to the M&SS.

The Working Group is opposed to security classification on any system contemplated for use in scientific exploration.

Recommendation 3: Observations of the Gravitational Field of the Moon.

A considerable increase in our knowledge of the gravitational field of the Moon, in addition to information derived from unmanned orbiter flights would be obtained by tracking from the

Moon itself. It is recommended that design studies be undertaken for Doppler beacons or transponders on the lunar surface to track lunar satellites.

It is recommended that a gravity gradiometer be utilized to measure detailed variations of the gravity field, supplementing those determined by orbital perturbations. The potential benefits of this instrument are great if an accuracy of $\pm 5 \times 10^{-10}$ gals/cm or better is attainable.

Recommendation 4: Lunar Orbiter (unmanned, photographic).

Stereophotogrammetric analysis of the photography obtained by the first block of Lunar Orbiters should be conducted to obtain information regarding the character of lunar topography and to gain experience in analyzing lunar photography.

Later first block Lunar Orbiters, or any of the second block, should be placed in orbits of a variety of inclinations, with priority for a polar orbit.

Recommendation 5: Altimetry from Lunar Orbiting Satellites.

Development of a radar or laser altimeter should be supported for incorporation in all subsequent lunar orbiting satellites.

Recommendation 6: Stellar Observations from the Lunar Surface.

Camera systems should be developed for stellar observations. The cameras may be used for independent determination of the direction of the pole, time, or any variations in rotation and librational effects.

Recommendation 7: Radar/Laser Ranging from the Earth to the Moon.

Ranging observations from the Earth to reflectors and/or transponders located on the Moon's surface should be performed to improve knowledge of the lunar ephemeris, physical librations, and the direction of the pole. The desired ranging accuracy is at least ±10 meters, preferably ±1 meter. The theoretical treatments of the orbital and rotational motions of the Moon should be reviewed and, if necessary, reformulated to assure that recommendations 6 and 7 can be effectively employed.

GEOLOGY

Introduction

The Geology Working Group recommends a 10-year program of lunar geological exploration (for the time period 1970-1980) to achieve the broad objectives of lunar exploration outlined by the Space Science Board of the National Academy of Sciences. This program consists of (1) the early Apollo missions, (2) AES missions, and (3) post-AES missions.

After completion of the early Apollo landings, about 1969, a more versatile exploration system should be implemented, permitting a longer stay time and greater exploration capability than will be possible in early Apollo. It is believed that the AES system, as presently conceived, has capabilities for lunar exploration that can be usefully exploited for at least five or six surface missions at a launch rate of one or more missions per year. A similar number of AES manned orbital missions should be flown during the period of AES surface exploration. At the minimum recommended rate of launch, the AES phase of exploration would draw to a close by the end of 1974. The AES phase should be followed by an exploration phase that includes long distance travel (up to 800 km) on the lunar surface and fixed site investigations with stay times of 2 months to 1 year. At a conservative or minimum rate of exploration, these missions should commence about 1975 and proceed at a rate of one per year through 1980. Additional orbital flights also appear desirable during this period so as to conduct simultaneous orbital and surface missions.

An exploration program of this scope should provide first order answers to most of the major questions that can now be asked about the Moon. Specifically it will provide the basis for a detailed analysis of the geologic history of the Moon and of the major processes that have acted upon the lunar surface and within the lunar interior.

Early Apollo Missions

The main geological objective for early Apollo missions will be study of the fine structure of the lunar surface, mainly in the plains areas favorable for early landing. Plains areas of interest include not only the maria, but also the plains areas of certain upland regions. These plains are depositional surfaces, modified by postdepositional processes of several kinds.

In the limited time available for geological investigation in the early Apollo missions, some of the primary questions to be answered are the nature and origin of the material underlying the plains. Was the material of the plains spread as flows of liquid lava, now solidified to rock or rock froth, or is it ash or granular material comminuted by explosions of various types, and spread as density flows, and now ranges from unconsolidated to solid depending upon the degree of heat or vacuum welding? Evidence of chemical differentiation of the plains material will be of great interest. Another important question is the nature and rate of the extremely slow processes that have operated on the Moon's surface.

To accomplish the objectives outlined above a series of traverses by the astronaut will be undertaken. Acquisition of position information along the traverses should be obtained as accurately as practicable with automatic devices. The astronaut should have the ability to observe subtle geologic relationships, to grasp the significance of these observations, and to direct his traverse and take samples accordingly. Time is of the essence in carrying out the surface traverses and as much time as possible should be allocated for them. The astronauts will use light, simple hand tools. The highest scientific priority should be assigned in this period to the return of the greatest number and widest variety of samples of lunar materials as feasible.

Descriptions of topographic and geologic relations along the traverse lines should be supplemented by stereoscopic photographs in order that the traverse can be completely reconstructed after the astronaut returns to Earth.

Lunar Orbiter Missions

Missions which are being examined for the period following the initial landers are manned Apollo lunar orbiters. Less than 1 percent of the lunar surface will be visited in the foreseeable future; thus the major source of geologic knowledge about the Moon will come from data acquired by remote sensors such as radar systems, mapping cameras, and infrared detectors carried on manned lunar orbiters.

A systematic program of geologic mapping is recommended, using data acquired from lunar orbiters, which would include preparation of geologic maps at the following scales:

1. 1:2 500 000. To provide a synoptic map for general planning and collating of a wide variety of data about the gross features of the Moon (6-month effort).

2. 1:1 000 000. For complete synoptic geologic mapping (3-year effort).

3. 1:250 000. For total coverage of the lunar surface (10-year effort). This is the major long-range goal.

4. 1:100 000 to 1:25 000. For special purposes. These maps would be directed toward solution of selected topical problems.

The sequence of orbiter missions recommended is as follows: One orbiter carrying a remote sensing package including a complex group of sensors should be flown prior to the first AES landings. Polar orbiters are desirable at the earliest time practicable in the AES phase of exploration for total coverage of the lunar surface by remote sensors. The Working Group feels that a minimum of three orbiters would be needed for complete survey.

The AES orbiters should be capable of carrying and deploying unmanned lunar surface probes for the purpose of reconnaissance. These probes might be either of the capsule or soft-lander type depending on how they are to be utilized to achieve one or more of the following objectives:

1. To measure at selected localities those properties of lunar surface material which determine the intensity and energy distribution of the radiations measured by lunar orbiters as a basis for interpretation and extrapolation of other orbiter measurements at other places.

2. To further characterize and confirm geologic units on the lunar surface already delineated by observation from Earth-based mapping and from orbital reconnaissance.

3. To select sites where sufficiently important problems exist to warrant further investigation by manned landings on the lunar surface.

4. To emplace instruments, such as a seismometer, in a surface net in order to measure properties related to internal structure and atmospheric variations.

AES Surface Missions

Following the early Apollo flights, it is expected that most of the operational problems involved in landing men on the Moon and returning them to Earth will have been solved. It is also expected that the astronauts' observations, coupled with the analysis of returned samples, will have provided direct evidence of the composition and age of some lunar materials and will establish the nature of the fine structure of at least the upper meter of the Moon's surface materials at the landing sites.

In the AES surface missions, the geological objective is the acquisition of detailed information regarding the major types of terrain on the lunar surface. At the present time, three types are of prime interest and are readily identifiable: (1) the maria, (2) the ancient more highly cratered highlands, and (3) major craters. The major objective in all of these areas would be to test the geologic interpretations based on the orbiter data and to obtain the detailed data on composition and structure that can only be obtained by landing on the surface.

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The following equipment would be required for this phase of lunar exploration.

1. Automatic position recording systems. These are required for tracking and recording movements of the astronaut, roving vehicle, and cameras. They will automatically telemeter the position information back to Earth. Great precision of position is not necessary; location of positions to 1 part in 1 000 is adequate for geological observations and for photogrammetric utilization of photographs acquired on the traverses.

2. Local Scientific Survey Module (LSSM). This would be a surface roving vehicle capable of carrying either one or two suited astronauts and a scientific payload of at least 600 lb. Operational range of 8 km radius is minimum, and 15 km would be more useful. Remote control of the LSSM would also be advantageous both before and after the arrival of the astronauts.

3. Lunar Flying Vehicle (LFV). The LFV is a one or two man rocket propelled craft capable of hovering and low flying to a distance of 15 km. It could be used for extending the operational range of the AES and studying features inaccessible to the LSSM due to topography. For this purpose it should be able to carry at least a 300 lb scientific payload. Continued study of the LFV is recommended, since its usefulness in lunar surface operations has not yet been demonstrated.

4. Lunar Drills. The development of a drill capable of penetrating to a depth of 3 meters in either rubble or solid rock is recommended. It should be operable from a roving vehicle and produce a 1-inch core. A drill capable of penetrating to greater depths is not required for the AES phase of exploration.

Post AES

Long Range Traverses

Traverses with a long range surface vehicle are needed to provide a broad regional integrated picture of the surface geology and crustal structure of the Moon. The data to be obtained from these traverses are essential for full interpretation of the data obtained from the remote sensors carried on lunar orbiters and also to tie together local detailed studies made during AES surface missions and at semipermanent lunar bases.

A series of traverses along the equatorial belt which will provide a continuous geologic and geophysical cross section across the major features of the lunar crust is recommended. For completion of these traverses, the vehicle should have the following characteristics:

1. A minimum range of 800 km.

2. Shelter for a three-man crew.

3. Mission duration capability of up to 2 months.

In addition, the vehicle should not be constrained to return to the starting point.

Fixed Base Studies

Some types of geologic study will require a surface complex allowing longer stay time than is presently envisioned by the AES concept. Geological requirements for such a base are as follows:

1. The measurement of presently occurring time varying phenomena.

2. The study of lunar surface processes.

3. Deep drilling. Several of the major scientific questions concerning the early history, crustal composition, and past surface properties of the Moon can best be approached by deep drilling. Depth to be reached should probably exceed 300 meters.

4. Detailed study of key geological areas.

GEOPHYSICS

Introduction

The Working Group concerned itself with the overall design of a lunar exploration program directed towards revealing, to first order, the physical properties of the Moon from the surface to the center. Major emphasis was given to the early Apollo missions and the AES because the constraints were either fixed or reasonably well defined and lead times for the development of experiments were becoming critically short. Although some effort was expended on a longer range lunar program (Apollo Logistics Support System (ALSS), Lunar Exploration System for Apollo (LESA), and beyond) it was felt that, in view of costs and scientific manpower commitment, a review in depth could only be made in the context of priorities associated with an overall program of planetary exploration.

Geophysics on Early Apollo Missions

The Lunar Surface Experiment Package (LSEP), to be carried on-board the early Apollo missions, represents a major opportunity for performing a large group of geophysical experiments. This package, in essence an observatory, has capabilities which in many respects exceed those which are achievable on Earth.

Since geophysical observations are usually synoptic in character it would be desirable to build up an array of observation points on the Moon. To insure complete recovery of all data a continuous recording system is a necessity. To satisfy this requirement the Working Group recommends the construction of a minimum of three 85 ft Earth-based receiving dishes to be placed and operated for continuous monitoring of lunar surface payloads.

Also, it would be advantageous to have two or more LSEP observations overlap in pattern and life times (4-8 months). From a geophysics viewpoint the LSEP should include the following components:

1. Experiments (candidate)

   a. magnetometer
   b. gravimeter
   c. heat-flow experiment
   d. passive seismometer
   e. active seismometer
   f. lunar atmosphere measurement
   g. solar wind detector and proton spectrometer
   h. micrometeorite and secondary detectors

2. Data subsystem (telemetry controls and antenna)

3. Electrical interconnection subsystem

4. Structural subsystem

5. Thermal control subsystem (if active)

6. Power generation subsystem

Pertinent data on the instruments are summarized in table I.

The package, as envisioned at the present time, may include a maximum of eight experiments. Priorities have been established on these experiments to assure order if reduction in number is required later. The factors contributing to the priority arrangement are: scientific significance, weight, volume, data transmission rate and power requirements, and feasibility. After coordination with the other Working Groups, the following priorities were recommended:

TABLE I. – CHARACTERISTICS AND PRIORITIES ASSIGNED TO GEOPHYSICAL EXPERIMENTS CONSIDERED BY THE GEOPHYSICS WORKING GROUP FOR INCLUSION ON THE EARLY APOLLO MISSIONS

[All experiments are considered to be of major scientific importance and recommended for inclusion in the missions. All experiments are for inclusion in the LSEP except for the short array mode of the active seismic experiment which the astronaut will complete during his stay time on the lunar surface, and the gravity meter experiment which is recommended for the AES Missions.]

	Weight (lbs)	Power (watts)	Size (cu ft)	Information rates (bps)	Astronaut time (min)	Mission 1	Priorities mission 2	Mission 3
Magnetometer/ particle detector	13	5	0.5	35	Small	2	2	4
Gravity meter	30	15 int @ 30% 5 cont	1.0	Small	Small	AES	----	----
Passive seismic (long period)	20	1 cont	0.7	350-800	Small	1	1	5
Passive seismic (short period)	5	1 cont	0.3		Small	Both modes	Both modes	3
Active seismic[a] (long array)	20	3-20 min	2.0	7000 real time recorder, slow read-out	Small	(c)	(c)	2
Active seismic (short array)	7	20 int LEM power supply	0.5	return tape	45 max	3	3	----
Heat flow (without drill)	5	2 cont	0.5	Small	10	2	----	----
Heat flow[b]	15	2 cont LEM power to drill	1.0	Small	30	3	2	1

[a]Readout variable; consistent with available telemetry.

[b]One meter holes drilled by astronaut.

[c]Long and short modes if weight is available, otherwise short array mode.

1. Passive seismograph (about 25 lb).

2. Magnetometer/particle detector (about 13 lb) and heat flow measurements (15 lb). Equal priority.

3. Active seismograph (7-20 lb).

4. Atmospheric measurements (10 lb).

5. Micrometeoroid detector (about 15 lb) and electric field measurement (under 5 lb). Equal priority.

Several recommendations pertaining to the early Apollo mission were singled out for special emphasis.

1. The tidal gravimeter is recommended for deferment to the AES mission because one of its primary purposes does not include returning direct data on the lunar interior. The other function of the gravimeter is partially covered by the seismograph experiment. Another consideration for its deferment is the high weight and problem of developing such a complex instrument.

2. The heat flow experiment is of major significance but problems may arise because of the need to emplace the probes to depths of at least 1 meter. The minimal weight is estimated at 5 lb if the astronaut is to emplace the probe without auxiliary tools. In the 15 lb mode, a special drill is included which greatly enhances the experiment. The drill is recommended for mission 2 since drilling feasibility can be assessed after mission 1.

3. Changes in the LSEP experiments should be permissible between missions 1 and 3, if not 1 and 2 or 2 and 3. Modular design could make this possible.

4. Telemetry capability sufficient to recover all data generated by the LSEP is required in the early missions if not all of them. Real time data recovery is not required except possibly as a backup mode if a data storage system should fail.

5. If a high priority experiment fails to be included in a given mission by virtue of considerations beyond the control of the experimenter, it should be included in the next mission without loss in priority.

Geophysics on Post-Apollo Missions

The AES missions offer an augmented capability for lunar exploration. Emplaced Scientific Stations (ESS), traverses to distances of the order of 10 km, and geophysical stations at the end of traverses are possible. The emplaced observatories have a weight and data rate capacity which permits inclusion of essentially all station type geophysical observations. Heat flow measurements are not only assured because of the drilling capability, but their precision is extended by the greater depths at which temperature observations are made and the larger number of holes that are available for logging.

Traverses in roving vehicles make possible the study of gravity and magnetic anomalies associated with local and regional geophysical structures. Active seismic experiments with profiles 10 km long (penetration of several kilometers) are possible. The simultaneous and automatic measurement of many physical properties and natural and induced fields can be carried out by towing a comprehensive logging package behind the vehicle.

At the end of the traverse a satellite ESS which can survive for one or more years can be off-loaded and set up by the astronaut. Each AES landing site can thereby become a triangular array some 10 km on the side. This greatly augments the capability of passive seismic experiments to define the interior, allows for reversed active seismic profiles, and strengthens the heat flow, magnetic, and lunar atmospheric experiments.

AES Orbital Geophysics Experiments

Manned spacecraft orbiting the Moon present a significant opportunity to measure surface and near-surface geophysical parameters of the Moon. Proposed experiments may be divided into two general classes.

Deep Probing Orbital Instruments. Those providing information about structural variations at depths of kilometers and beyond.

The Working Group recommends that a magnetic survey be made to study the subsurface of the Moon. This could be done by a low-orbit spacecraft provided that the magnetic field of the Moon proves sufficiently strong.

The Geophysics Working Group is in accord with the recommendations set forth by the Geodesy/Cartography Working Group regarding the importance of a gravity gradiometer accurate to $\pm 5\times10^{-10}$ gals/cm.

Orbital use of the electromagnetic pulse probe can provide significant geophysical information. It operates on the principle that electrical conductivity of extremely dry igneous rocks, at least at moderate temperatures, is low enough to expect penetration of an electromagnetic wave to depths of kilometers and tens of kilometers at frequencies in the region of approximately a decade on either side of 1 megacycle. A pulsed carrier at such frequencies, therefore, has the potential for probing to this depth and differentiating the various layers present.

Surface Observing Orbital Instruments. Those providing information about structure and composition of the surface from depths of microns to a few meters.

Imaging instruments, including UV imagers, cameras, IR imagers, and high-resolution radars have demonstrated value for surface and near-surface structure and composition studies and for the study of thermal anomalies. Coverage of essentially the entire Moon by these sensors is recommended during early flights.

Nonimaging remote sensors, such as the passive microwave, radar scatterometer, IR, X-ray, gamma-ray, and alpha-particle emission experiments, are recommended for inclusion in lunar orbital payloads pending the results of the current NASA-conducted remote sensor feasibility studies.

Because lunar surface exploration will be limited in the near future, remote sensing will for many years provide the only means of studying the entire Moon. Because of the nature of remote sensing, however, it cannot provide information with the same precision and detail as surface measurements. By dropping surface probes, there is the possibility of establishing highly desirable networks of geophysical observatories.

Specific Areas of Interest for Overall Moon Program

Seismic Refraction Studies

The answers to two basic questions are needed for the planning of refraction profiles on the lunar surface: what is the maximum sensitivity that can be attained by seismometers on the Moon and what is the efficiency of explosive and impact sources of seismic energy on the Moon?

Studies of the seismic efficiency of impact sources in various media might be undertaken, together with the design of an appropriate seismometer package. The package would be deployed by traverse vehicles or dropped in probes from orbiters. Large sources might be provided by impacting exhausted Saturn stages. If these experiments are successful, a final shot into an extensive array of seismic stations might involve an entire Saturn V payload. These experiments would provide lunar travel time data that would permit us to determine the structure of the Moon with a precision approaching that attained on the Earth.

Long Gravity and Magnetic Profiles

It is expected that a good definition of the large scale features of the Moon's gravity and magnetic fields will be obtained from satellite data and the Apollo landings. Such information might enable us to design vehicles for long, remote-controlled traverses on the lunar surface.

Heat Flow

Early Apollo and AES missions will determine average heat flow at the lunar surface. Regions of anomalous heat flow on the Moon should be located and studied. These measurements might be easily made if suitable traversing vehicles are developed, or it may be feasible to implant large numbers of heat flow probes along with other instruments from orbiting satellites.

Observatory Measurements

It may be desirable to increase the number and the lifetime of observatories of the type established in the Apollo missions and to add more sophisticated instruments to these observatories. For example, we may wish to add instruments that measure change in strain, strain seismometers and local geodetic networks.

Detailed Studies of Specific Features

It may be desirable to conduct intensive studies of specific features such as major craters, volcanoes or mountain ranges. Dense networks of passive seismic stations coupled with seismic refraction profiles, gravity surveys and magnetic surveys would be involved in these investigations. Close coordination with geological and geochemical studies will be required to study such features.

Physical Properties

Data on the physical properties of lunar material are needed for the interpretation of field observations. The necessary data may be obtained by in situ measurements or measurements in the laboratory on either actual lunar samples or Earth materials that simulate lunar materials.

Passive Seismology—Gravity

The possibility of using the Moon and Earth as detectors of gravity waves by monitoring free oscillations and other gravity perturbations makes the long period seismometer-gravimeter an attractive experiment. The existing state-of-the-art indicates that an instrument can hopefully be developed combining the best features of both existing instruments.

Recommendations

The experiments listed above are too complex to be undertaken in the first stages of lunar exploration, but they should be considered for the future.

Feasibility studies should be initiated and supported by NASA to determine if these experiments are appropriate for a later stage of lunar exploration.

BIOSCIENCE

Objectives

The general objective of bioscience investigations on the Moon is to answer the fundamental questions regarding the origin of the Moon, the universe and life, and the development of life or life precursors. To achieve this objective, investigations will be conducted primarily in organic chemistry and biology.

The specific objectives of the organic chemical exploration of the Moon involve the search for molecules of possible biological or prebiological origin. Detailed knowledge of the amount, distribution and exact structure of the organic compounds, if any, present on the Moon is of extreme importance. Since the organic chemical investigations used in attempts to answer these questions would be on a molecular level, the conclusions would not be dependent on the assumption of life and life-related processes as we know them. They, therefore, represent a broader and more general approach to the problem of detection of extraterrestrial life than is presented by direct culture or by wet-chemical, yes-no, life-detection devices.

The biological objectives for the lunar exploration program involve the search for evidence of viable or nonviable organisms and the search for any types of "life" systems that may be present or may have been present on the Moon. The biological objectives would also include search for life-associated macromolecules and their constituent moieties such as nucleosides, bases, sugars, lipids, and hydrocarbons.

The methods used in connection with the above objectives would include detailed attempts to isolate and culture "microlife" systems by inoculating standard culture media, tissue cultures, embryonated eggs, and plant and animal hosts. These tests would differ from those performed in the Lunar Sample Receiving Laboratory in that they would be more exhaustive and would be conducted as research projects with appropriate follow-ups, rather than as standard screening tests. X-ray probe microanalysis also would be used as required, as well as analytical methods such as light optical histochemical straining, electron microscopic histochemistry, and ultrastructure and cathodeluminescence microanalysis. For determining the structure of organic compounds, mass spectrometry seems to be the method of choice. Moreover, the interpretation of mass spectrometric data does not require any prior knowledge concerning the material under investigation.

Contamination Control Objectives and Methods

The first phase of contamination control relates to minimizing the biological contamination of the Moon. The Working Group is aware that complete prevention of Moon contamination is not possible. However, it strongly recommends that possible contamination be sufficiently studied and characterized to assure that valid biological and organic determination will be obtained during subsequent study with lunar samples.

To minimize the LEM contamination, the LEM's atmosphere should be vented through an ultrahigh efficiency biological filter prior to exits of the astronauts from the LEM. Also, all equipment to be moved from the LEM to the surface of the Moon should be sterilized with ethylene oxide or heat prior to departure from Earth. The amount and extent of microbial and organic contamination from the astronauts' suits should be studied in order to determine what steps must be taken to prevent sample contamination.

It is recommended that a study be made of the entire combustion products to determine the organic contaminant.

The second phase of contamination control relates to possible back-contamination of Earth with harmful lunar materials. The overall objective in this case is to assure that no catastrophic events occur on Earth as a result of the return and experimental use of the lunar samples. The probability that viable organisms will be found on the Moon is extremely small, and the chance that they would be dangerous if they did exist is even smaller.

A Quarantine Laboratory in the Lunar Sample Receiving Laboratory (LSRL) should be used for testing appropriate representative lunar samples for the presence of agents that might be infectious or toxic for man, animals and plants. The laboratory would also act as a central point for gross characterization and distribution of sample material. It should be the goal of this laboratory to provide safety clearance for lunar samples, if possible, within a period of approximately 30 days. Other functions of the LSRL should be to conduct gas analysis and low-level radiation counting on lunar samples; to perform mass spectrometry measurements of the pyrolyzed lunar sample (650-100 mg) for organic compounds and to act as a permanent repository for the storage of the samples.

Apollo Sampling Requirements and Problems

The Working Group considers that the highest priority of work time on the lunar surface should be given to the collection of samples. Samples for bioscience use should be collected as far from the LEM and from as many sites as realistically possible. A sufficient sample would be from 0.25 to 0.5 kg from each site. If aseptic collection of all samples is not possible, then separate bioscience samples must be collected in an aseptic and chemically clean manner for (1) bioscience research after release from the LSRL, and (2) for quarantine purposes in the LSRL. Whether collected separately or not, the bioscience disciplines would prefer both surface and subsurface samples, both meteoritic and volcanic samples (if both exist), and small aggregate materials as well as rocks. If a hole is drilled during one of the later landings, the core or parts of it at each depth is of interest also.

To achieve these ends, it is recommended that a feasibility and design study be initiated immediately that will lead to the development of a manually-activated lunar-sample-collection tool for acquiring organically and biologically clean surface and near-surface samples and that 5 kg of weight be allocated for it. Also, it is recommended that all astronauts be given training in aseptic and chemically clean sample collection techniques.

For bioscience purposes the amount of information derived from research with lunar samples will increase considerably with increases in the amount of sample available. For all the types of research described in this report a minimum of 5 to 10 kilograms of sample would be needed. The amount of sample required for quarantine purposes should not exceed 5 percent of the total returned sample; 5 to 10 grams minimum.

The following approximate breakdown for sample allocation is recommended:

Permanent storage in the LSRL (museum samples)	10%
Storage in the LSRL for second generation tests	40%
Quarantine testing	5%
Distribution to the scientific community	45%

Sample Packaging

The outer rigid sample containers may be made of stainless steel or of Inconel. These seem to be the most practical construction materials. Teflon may be used as a gasketing material for the containers. If a back-up closure device is required, a metal knife edge seal penetrating into a soft metal such as gold might be considered. <u>Teflon is the only plastic known to be acceptable to the organic chemists</u>. The rigid containers are to be closed in the lunar vacuum for the return.

The inner containers should be made of a teflon-metal laminate. These bags must be flexible, sterile, and able to achieve a vacuum seal. It may be desirable for them to be remotely filled, closed and labeled, using a special aseptic sample tool.

Before teflon is finally accepted as a suitable material for gaskets and for sample collection bags, the working group recommends that its behavior under near lunar pressures (10^{-12} Torr), under various types of radiation exposure (ultraviolet, infrared, etc.), and under temperature up to 400° K be investigated.

Consideration should be given to the possibility of aseptically enclosing a lunar sample for permanent storage on the lunar surface. This would assure, as exploration proceeds, the existence of at least a small portion of the lunar crust in as noncontaminated a condition as possible.

Considerations for AES

The bioscience disciplines should have a continued and increased interest in Moon exploration during AES. The biologists and the microbiologists will want to undertake projects of the general nature of (1) the survivability of terrestrial organisms and micro-organisms under lunar conditions, (2) the reaction of lunar materials with Earth organisms, (3) the study of many biological phenomena under lunar conditions.

The use of orbital lunar landers will permit the landing of automatically operating bioscience packages on the lunar surface. In this way contamination from the LEM or from the astronauts can be avoided and studies can be made at locations not otherwise easily accessible.

We envision also that a sophistication of the sample collection techniques will be possible for AES, e.g., better selection of types of materials to be returned to Earth; more careful selection of sites which would yield or promise to yield biologically or chemically interesting material; and preliminary *in situ* screening of material before return to Earth.

GEOCHEMISTRY (MINERALOGY AND PETROLOGY)

Introduction

To resolve the many problems of the Earth-Moon system and the Moon itself, it is essential that the following projects be undertaken:

1. Comparison of the composition of the Earth and Moon in terms of bulk chemistry and certain element and isotope ratios.

2. Comparison of the time scale of lunar events with that established for Earth history.

3. Determination of the evolution of the Moon by establishing the relative ages of major lunar events.

4. Establishment of the origin of the Moon. Has it persisted as a cold accumulation of undifferentiated "primitives" material or if there is evidence of chemical differentiation?

5. Establishment of the gross composition of the lunar surface as a whole.

6. Establishment of the relative roles played by internal processes and external processes in shaping the present lunar surface topography.

7. Establishment of the possibility to conduct more exhaustive surveys of the Moon—such as search for life support materials, e.g., water, oxygen, and energy sources.

Early Apollo

The single most important scientific objective of the Apollo missions is the return of as many lunar surface samples as practicable.

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Sample containers should be fabricated from materials of known and simple chemistry. Stainless steel and Inconel are considered feasible for sample boxes. Teflon is recommended for sample bags and as a gasket material.

It is recommended that a facility be provided to receive the lunar samples and prepare them for distribution to the selected scientific investigators. In this laboratory, only those measurements which are immediately necessary will be performed. This will include searching for pathogenic agents, low level counting and gas analysis. A further function of the laboratory will be logging, cataloging and distribution of samples.

Described below are some of the more important geochemical measurements to be performed on returned lunar samples. Other measurements are described in the Working Group Report.

Essential Measurements

Bulk analyses and determination of the elemental abundances should be performed to find answers to questions of the Moon's differentiation and fractionation, energy sources, nucleosynthetic processes, evidence of lunar degassing, and separation of metallic phases. In addition, isotope investigations to study nucleogenesis, radioactive aging, stable isotope differentiation, and phase identification and analysis should be performed.

It is proposed that a series of dry-run investigations be conducted on selected Earth materials with opportunities for potential investigators of the lunar samples to participate. One purpose of these dry-run investigations is to allow interlaboratory correlation and comparison of different experimental approaches and techniques. This may help point out areas where present techniques and facilities could be improved. Specific end products of this program will be:

1. Selection of principal investigators.

2. Basis for funding other investigators of demonstrated competence.

3. Upgrading the scientific capability of laboratories.

4. Definition of a group of well analyzed rocks.

Essential if Sample Suitable

Perform bulk sample analyses to determine infrared and ultraviolet properties, modal analysis and thermal gravimetric properties. Study separated phases for major and trace element partition, oxygen in each phase and fission tracks. Determine low-temperature specific heats, heat of solution, and heat capacity.

Apollo Extension System (AES)

The longer stay time probably will be sufficient for collection of more material than can be returned to Earth. Hence field selection is necessary, and some geochemical tests related to characteristics which may be altered by return can be done on the Moon. Sample return is still the most significant objective in these missions. Local mapping should also have a high priority for establishing the geological environment. The primary objective of analytical devices used on the lunar surface should be to extend the power of the observer and enable him to differentiate materials which are visually similar.

Specific recommendations:

1. An optimum sample return capability would be between 200 and 250 km (450-600 lb) per mission.

2. At least one of the astronauts on each AES mission should be a trained, experienced geologist. An attempt should be made to increase the number of such persons in the astronaut program.

3. The astronaut's position on the lunar surface should be monitored automatically during mapping and sample collection. Every effort should be made to minimize the proportion of the astronaut's time spent in mechanical duties.

4. Communication between AES astronauts and Earth-based scientists, for day-to-day mission planning and discussion of problems is desired. Such communication should be restricted to brief discussions at prearranged times and when requested by the astronaut.

Diagnostic Equipment for Sample Collection

Diagnostic equipment should be developed to enable the astronaut to make intelligent selections of samples for return to Earth. The intent of such instrumentation is specifically for the above purpose and not for *in situ* detailed geochemical or petrographic investigations.

Certain analytical tools lend themselves to the directed search for specific materials such as water-containing minerals, material bearing organic compounds, sources of gas emission, and areas of thermal activity.

Instruments suitable for defining the distribution of various materials on the lunar surface are of wide range, close range, near contact and optical contact variety. Wide range instruments would include atomic absorption for detection of active outgassing areas, mass spectrometer for detection of outgassing, and a hand-held infrared radiometer to detect positive thermal areas. Close range instruments include a neutron surface analysis unit to characterize water and organic surface matter. A near contact instrument would utilize atomic absorption for detection of encrustation from fossil outgassing. In the optical contact range are included single crystal IR probes for the detection of water and lunar surface hydration patterns. Also in this group would be X-ray fluorescence for element analysis.

The nature of the atmosphere and transient phenomena in the atmosphere must be investigated. Measurements are necessary to evaluate the relative importance of internal degassing, degassing by volatilization due to impact processes and accession of gases from the solar wind.

PARTICLES AND FIELDS

The Particles and Fields Working Group Report is divided into specific areas of investigation. These areas are listed in detail below. Within each group is information on what phase of experiments should be followed and why they are necessary, specific data to be obtained, and approach to be used.

The Lunar Magnetic Field and the Solar Wind Interaction with the Moon

These two subjects in the view of the group are very closely related and probably are parts of the same program. If the lunar field is produced by accretion of solar field due to the solar wind hitting the Moon (as seems likely) then the two subjects are inseparable.

It is recommended that a three axis magnetometer and particle detector package be included in the Apollo Lunar Surface Experiment Package (LSEP). In addition, this instrumentation should be flown in orbit simultaneously with surface operation and be capable of operating on the surface continuously during both lunar day and night. Ultimately it would be desirable to have a network of magnetometer stations. Of fundamental interest would be stations on opposite sides of the Moon near the equatorial plane.

In the AES missions, coordinated measurements of particles and fields should be made at different altitudes, on and above the lunar surface (10 m and 40 km).

The Lunar Electric Field

The Moon very likely has an electric field for the first 10-100 m altitude, but the magnitude of this field is difficult to estimate. This field is clearly related to the interaction of the solar wind with the lunar surface. It is recommended that a measurement of the vertical component of the electric field on the lunar surface be attempted in the Apollo program as early as possible.

Galactic Cosmic Rays

Cosmic ray studies that should be performed outside the magnetosphere and could profit from the on-route capabilities of Apollo include investigations of very heavy primary nuclei, studies of low-energy cosmic-ray nuclei and studies of cosmic gamma rays. Studies of the Moon's cosmic-ray albedo would be useful for assessing the albedo background; these experiments could be flown in orbit on the Service Module.

Long-range consideration should be given to the conduct of cosmic X-ray and neutrino experiments on the lunar surface and the monitoring of low energy galactic cosmic rays.

Solar Energetic Particles

The occasional violent outbursts of protons from the sun related to solar flares can be studied from the Moon in ways not possible from the Earth. As part of the AES program, it is recommended that a particle telescope be flown on lunar orbiter to study solar proton anisotropies and that a multiple-station particle telescope system be developed for a more complete study of anisotropy of different charged components of solar and the lower energy galactic cosmic rays. The system should have at least two ground stations on opposite sides of the Moon for detailed and continuous study of solar cosmic ray events. The addition of an orbiting particle telescope would greatly enhance the usefulness and reliability of the system.

Neutrons

A study of neutrons emerging from the surface of the Moon can provide information on the chemistry of the Moon. It is recommended that a neutron experiment be considered for flight on early lunar orbiters to survey the hydrogenous content of the surface.

Radio Astronomy and Radio Propagation

A sensitive receiver with a dish antenna should be set up on the lunar surface to measure cosmic, solar, and terrestrial electromagnetic radiation in the frequency range of 0.001 to 5 megacycles per second. It is also recommended that some cislunar and lunar surface radio propagation investigations be conducted. For example, measurements by Earth-lunar transponder(s) of integrated electron densities in the cislunar space, studies of the effects of the interposition of the Earth or Sun-Earth magnetosphere between the Earth and the Moon, measurement of impedances with antenna(s) deployed upon the lunar surface, and the evaluation of ground wave propagation and radio propagation in general, upon the lunar surface would be valuable.

Lunar Atmosphere and Ionosphere Recommendations

A spectrometer (preferably a neutral mass-spectrometer, but at least an ion mass-spectrometer) should be incorporated in the first Apollo Lunar Surface Experiment Package (LSEP).

Both ion and neutral mass-spectrometers should be included on a lunar orbiter for determination of a partial atmospheric composition profile.

In view of the relatively large payload capabilities in the extended Apollo missions, an atmospheric variability survey (neutral mass-spectrum, density, and flow) should be undertaken to form the basis for a network (one survey station of each type per lunar mission).

General

In view of the possibility that radiation sources and stray magnetic fields in the Apollo spacecraft may interfere with some scientific experiments, it is recommended that attention be given to the development of an airlock and subsatellite system. The Apollo LSEP design should be modular so that different experiments can be included after the first successful Apollo mission.

Lunar Orbiter

On Lunar Orbiter, the Group recommended a package similar to the LSEP be flown in a magnetically and radiation-clean spacecraft. These orbital experiments should be carried out simultaneously with and for the same durations as the LSEP experiments. Two types of orbits are recommended: (a) in the planned altitude range of 50 to 100 km to study day-night changes in the particles and fields environment with a 2-hour period, and (b) at altitudes of 100 to 2000 km in an elliptical orbit to penetrate any shock front.

LUNAR ATMOSPHERE MEASUREMENTS

Introduction

Measurements of the lunar atmosphere are of interest from an atmospheric physics viewpoint. Additionally, such measurements can be expected to significantly supplement the geologic data gathered on the Moon, since the lunar atmosphere may have evolved from solid lunar material. Geology without lunar atmospheric studies, or vice versa, would increase unnecessarily the number of conjectures that must be made to properly appreciate the lunar evolutional process and its present constitution. Since Apollo missions may contribute significantly to the contamination of the lunar atmosphere, it is important that measurements of the lunar atmosphere be accomplished as near the beginning of the program as possible.

Possible Sources of Lunar Atmosphere

The wide variation in theoretical predictions concerning the lunar atmosphere arises mainly from differing concepts concerning the source mechanisms. Examples of these concepts are:

1. An original atmosphere with no further accretion.

2. Volcanism or outgassing of volatiles from the interior of the Moon.

3. Meteoric volatilization.

4. Release by energetic particles.

5. Solar wind accretion.

Contamination

It is estimated that the total lunar atmospheric mass is about 100 metric tons. The Apollo's LEM will release up to 5 metric tons of exhaust gases. Since the vehicle carrying the atmospheric measurement experiment may itself seriously contaminate the atmosphere, the experiment should be capable of operating for several months. A first attempt at lunar atmospheric measurement should be made from an orbiter before contamination. In addition, it would be desirable to record any changes in the atmosphere that may occur between lunar day and night.

The accumulation of condensed rocket gases may possibly alter existing primitive deposits of frozen water and carbon dioxide in permanent or semipermanent shaded regions on the lunar surface. Also these exhaust gases will be modified by charged particle and electromagnetic-radiation energy from the Sun. The changes could affect scientific investigation of the overall lunar surface materials due to absorption and desorption of gases. It is, therefore, imperative that consideration be given to retention times of rocket exhaust gases in the lunar atmosphere and their effect upon future manned lunar surface exploration.

Apollo

Optimally, the lunar atmosphere experiment should measure the following neutral constituents: total pressure, and mass spectrum; and the following ionic constituents: total concentration, mass spectrum and directed flux.

After reviewing the measuring capabilities of various instruments and instrument availability, the following priorities of possible atmospheric measurements for the first three Apollo missions were suggested:

First Mission: neutral mass spectrum (if adequately developed), neutral particle pressure, total ion concentration, directed ion flux, and ion mass spectrum.

Second Mission: neutral particle pressure, directed ion flux, ion mass spectrum, neutral mass spectrum, and total ion concentration.

Third Mission: neutral particle pressure, neutral mass spectrum, ion mass spectrum, directed ion flux, and total ion concentration.

The search for existing volcanism is exceedingly important since such phenomena may provide volatiles that are useful for life support (both intrinsic and extrinsic). The location of active volcanic sites, if they exist, should be actively pursued.

Lunar Orbiter

The contamination problem provides a powerful argument that a first attempt at lunar atmosphere direct measurement should be made from an orbiter. The merit of such an approach, assuming that the altitude of the orbit would be low enough, is that: (a) a reasonable opportunity would be available for making measurements prior to contamination, (b) any burst of volcanic origin such as that recently detected optically might well be detected directly, and (c) outgassing at the dawn meridian might be detected. Continuous monitoring of regions of sporadic or periodic outgassing would detect gases with short retention times in the lunar atmosphere.

ASTRONOMY

Resolutions

The Astronomy Study Group was interested in the Apollo Extension System (AES) program for the 1970-1975 time period. As a source for initial discussion, the observatory base capabilities and possible astronomy experiments described in the LESA Report[1] were reviewed.

The following resolutions were made:

The group considers that the Moon may well offer an attractive and possibly unique base for astronomical observations and recommends that studies begin as soon as possible to explore the lunar capabilities for astronomy. These studies should involve evaluating engineering studies on Earth, conducting environmental studies on the Moon, and testing with small telescopes on the Moon.

It is felt that it is extremely important to start feasibility studies for a dish of approximately 100 feet to be used between millimeter and infrared wavelengths immediately after 1975. The dish has to be above the Earth's atmosphere.

The group considers that the information to be gained from radio astronomy observations at frequencies between 10 Mc/s and 50 kc/s is of considerable importance. To make these observations on a reasonable number of radio sources, and to map the continuum radio emission over the sky a beam area of about 100 square degrees or less at 1 Mc/s is necessary.

The group recommends that a feasibility study should be started as soon as possible to determine whether the antenna should be placed in high Earth orbit or on the lunar surface, and the type of antenna to be used in each case. Information about the lunar environment is essential to decide if the Moon is a suitable place for such an array, and should be obtained as soon as is possible.

The major environmental areas requiring study were discussed for radio, optical and X- and gamma-ray astronomy.

[1]North American Aviation, Inc. Report SID 65-289-4, A Study of Scientific Mission Support Lunar Exploration System for Apollo. June 16, 1965

Radio Astronomy

1. Mechanical properties (bearing strength, stability, etc.)

2. Electrostatic charge (dust and surface rock)

3. Background noise (radio interference from Earth or spacecraft)

4. Impedance and dielectric properties (lunar subsurface)

Optical Astronomy

1. Mechanical properties (bearing strength, stability, etc.)

2. Micrometeoroids (primary and secondary flux, erosion of mirrors, etc.)

3. Light background (luminescence, dust and atmosphere)

4. Thermal environment (above, on, and below the surface both lunar day and night)

5. Surface characteristics (reference points on Moon)

X- and Gamma-Ray Astronomy

1. X-ray background (from solar wind, cosmic ray, bombardment, etc.)

2. Gamma-ray background (radioactivity, etc.)

Need for Environmental Data

It was apparent that adequate environmental data are not available at present. Problems of a lunar base were discussed, but in many instances it was not possible for the Group to specify in any detail the environmental data which would be required.

The importance of studying the lunar environment at an early date was emphasized for all branches of astronomy. The studies need to determine precisely what environmental data should be acquired before engineering design can be started for astronomical facilities on the Moon.

Weighting of Experiments

Many types of experiments and instruments were discussed which are described in the Study Group Report. For flight priority it was decided to consider the individual experiments in the LESA report and to cast secret ballots on each. It is important to note that only lunar surface operations during the 1970 to 1975 time period were considered in the voting. It was felt that the votes on a number of the experiments would change rather markedly if the time period should be extended.

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REPORT OF
GEODESY/CARTOGRAPHY WORKING GROUP

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INTRODUCTION

The Geodesy/Cartography Working Group considers as its area of interest such scientific observations and investigations during the various phases of the lunar exploration program as will provide quantitative geodetic and cartographic information. Such knowledge supports geological, geophysical and other scientific experiments by providing the means for correlating the theoretical and experimental results in these disciplines with geodetic and/or cartographic parameters.

The following tasks appear to the working group to be essential steps in a lunar geodetic-cartographic program:

1. Establish a selenocentric coordinate system, related unambiguously to the Right Ascension-Declination System.

2. Describe, in sufficient detail, the gravitational field of the Moon.

3. Derive a reference figure with respect to a point which is representative of the Moon's center of mass.

4. Establish a three-dimensional geodetic control system over the entire surface of the Moon in terms of latitude, longitude, and height above the chosen reference figure.

5. Define and develop systems for the collection of raw data which are suitable for compilation of topographic maps at various scales, using photogrammetric methods.

6. Define and develop techniques and instruments for the reduction of acquired data and presentation of these data in a useful form.

7. Select and implement additional geodetic measurements to provide complementary results for analyzing in depth such phenomena as rotation and physical librations of the Moon, lunar tides, etc.

8. Establish specific research and development programs which show promise of effecting significant improvements in knowledge of lunar geodetic parameters.

The working group considered the overall feasibility of a lunar geodetic-cartographic program and its evolutionary aspects in terms of the results which can be expected during the progress of the Lunar Orbiter, early Apollo, and AES programs.

The general consensus of the working group is that geodetic surface operations can contribute significant information when carried out over rather extended areas of the Moon. In addition, it was concluded that valuable geodetic information can be gathered from landing sites by photographing the star background, suggesting the development of special camera systems as indicated in Recommendation 6.

Because the basic geodetic control framework will be provided by orbital photogrammetric systems, the extent to which maps must be supplemented by navigational devices (measuring horizontal and vertical positions on the surface) will depend largely on the need of the astronauts for navigational information.

Among other considerations, it was concluded that a better knowledge of the size and shape of the Moon is necessary to attain the full scientific value of geodetic-geophysical measurements: (1) to indicate the extent of differentiation (isostatic or otherwise) in the interior, and the departures from hydrostatic equilibrium in the density distribution, resulting in the variations of gravity and topography over the surface; (2) to indicate the nature of disturbing effects on a planetary scale, and the nature of the response of the planet to these effects, as reflected in temporal variations in rotation and the direction and intensity of gravity; and (3) to establish a network of control points essential for cartographic purposes.

Furthermore, the information delineated above is essential for the reduction and/or location of observations obtained by other investigators who are interested in selenography, the origin of the Moon and the origin of the Earth-Moon system.

Three-dimensional positional accuracies on the order of ±100 meters (1 sigma) are necessary to answer questions relating to the extent of isostasy, etc. Accuracies of ±10 meters (1 sigma) or better in the radial direction are desirable to utilize satellite-borne gravity gradiometer measurements.

These requirements emphasize the interest of the working group in the development of an accurate method for altimetry from an orbiting satellite, as expressed in Recommendation 5. Accurate spacecraft altitudes, measured at intervals of about 10^3 times the standard deviation of the altimetry, are preferable to less accurate but continuous profiles.

In addition, the following subjects are recognized by the working group for their urgency and importance, but require further study:

1. Establishment of a unique lunar coordinate system, datum origin, reference figure, and map projection.

2. Evaluation of methods of data reduction, considering existing techniques and capabilities of established mapping organizations.

3. Solution to the problem of matching the maximum possible field of view of photogrammetric cameras, versus film exposure latitude and the reflecting characteristics of the lunar surface.

4. Evaluation of the allowable dosage of radiation on the various photographic materials with respect to the on-board and environmental radiation sources.

5. Astronaut training requirements for the successful completion of geodetic or cartographic measurements.

The following recommendations generally reflect those areas which were considered in some detail by the working group, but are not necessarily indicative of all major areas of concern.

RECOMMENDATION 1: GEODETIC/CARTOGRAPHIC CAMERA SYSTEMS FOR AES

The working group has carefully considered the requirements for photographic systems capable of producing a significant increase in knowledge of lunar geodesy and cartography.

1. The working group endorses the general content of the "Proposal for AES Lunar Orbital Flight Experiment in Relation to the Acquisition of Multipurpose Photography," suggested by the NASA/OSSA/SM Photographic Team (See Appendix I). The group strongly urges that an intensive study be undertaken immediately to determine the design parameters of optimum camera systems for lunar geodesy and cartography, in order to have systems available for inclusion on the AES missions.

2. It is recommended that first priority be given to the development of a metric camera system capable of producing, by photogrammetric triangulation, a standard error of 10 meters in the three coordinates of spacecraft camera exposure stations and the network of photo-identifiable points on the lunar surface.

   The most stringent requirements for geodetic information are presently levied by the geological and geophysical working groups. For geological investigation, the need for maps with a scale of 1:250 000 for the entire surface area of the Moon, and some with a scale of 1:25 000 of selected areas, requires three-dimensional control accuracies from 2.5 meters in selected areas to 25 meters over the entire surface of the Moon. Accuracies on the order of ±10 to ±100 meters over the entire area of the Moon are presently required to reduce the influence of particular spherical harmonics in the lunar topography to a lower fraction in the corresponding term in the external field (compare Appendix II), and to provide the necessary geometric fidelity in the presentation of the lunar surface in order to utilize the gravity gradiometer measurements. The working group, however, recognizes the value of an evolutionary approach, as evidenced with the initiation of the unmanned Lunar Orbiter Program and the geodetic-photogrammetric payload contemplated for the early Apollo missions (compare Recommendation 2).

The group, however, is convinced that an accuracy of ±10 meters is within the capability of current technology, and that a system satisfying these requirements lies well within the spacecraft and mission constraints of the AES program. At the same time, such a system will have the capability of collecting raw data suited to satisfy, in the future, somewhat increased accuracy requirements, when using more sophisticated data reduction and analysis techniques.

3. It is recommended that, if feasible, the basic cartographic camera system be designed around the conventional configuration of a 6-inch focal length, 9 × 9 inch format camera in order to make the photography most directly usable to the widest sector of the scientific community.

4. It is recommended that the basic cartographic camera be directly coupled with a stellar camera, from which the angular orientation can be determined to a few seconds of arc. This is essential as a constraint on the error propagation in the photogrammetric triangulation and as a means of establishing the right ascension and declination of the Moon's axis of rotation.

5. In order to utilize stellar data, it is essential that time be available on the spacecraft and that it be recorded synchronously with each cartographic and stellar exposure. A precision of 1 millisecond throughout the duration of the photographic mission is required and is well within the capability of present technology.

6. The group considers accurate altimetry essential for controlling the scale of the photogrammetric triangulation and for subsequent determination of the dimensions of the lunar figure, because of the likely complexity of orbital perturbations. In order to establish the figure within the suggested 10 meter tolerance, the precision of the altimetry should approach one part in 200 000. For photogrammetric purposes, a laser altimeter pulsed synchronously with the cartographic camera exposure, and of sufficient power to produce a recognizable spot of light on the photography, would be useful. If this could be accomplished, there would be no photogrammetric requirement for boresighting the camera and altimeter, nor for precise stabilization of the altimeter to the vertical.

7. The group recommends that, in the design of the photogrammetric system, serious consideration be given to the current state of knowledge of lunar reflecting characteristics and its effect on angular coverage, stereoscopic fusion, etc.

8. The group recommends that immediate attention be given to the problem of developing suitable programs for rapid, efficient, and rigorous reduction of the photogrammetric triangulation, including the use of orbital dynamics as a supplementary control.

9. Because of its utility to many other scientific disciplines, and its applicability to refining the details of large scale maps, the group assigns second priority to the development of a high-resolution, convergent panoramic camera system. Such a system should provide an increase in resolution, by a factor of approximately 4, above that provided by the cartographic camera system. However, the group does not anticipate that convergent panoramic photography can, by itself, provide significant geometric information.

10. The group recognizes the usefulness of ultra-high resolution, synoptic, and multispectral photography for other

disciplines, and endorses the inclusion of such systems in the AES missions. However, such photography is considered to be of limited utility for geodetic and cartographic objectives.

RECOMMENDATION 2: APOLLO MAPPING AND SURVEY CAMERA SYSTEMS

The working group has been informed that a separate Mapping and Survey Camera System is contemplated for selection of Apollo landing sites. Unfortunately, only very limited details of this photographic system are available for review by the scientific community.

1. While recognizing that the primary mission of the Apollo Mapping and Survey Camera System is identified as selection of lunar landing sites, the group is concerned that the system may possibly be considered for later AES missions.

2. From its limited knowledge of this system, the considered opinion of the working group is that the system is limited in its potential for providing substantial support to the task of photogrammetrically establishing a basic geodetic control net on the surface of the Moon, and at the same time allowing the determination of the geometry of the orbit to an accuracy necessary for the analysis of the lunar gravitational field.

3. The group recommends that, for AES missions, a camera system be developed which can make a significant contribution to scientific progress in lunar geodesy and cartography. For this purpose, the group refers to Recommendation 1 for a Geodetic/Cartographic Camera System.

4. The group feels that the scientific value of any data is severely compromised if all details of the sensor, the records, and the data reduction are not completely available to the scientific community, and wishes to go on

record as being opposed to the imposition of security classification on this or any other system contemplated for use in scientific exploration.

RECOMMENDATION 3: OBSERVATIONS OF THE GRAVITATIONAL FIELD OF THE MOON

The gravitational field of the Moon, to harmonics of the 10th degree or higher, should be obtainable from the analyses of orbital perturbations of lunar satellites, provided there is sufficient variety of inclinations to resolve ambiguities. More detailed information can be obtained from gravity gradiometer observations and surface gravity observations. The variations of the gravitational field obtained from orbital perturbations and gravity gradient measurements should suffice to determine the equipotential figure of the Moon, making surface observations for this purpose unnecessary.

1. Information on the gravitational field deduced from lunar satellites and the accuracy of orbital position determination will both be limited to velocity measurements. Considerable improvement would be obtained by tracking from the Moon itself. In addition, accurately located points on the lunar surface would be obtained which would greatly contribute to controlling the photogrammetry and altimetry. The working group recommends that design studies be undertaken for radio beacons or transponders on the lunar surface for the purpose of tracking lunar satellites.

2. Gravity gradiometer measurements, with an accuracy of $\pm 3 \times 10^{-11}$ gals/cm, currently estimated as attainable, would provide a great amount of detail concerning the variations in the lunar gravitational field. In view of the difficulties in interpreting gradient data, the minimum accuracy acceptable should be that which enables comparison of the gravitational field obtained from the gradiometer, with that obtained from orbital perturbations. This accuracy is estimated to be $\pm 5 \times 10^{-10}$ gals/cm for a

smoothing distance of 18° (roughly 500 kilometers, or 5 minutes in orbit) or less. The working group recommends that development of a gradiometer to be used in lunar satellites be strongly supported as long as an accuracy of $\pm 5 \times 10^{-10}$ gals/cm ($\pm 1.5 \times 10^{-11}$ g/ft, or ± 0.5 Eotvos unit) standard deviation appears reasonably attainable by spacecraft-gradiometer systems. It is further recommended that testing of this gradiometer be done in Earth-orbiting satellites.

3. The placing of the gradiometer in a manned satellite appears to be justified on the grounds of ease of operation and economy. However, it would seem difficult to find a configuration which will enable attainment of the desired accuracy over extensive time durations without severe restrictions on astronaut motion and other "noise" sources. The modification of a small subsatellite, loosely tethered to a manned satellite, should be considered. The group also recommends that a careful estimate be made of the merits of developing an automated gradiometer for use in an unmanned satellite.

4. Gravity measurements on the surface of the Moon should be considered as supplemental data to geological and geophysical investigations. The group supports gravity observations on the surface of the Moon for those purposes. These observations should be tied to one uniform reference system through the variations measured by gradiometers and orbital perturbations.

RECOMMENDATION 4: LUNAR ORBITER (UNMANNED, PHOTOGRAPHIC)

The Lunar Orbiter, as an approved program, will provide an opportunity for collecting, at an early date, valuable scientific data for lunar geodesy and cartography.

1. It is recommended that stereophotogrammetric analysis of the photography obtained by the first block of Lunar Orbiters be carried out in order to obtain information regarding the character of lunar topography, and to gain experience in problems of analyzing lunar photography.

2. It is recommended that the possibility of utilizing the same camera system, or a modification thereof, for more widespread photography from a second block of Lunar Orbiters be carefully studied. Accuracies on the order of ±1 km horizontally and ±100 meters vertically for global coverage would be useful. (See Appendix II by W.M. Kaula.)

3. It is recommended that later satellites of the first block of Lunar Orbiters, or of any second block, be placed in orbits with a variety of inclinations, with priority placed on a polar orbit. This would permit additional photography to be obtained, and would reduce ambiguities and increase the sensitivity of determinations of the lunar gravitational field.

4. It is recommended that a radar or laser altimeter be developed for inclusion in any second block of Lunar Orbiters (and all subsequent lunar photographic satellites), in order to measure the distance between the spacecraft and the lunar surface.

5. The group supports the planned tracking of Lunar Orbiters and the analysis of tracking data for determination of the variations of the lunar gravitational field.

RECOMMENDATION 5: ALTIMETRY FROM LUNAR ORBITING SATELLITES

It is urgent that support be given to the development of radar or laser altimeters for incorporation in all subsequent lunar orbiting satellites, in order that distances from the spacecraft to the topographic surface may be determined accurately.

Limitations on adequate illumination may make it difficult to obtain the detailed determination of the shape of the Moon from photography alone, and, in addition, independent distances to the lunar surface are desirable in order to control photogrammetry. Much of the Moon is inaccessible to Earth-based ranging systems. An increasingly better knowledge of the shape of the Moon is necessary in order to attain full scientific utilization of the variations of the gravitational field obtained from orbital analysis.

RECOMMENDATION 6: STELLAR OBSERVATIONS FROM THE LUNAR SURFACE

The working group recognizes that stellar observations from the surface of the Moon, preferably with reference to the local vertical, can be used for an independent determination of the direction of the pole, for time determination, for determination of variations in rotation and librational effects, and, eventually, to accurately define longitude in a lunar geodetic control system and to constitute a gravitational "clock" much more accurate than possible on Earth. The level of accuracy to be attained at any stage depends on weight, power, and stay-time limitations. Initially, a direction of the lunar pole to ±10" would be useful. Eventually, it is desirable that direction and time be determined to accuracies of ±0.05" and $\pm 0.1 \times 10^{-3}$ seconds, respectively, and that lifetimes of several months and more be realized.

The working group recommends continued development of camera systems to be used for the purposes mentioned above.

RECOMMENDATION 7: RADAR/LASER RANGING FROM THE EARTH TO THE MOON

It is recommended that ranging observations from the Earth to reflectors and/or transponders located on the Moon's surface be carried out in order to improve knowledge of the lunar ephemeris, physical librations, and the direction of the pole.

The desired ranging accuracy is at least ±10 meters, preferably ±1 meter.

Initially, laser reflectors should be emplaced by Surveyor landers. Eventually, reflectors and/or transponders should be located on at least three points which are widely distributed in latitude and longitude. They should be operable for extended periods (a minimum of several lunar nights) and must be photo-identifiable on Lunar Orbiter and subsequent photography. The group recommends their inclusion in the scientific payload for all lunar landings.

The eventual choice of laser reflector versus radar transponder requires further study and experimentation, including an evaluation of the effects of the lunar environment.

APPENDIX I

PROPOSAL FOR AES LUNAR ORBITAL FLIGHT EXPERIMENT IN RELATION TO THE ACQUISITION OF MULTIPURPOSE PHOTOGRAPHY

This proposal presents the characteristics for a group of photographic cameras designed to meet the requirements of the scientific community for sensing of the lunar surface. It is based on the input to NASA from interested scientists and agencies as resolved by the NASA/OSSA/SM photographic team which has been meeting at intervals during the past 12 months.

Numerous proposals and experiments in relation to this matter have been submitted which may be summarized in the following types of photography:

1. Metric coverage of the Moon for mapping purposes
2. High resolution broad area coverage
3. Ultra high resolution of limited areas
4. Synoptic coverage
5. Multispectral response

The five above-listed categories of photography can be directly translated into a comprehensive camera system, the characteristics of which are shown on the following chart.

Lunar Photographic System Chart

Designation	No. of cameras	Camera type	Format	Focal length (inches)	Approximate* ground resolution (meters)	Prospective users	Extent and type of coverage
1 Metric (Mapping)	2 or 3	Frame	9" x 9"	6	<10	Lunar cartographers, geodesists and other scientists	Complete, stereo, limited multi-spectral
2 High Resolution	2	Panoramic convergent	70 mm by 74^{o} sweep	12	<3	Lunar scientists including cartographers	Complete as possible, stereo, limited multi-spectral capability
3 Ultra High Resolution	1	Reflective, tracking telescope and small frame camera	70 mm	up to 144 (aperture up to 16)	<1	Lunar scientists including cartographers	Small selected areas, monoscopic, wide multispectral response
4 Synoptic	1	Frame	4-1/2" x 4-1/2" or 9" x 9"	1-1/2 to 3-1/2	25 to 75	Lunar scientists including geodesists and cartographers	Complete stereo, limited multi-spectral
5 Multispectral ---------- Desired responses may be obtained from above system but further testing may indicate need for additional cameras (3-1/2" or 6") to give a greater variety of spectral responses.							

*Resolutions are based on an orbital height of 80 km. Variations in orbital height will change resolution accordingly.

Additional details in relation to the systems may be found in the following:

1. NASA letter of June 25, 1965, subject: Minutes of NASA/ OSSA/SM Photographic team. Meeting held in Washington on June 8 and 9, 1965.

2. Dr. Badgley's letter of July 6, 1965, in relation to submission of Formal Spaceflight Experiments for Manned Lunar Orbital Flights.

The endorsements by the concerned working groups and individuals are requested. Such endorsement is considered to be an essential prerequisite for presenting the system to the NASA Space Science Steering Committee.

APPENDIX II

ACCURACY REQUIRED FOR GLOBAL VARIATIONS IN LUNAR TOPOGRAPHY

by W. M. Kaula

To settle such questions as isostasy, the error in knowledge of a particular spherical harmonic in the lunar topography should cause an error in the potential calculated therefrom, which is a minor fraction of the anticipated magnitude of the corresponding term in the external potential.

Let us assume

(1) The order of magnitude of variations in the Moon's gravitational field is that predicted by the equal stress hypothesis: i.e., about $\pm 2\times 10^{-4}/\ell^2$ for the normalized dimensionless coefficients

$$\overline{C}_{\ell m},\ \overline{S}_{\ell m},\quad \text{or about } \pm 2\times 10^{-4}\ \frac{GM}{R}\frac{1}{\ell^2} \approx 5\times 10^6/\ell^2\ \mathrm{cm^2/sec^2}$$

potential at the lunar surface.

(2) Harmonics to degree 10 will be determined from satellite perturbations.

(3) The allowable ratio of the rms error in potential calculated from the topography to potential is $\frac{1}{5}$.

(4) Altimeter errors at intervals of about 10° (300 km) are random with respect to each other.

Given global coverage of altimetry at 10^{o} intervals, we have 410 points from which to determine the harmonic coefficients $h_{\ell m}$ of the topography.

$$h_{\ell m} = \frac{1}{410} \sum_i h_i \overline{Y}_{\ell m} (\phi_i, \lambda_i)$$

where $\overline{Y}_{\ell m}$ is the surface spherical harmonic normalized to $2\sqrt{\pi}$. Hence if the elevations h_i have equal variances $\sigma^2 \{h\}$ random with respect to each other (assumption 4), since $\sigma^2 \left\{\overline{Y}_{\ell m}\right\} = 1$ we have:

$$\sigma^2 \left\{h_{\ell m}\right\} = \frac{1}{410^2} 410\sigma^2 \{h\}$$

or

$$\sigma \left\{h_{\ell m}\right\} = \frac{\sigma \{h\}}{\sqrt{410}}$$

A harmonic $h_{\ell m}$ in the topography of density ρ will contribute to the potential $T_{\ell m}$ (h); using the formula for a surface distribution over a sphere or radius R:

$$T_{\ell m} (h) = 4\pi G R \frac{\rho h_{\ell m}}{2\ell + 1}$$

$$\approx \frac{420}{2\ell+1} h_{\ell m}$$

on the Moon for $h_{\ell m}$ in centimeters. Thence for the allowable uncertainty σ {h}

$$\sigma\ \{h\} = \sqrt{410}\ \sigma\left\{h_{lm}\right\} = \frac{(2l+1)\ \sqrt{410}}{420}\ \sigma\left\{T_{lm}\ (h)\right\}$$

$$= \left(\pm\frac{(2l+1)\ \sqrt{410}}{420}\right)\left(\frac{1}{5}\right)\left(\frac{5\times10^{6}}{l^{2}}\right)$$

$$\approx \pm\frac{10^{5}}{l}\ \text{cm},$$

applying assumptions (1) and (3).

Finally applying assumption (2), put 10 for l and we get

$$\sigma\ \{h\} \approx \pm10^{4}\ \text{cm} = \pm100\ \text{meters}.$$

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REPORT OF GEOLOGY WORKING GROUP

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INTRODUCTION

The Geology Working Group took as its primary goal the establishment of a sound, long-range plan of lunar geological exploration working within the framework of the known capabilities of the Apollo program and the proposed follow-on programs but not necessarily constrained by those programs. The objective of the exploration plan is to insure that the necessary geological information will be collected and, when integrated with other data, it will lead to first order answers to the major geological questions concerning the Moon. The working group was divided into 8 subgroups concerned with individual phases of the plan, each with its own chairman, and assisted by several rapporteurs. The subgroups were:

1. Strategy of lunar exploration

   E.M. Shoemaker (chairman)
   D.A. Beattie (member)
   E.N. Goddard (member)
   H.H. Hess (member)
   J.H. Mackin (member)
   A.C. Waters (member)
   D.P. Elston (rapporteur)

2. Geologic investigations in early Apollo missions

   J.H. Mackin (chairman)
   D.A. Beattie (member)
   R.W. Cunningham (member)
   H.H. Schmitt (member)
   D.P. Elston (rapporteur)

3. Geologic mapping of the Moon from data acquired by lunar orbiters

R.E. Wallace (chairman)
W.A. Fischer (member)
J.E. Gillis (member)
Robert Reeves (member)
R.C. Speed (member)
Harold Masursky (rapporteur)
J.F. McCauley (rapporteur)

4. Geologic investigations in AES surface missions

A.C. Waters (chairman)
D.P. Elston (rapporteur)
G.A. Swann (rapporteur)

5. Use of a long-range laboratory vehicle for post-AES geologic exploration of the Moon

E.N. Goddard (chairman)
J.T. O'Connor (rapporteur)

6. Geologic investigations from a lunar base

R.C. Speed (chairman)
S.R. Titley (rapporteur)

7. Geologic training of the astronauts

A.C. Waters (chairman)
R.W. Cunningham (member)
A.H. Chidester (rapporteur)

8. Career proficiency maintenance for scientists in the astronaut program

H.H. Hess

The report of the Working Group consists of these eight subgroup reports which were reviewed and approved by the Working Group as a whole during the final days of the meeting. Coordination was effected, insofar as possible, with the other Working

Groups. It is anticipated that a continuous review and updating of these reports will be required and that further coordination with the other Working Groups will be necessary if a scientifically sound lunar exploration plan is to evolve.

STRATEGY OF LUNAR EXPLORATION

GEOLOGIC OBJECTIVES OF LUNAR EXPLORATION

The broad scientific objectives of the exploration of the Moon, as outlined at the 1965 Summer Study of the Space Science Board of the National Academy of Sciences, are to determine (1) the structure and processes of the lunar interior, (2) the composition, structure, and processes of the lunar surface and (3) the history of the Moon. Within these categories of knowledge, most of the major questions are basically geological in character—they are the same basic questions we wish to solve with respect to the Earth and the other terrestrial planets.

As applied to the Moon, some of the specifically geological questions are:

1. What is the average composition of the rocks at the surface of the Moon and how does the composition vary from place to place? Are volcanic rocks present on the surface of the Moon?

2. What are the principal processes responsible for the present relief of the lunar surface?

3. What is the present tectonic pattern on the Moon and distribution of tectonic activity?

4. What are the dominant processes of erosion, transport, and deposition of material on the lunar surface?

5. What is the age of the Moon? What is the range of age of the stratigraphic units on the lunar surface and what is the

age of the oldest exposed material? Is a primordial surface exposed?

6. What is the thermal history of the Moon? What has been the distribution of tectonic and possible volcanic activity in time?

7. What has been the past flux of solid objects striking the lunar surface and how has it varied with time?

8. What has been the flux of cosmic radiation and high-energy solar radiation over the history of the Moon?

9. What past magnetic fields may be recorded in the rocks at the Moon's surface?

These questions must be translated into terms of immediate scientific objectives that can be achieved with the exploration techniques at hand, in order to proceed with a program of exploration designed to answer them. Many of the answers will be obtained from systematic geologic mapping of the Moon, which is aimed at unraveling the stratigraphic sequence of deposits and the structure of the exposed rocks. Geologic mapping can be accomplished most effectively by surveying of the Moon with remote-sensing instruments from lunar orbiting spacecraft coupled with local detailed studies on the lunar surface.

The task of working out the broad outlines of the stratigraphy and structure of the lunar surface is already well underway, based on telescopic observation and measurements. The surface of the Moon is known from the telescopic observations to be highly heterogeneous. Differences in color, albedo, polarizing, and thermal properties, which are correlated with differences in physiographic characteristics, are the basis for recognition and mapping of stratigraphic or geologic units; a complex sequence of events is recorded in the observed stratigraphy and structure of the lunar surface. The observed diversity of layers of material with different physical characteristics and the complexity of structure of the lunar surface show, moreover, that an extensive program of exploration and a carefully planned strategy will be required to obtain even rough answers to most of the major questions.

RECOMMENDED PROGRAM OF EXPLORATION

The Geology Working Group recommends a 10-year program of lunar geological exploration (beginning with the first manned landing) aimed at achieving the broad objectives outlined by the Space Science Board of the National Academy of Sciences. We visualize the geological exploration of the Moon as progressing through several phases as the Apollo and more advanced lunar exploration systems are developed. These phases include (1) the early Apollo missions, (2) AES missions, and (3) post-AES missions. This is a sequence of increasing size of the features explored in the surface missions. Although the exploration is conceived as extending over a 10-year period, it would be possible to accelerate the program and conduct the same number of missions in a shorter period of time.

The first phase of the program, consisting of the early Apollo missions, should be very brief. The astronauts will be limited to small areas that can be explored on foot and will be able to spend only brief periods on the lunar surface. After completion of the early Apollo landings, which is expected about 1969, a more versatile exploration system should be implemented, permitting a longer stay time and greater exploration capability than will be possible in early Apollo. It is believed that the AES system, as presently conceived, has capabilities for lunar exploration that can be usefully exploited for at least five or six surface missions at a launch rate of one or more missions per year. A similar number of AES manned orbital missions should be flown during the period of AES surface exploration. At the minimum recommended rate of launch, the AES phase of exploration would draw to a close by the end of 1974.

The AES phase should be followed by an exploration phase that includes long-distance travel (up to 800 km) on the lunar surface and fixed-site investigations with stay times of two months to a year. At a conservative or minimum rate of exploration, these missions should commence about 1975 and proceed at a rate of one per year through 1980. Additional orbital flights also appear desirable during this period so as to conduct simultaneous orbital and surface missions.

An exploration program of this scope should provide first order answers to most of the major questions that can now be asked about the Moon. Specifically it will provide the basis for a detailed analysis of the geologic history of the Moon and of the major processes that have acted upon the lunar surface and within the lunar interior.

Early Apollo Missions

The principal geological objectives of early Apollo missions will be study of the fine structure of the lunar surface, mainly in the plains areas favorable for early landing, and study of the nature of the plains materials. Plains areas of interest include not only the maria, but also the plains of certain upland regions. These plains are depositional surfaces, modified by postdepositional processes of several kinds.

In the limited time available for geological investigation in the early Apollo missions, the two primary questions to be answered will be (1) the lithologic composition, structure, and thickness of the superficial layer of fragmental material believed to cover most parts of the plains and other areas on the Moon and (2) the composition and origin of the material underlying the plains. Was the material of the plains spread as flows of liquid lava, now solidified to rock or rock froth, or is it ash or granular material comminuted by various processes, which now ranges from unconsolidated to solid depending upon the degrees of heat or vacuum welding? Are the plains materials chemically differentiated? What are the principal processes that have modified the surface of the plains and resulted in the craters, patterned ground, and other features observed in the Ranger photographs?

Answers to these questions will be sought from the geological observations of the astronauts, from photographs, and from samples taken along a series of foot traverses from the lunar excursion module. The astronauts must have the ability to observe subtle geologic relationships, to grasp the significance of their observations, and to direct their traverses and take samples accordingly. Time is of the essence in carrying out the surface traverses, and as much time as possible should be allocated for them. The astronauts should use light, simple hand tools and camera. Acquisition of position information along the traverses should be obtained as accurately as practicable with automatic devices. The highest scientific priority should be assigned in this period, to the return of the greatest number and widest variety of samples of lunar material as feasible.

There is a good chance that the samples obtainable in a small area on the lunar surface that can be investigated by the astronauts in an early Apollo landing may contain information not only about the local part of the Moon on which the landing takes place but also about a much wider region. The reason for this is that many rock fragments on any part of the Moon's surface probably have been derived from distant parts of the Moon. It will be important, therefore, to conduct sampling in such a way as not to overlook any of the exotic pieces that may be present. The samples taken should provide information both on the local rock material that underlies the plains and also on the petrologic heterogeneity of the Moon.

Descriptions of topographic and geologic relations observed along the traverses of the astronauts should be supplemented by numerous stereoscopic photographs. The photographs provide a detailed record of the surface features, which can later be analyzed quantitatively, and will provide the geologic context at the site of each sample locality. It will be important to record the orientation of the cameras during exposure of the photographs for use in later photogrammetric and photometric reduction of the photographic data.

AES Lunar Orbiter Missions

Less than 1 percent of the lunar surface will be visited in the foreseeable future; thus the major source of geologic knowledge about the Moon will come from data acquired by remote sensors such as radar systems, mapping cameras, and infrared detectors carried on manned lunar orbiters. It will be important to obtain an overall view of the geology of the Moon as early as possible in order to plan the most effective deployment of surface missions. A series of Lunar Orbiter Missions should be planned, therefore, for the beginning of the AES phase of exploration.

A systematic program of geologic mapping is recommended, using data acquired from lunar orbiters, which should include preparation of geologic maps at the following scales:

1. 1:2 500 000 scale—to provide a synoptic map for general planning and collating of a wide variety of data about the gross features of the Moon (6-month effort)

2. 1:1 000 000 scale—for complete synoptic geologic mapping (3-year effort)

3. 1:250 000—for total coverage of the lunar surface (10-year effort). This is the major long-range goal

4. 1:100 000 to 1:25 000—for special purposes. These maps would be directed toward solution of selected topical problems

The sequence of orbiter missions recommended is as follows: One orbiter carrying a remote-sensing package including a complex group of sensors should be flown prior to the first AES landings. Polar orbiters are desirable at the earliest time practicable in the AES phase of exploration for total coverage of the lunar surface by remote sensors. The Working Group feels that a minimum of three orbiters would be needed for complete survey.

The AES orbiters should be capable of carrying and distributing lunar surface probes for the following purposes:

1. To make measurements for calibrating remote-sensing techniques

2. To characterize the fine features of the geologic units being mapped, where specific point samples are needed

3. To emplace scientific apparatus such as seismometers in a surface net as necessary

The amount of data to be obtained in the Lunar Orbiter missions is very large. At a minimum the full-time efforts of approximately 300 scientists of diverse training will be required in peak years of the recommended program to analyze the data and prepare geologic maps.

AES Surface Missions

Following the early Apollo flights, it is expected that most of the operational problems involved in the landing of men on the Moon and their return to Earth will have been solved. It is also expected that the astronauts' observations and the analysis of returned samples will have provided direct evidence of the composition and age of some lunar materials and will establish the nature of the fine structure of at least the upper meter of the Moon's surface materials at the landing sites.

In the AES surface missions, the geological objectives are the acquisition of detailed information regarding the major types of terrain on the lunar surface. At the present time, three of these which are of prime interest are readily identifiable, (1) the maria, (2) the ancient more highly cratered highlands, and (3) major craters. The major objective in all of these areas would be to test the geologic interpretations based on the orbiter data and to obtain the detailed data on composition and structure that can only be obtained by landing on the surface.

Early attention should be given to the design and development of certain systems, vehicles, and instruments needed to carry out the surface exploration.

<u>Automatic position recording systems</u>. These are required for tracking and recording movements of the astronaut, roving vehicle, and cameras. They will automatically telemeter the position information back to Earth. These systems should also be capable of automatically recording the orientation of cameras mounted on the vehicles or carried by the astronauts. Great precision of position is not necessary; location of positions to 1 part in 1000 is adequate for geological observations and for photogrammetric utilization of photographs acquired on the traverses.

<u>Local Scientific Survey Module (LSSM)</u>. This would be a

surface roving vehicle capable of carrying either one or two suited astronauts and a scientific payload of at least 600 lb. A minimum operational range of 8 km radius is required for investigation of the geologic targets in the AES phase of exploration. Telescopic studies of the distribution of lunar geological units and features suggest that an operational range of 15 km radius would be much more useful if fuel and life support systems can be devised to permit this range. The vehicle speed must be such that a man can drive to a distance of 8 to 15 km from the shelter or base at the LEM and still have at least 2 or 3 hours in which to perform scientific tasks. A surveillance-imaging system should be designed to operate from the LSSM, and the positional and image data relayed either directly to Earth or through a telemetry link in the landed LEM to Earth. The LSSM has considerable potential for remote operation, both prior to and after the departure of the astronauts. Remote control of the LSSM from Earth for extended periods both before and after the manned surface mission would be useful. Reconnaissance by remote control before arrival of the astronauts would not only provide site certification, but would also provide information for scientific mission planning. The ability to remotely control the LSSM from Earth after the manned mission would allow correlation of features analyzed in that mission with features analyzed during previous missions, and provide both engineering and scientific site selection data for future missions.

Lunar Flying Vehicle (LFV). The LFV is a one or two man rocket propelled craft capable of hovering and low flight to a distance of 15 km. The LFV is presently envisioned to have limited uses for extending the operational range of AES, and for studying features inaccessible to the LSSM due to topography. The rate of fuel consumption, and the inability to observe and collect from the surface limits the use of the LFV, as an exploration tool, but because of its possible application to visiting critical areas that are just out of range otherwise inaccessible to exploration by the LSSM, continued development of the LFV is recommended.

Lunar Drill. The development of a drill capable of penetrating to a depth of 3 meters in either rubble or solid rock is recommended. It should be operable from a roving vehicle and produce a 1-in. core. A drill capable of penetrating to greater depths is not required for the AES phase of exploration.

Post AES Missions

Systems more advanced than those now contemplated in the AES program will be required for full geologic investigation of the Moon. For some problems traverses of hundreds of kilometers length are required and for other problems greater stay time on the lunar surface will be required than can be provided by the AES systems. These requirements call for long-range laboratory vehicles and for lunar bases.

Long-Range Laboratory Vehicles for Geological Exploration

Traverses with a long-range surface vehicle are needed to provide a broad regional integrated picture of the surface geology and crustal structure of the Moon. The data to be obtained from these traverses are essential for the complete interpretation of the data obtained from the remote sensors carried on lunar orbiters and also to tie together local detailed studies made during AES surface missions and at semipermanent lunar bases.

A series of traverses along the equatorial belt is recommended which will provide a continuous geologic and geophysical cross section across the major features of the lunar crust. These traverses would also provide broad regional correlation of stratigraphic units and deeper structure which would be impossible from widely scattered local AES exploration sites or fixed bases.

The laboratory vehicle should have the following characteristics:

1. A minimum range of 800 km

2. Shelter for a three-man crew

3. Mission duration capability of up to 2 months

In addition, the vehicle should not be constrained to return to the starting point.

Probably the optimum method of conducting the traverses will be to use two vehicles traveling together. Among the team manning the vehicles there should be some specialists who are trained essentially as lunar surface scientists, rather than astronauts, in order to obtain maximum scientific utility of the long-range laboratory vehicles. It will be necessary to have aboard the vehicles equipment for the quick analysis of lunar material, because it will be impossible to return to Earth the very large quantities of samples that could be obtained on the long traverses. Considerable on-board and scientific investigation and selection of the critical samples to be returned to Earth will thus be required.

At least four long traverses, each of 800 km length should be connected up, to obtain a continuous geological and deep geophysical profile of the lunar crust.

Lunar Bases

A lunar base is defined as a surface complex which will allow longer stay time than is presently envisioned by the AES concept. Geological requirements for such a base are as follows:

1. The measurement of presently occurring time varying phenomena.

2. The study of lunar surface processes.

3. Deep drilling. Several of the major scientific questions concerning the early history, crustal composition, and past surface properties of the Moon can best be approached by deep drilling. Depth to be reached should probably exceed 300 meters. Deep drilling should be done only at sites that have been selected after a very intensive exploration of the lunar surface. One important site would be on an area thought to include the most primitive parts of the lunar surface.

4. Detailed study of key geological areas. In critical geologic localities the details of the surface features should be exhaustively studied over a period of a few months.

GEOLOGIC INVESTIGATIONS IN EARLY APOLLO MISSIONS

RESTRAINTS AND SCIENTIFIC OBJECTIVES

Any realistic statement of the scientific objectives of the early Apollo missions must recognize that these objectives are necessarily secondary to the purely operational problems. In the first manned landings the primary concern will be to learn as much as possible about the functioning of the various mechanical systems and the astronauts, reactions to a strange environment, and then to bring this information and the astronauts back to the Earth. Selection of the landing sites, for example, is dictated by safety considerations rather than scientific interests. The early Apollo sites will probably be on maria floors or other lunar plains, remote from rugged topography, and the scope of the geological observations will be limited. Scientific work-times will be brief compared with later missions; tools and procedures will be on trial, and the efficiency that can be reasonably expected will be limited by the newness of virtually all operations.

The lunar plains are depositional surfaces, modified by post-depositional processes of several kinds. The primary questions to be answered by early Apollo missions are the nature and origin of the material underlying these plains. Were the plains materials formed as flows of liquid lava, and now range from solid rock to rock froth, or were they deposited as ash or granular material from density flows, and now range from unconsolidated to solid depending on the degree of heat or vacuum welding? A second important question concerns the nature and rates of the processes that have taken place on the lunar surface. Because the rates are exceedingly slow, the processes can best be approached by study of their long-term effects on materials and topographic forms of the lunar plains.

A basic general policy is that a higher priority should be assigned to the collection of samples than to other kinds of work in the early Apollo missions, principally because the greatest void in our understanding of the Moon is direct knowledge of the lunar materials. The highest priority should be given to those samples,

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observations, and operational techniques that will be most useful in giving direction to the planning of instrumentation and investigations for missions to follow, as compared with obtaining information that may be of equal or greater scientific importance but is, in effect, dead-end. For example, numerous small samples representing the widest possible variety of materials are preferable to a few large samples, of the same total weight. A variety of samples will permit laboratory studies leading to a grasp of the significance of each of the different materials present at the landing site and the best ways of identifying and handling such materials on subsequent missions. The most efficient sampling program will be intelligently directed to test one or more theoretical models. The astronaut must be mentally prepared to deal easily with such models, to grasp the significance of his observations in terms of them, to confirm, modify, or replace them as he moves about on the lunar surface, and to change his operations accordingly. The scientific success of the early Apollo missions will depend more on this mental capability of the astronaut than on all of his mechanical gear. The worst possible sampling method in any manned landing would be by use of a grid or any other fixed interval method which makes no use of the astronaut's ability to observe and interpret, or of the immense fund of information that has been obtained by remote sensing.

THEORETICAL CONSIDERATIONS

Concept of an Impact-Shattered Blanket

The high resolution Ranger photographs together with available telescopic measurements of the physical properties of the lunar surface indicate that the lunar plains are surfaced by fragmental materials, mostly fine grained, and that the surfaces are pock marked by craters, which range from sharp rimmed and steep sided to those so subdued by erosion as to be barely recognizable. The ages of the plains probably vary widely, and it is believed that the degree of cratering of a plain is a function of its age. The distribution and shapes of the craters indicate that many, if not most, were formed by impact rather than volcanic action. Primary impact craters are defined as those formed by objects from an extralunar source, and secondary craters are those formed by objects thrown out in the formation of primary craters.

The observational data support the idea that most parts of the lunar plains are blanketed by a layer of material that has been shattered and pulverized by repeated impact; the blanket would be thin or nonexistent on a very young plain with few craters, and should thicken with time as the surficial material is repeatedly worked over by the cratering process. If the subjacent material is hard rock, the thickness of the blanket will correspond roughly to the depth to which that rock has been shattered and excavated by cratering, but if the subjacent material is itself granular or fragmental, the thickness of the blanket is merely the depth to which the plains material has been stirred by impact processes.

Lithologic Composition of the Blanket

Theoretical considerations indicate that there may be variations in the lithologic composition of the impact-shattered blanket, both from place to place and in vertical section at any one place on the lunar plains (Kuiper, 1965; Shoemaker, 1965). The objects impacting the surface at any one place are (1) extralunar and (2) from elsewhere on the Moon. It is reasonable to believe that a fraction of some or all of these foreign objects may be added to the blanket, that is, that the ratio of foreign material to local material in the blanket as a whole is time-dependent. Moreover, because the size of the impacting objects (and the depth of shattering or stirring caused by them) varies inversely with frequency of impact, there should tend to be a vertical compositional gradient in the blanket, from low percentages of foreign material near the base to a maximum at the surface.

The rate of enrichment in foreign material in the blanket, and the shape of the vertical compositional gradient curve, can be deduced readily for any set of background assumption, in the simple case in which the surface of the blanket maintains a constant average altitude. In this case, the rate of addition of foreign material equals rate of loss of blanket material. If there is any departure from this steady-state condition, that is, if the surface degrades because loss exceeds gain, or aggrades because gain exceeds loss, this will be reflected by corresponding changes in the rate of change in the overall thickness and average composition of the blanket, and in the shape of the vertical compositional gradient curve.

Alteration Effects

Independent of the mechanical mixing of foreign material, which tends to change the lithologic composition of a superficial layer, as noted above, there is a second alteration process caused by bombardment of the lunar surface by radiation and by atomic and nuclear particles of various types. The changes are roughly analogous to those involved in the development of a soil profile on Earth; the effect which may be observed by the astronaut will probably be a vertical gradient of darkening. Laboratory studies indicate the alteration processes are most effective within a few centimeters of the surface, but the actual thickness of altered material in a given place may be much greater (see below).

As in weathering profiles, the effects of the alteration processes on fine-grained material will probably differ from those on coarse fragments of rock on the surface or embedded in the fine-grained matrix; the alteration profile in the granular material and the alteration rinds on the upper surfaces of coarse fragments may provide complementary information on the alteration process and on the radiation exposure age of the surface.

The downward-penetrating alteration may be accompanied in some places by processes which operate upward from below. If there is now, or was earlier, a movement of fluids toward the lunar surface, pressure and temperature changes at or near the surface may cause precipitation of minerals to form a surface crust or a hardened zone in the granular material beneath the surface comparable with caliche crusts or zones in dry-land soils.

The optimum condition for development of an alteration profile is a stable surface. If the surface degrades, as on a slope being lowered by lunar erosion, or aggrades, as in an area of deposition near the base of such a slope, the alteration profile may be telescoped or attenuated as it is formed. If mechanical mixing by cratering accompanies the alteration and is limited to the depth of the alteration profile, the mixing will tend to blur zonation within the profile. If a newly formed crater is deep enough to bring up fresh material, the alteration development would start anew on the ejecta blanket, and the old profile would be preserved as a fossil soil at the base of the blanket.

The point made here is that time-dependent alteration profiles on the lunar plains are in many respects comparable with weathering profiles on Earth. Weathering profiles are probably the most useful single line of evidence in determining the Pleistocene and Recent history of many places on Earth; mechanical mixing, and degradation and aggradation of the surface, merely tend to complicate the interpretation of the profiles, and are taken in stride by the experienced Pleistocene geologist. There is a good possibility that alteration profiles may be equally useful on the Moon; early Apollo landings should provide opportunity for reconnaissance study of the problem.

SAMPLING MODEL

Arrangement of Materials Around a Fresh Crater

The problems of sampling in a typical landing site on the lunar plains can be illustrated with a hypothetical cross section such as that shown in figure 1. The oldest part of the surface in figure 1 is the relatively level area A; the youngest element of the surface is the fresh crater C, and crater B, subdued by erosion, is intermediate in age. The fresh crater may be considered to be a few meters to a few tens of meters in diameter, in the size range shown on the Ranger photography to be numerous enough on lunar plains so that there is a reasonable possibility that one or more such craters may be within traverse distance of the early Apollo landing sites. The crater is also large enough so that there is a good possibility that the depth of cratering may be greater than the thickness of the impact-shattered blanket. Smaller fresh craters will provide information that is useful but less critical for geologic interpretation; larger fresh craters should provide critical information but are fewer in number and hence less apt to be available for study.

Ideally the wall of the fresh crater might show, from the base upwards, (1) the material which underlies the lunar plain; (2) the full thickness of the impact-shattered mantle, perhaps showing a compositional profile and/or an alteration profile; and (3) a section of the ejected material. The floor of the crater is apt to be underlain by breccia, and the layering of the walls may be concealed or

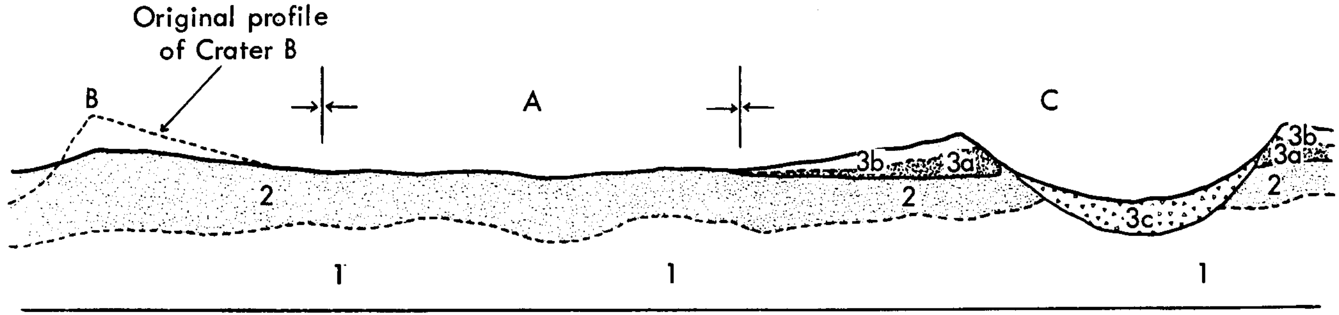

Figure 1. Diagrammatic section of a lunar plain.

Topographic elements

Area A. Oldest part of the surface; Crater B. Subdued by erosion, is intermediate in age; Crater C. Youngest element of surface.

Geologic materials

1. Native material; 2. Impact shattered blanket; 3a. Ejecta from Crater C, mostly derived from impact shattered blanket; 3b. Ejecta from Crater C, mostly derived from native material; 3c. Brecciated material formed in Crater C.

obscured in part by slumping and creep. Moreover, the walls may be so steep as to be difficult of access; the astronaut should sample them if he can, but it is likely that he will be able only to photograph and describe them.

If the rule holds true that materials in the ejecta blanket are deposited in reverse stratigraphic order, the upper surface of the blanket will provide samples derived from deep within the crater. For example, if the surface of the blanket is littered with blocks of rock differing in size, lithology, or degree of alteration from rock fragments on the surrounding plain, the implication is that the plain is underlain at depth at that place by that rock. On the other hand, a deposit of ash or dust, similarly limited to the upper surface and distal margins of the ejecta blanket, and differing in composition, degree of alteration, or other properties from the impact-shattered blanket of the surrounding plain, would suggest that the plain is there underlain by granular materials, rather than rock.

If the character of the materials beneath the impact-shattered blanket could be established in only one place, it would be a great gain; with some luck the early Apollo missions may establish it in several places, on plains of different ages. Samples of the material subjacent to the blanket, whether rock or granular, are the most meaningful that may be available on the lunar plains.

Profile Sampling of Matrix Material

Even if no accessible fresh craters penetrate to the base of the impact-shattered layer, valuable evidence bearing indirectly on the nature of the subjacent material, and directly on the origin of the fine structure of the surficial layer, can be obtained by study of surface profiles. Walls of fresh craters may provide such profiles. If they do not, sampling the walls of trenches 10-50 cm deep, dug with a specially designed trowel may be a method which has a good chance of success in surficial material with a wide range of grain size and degree of induration. If the wall of such a trench shows zonal differences in color, texture, composition, or other properties, the relationships should be described, photographed, and documented by samples cut with the trowel so as to be representative of each zone. If there is no visible zonation, samples should be cut at stated intervals from base to top of the trench wall with equal care for comparison with profiles of other ages and composition. The absence of zones may be as significant as their presence.

Depending on the physical properties of the superficial material, drive-tube samples may be easier or more difficult to obtain than samples cut with a trowel. In some materials the drive-tube sampling method may not work, but under favorable conditions the method provides (1) a suite of undisturbed or little-distorted samples representing the entire profile; (2) samples to a greater depth than any reasonable dug trench, and (3) samples that are uncontaminated or have a minimum of contaminants introduced in the collection process, and (4) samples that can be maintained in lunar environmental conditions by addition of gas-tight jackets around the coring tubes. These advantages are so great that we recommend that three drive-tube sample devices be carried for trial on the first Apollo mission. The apparatus is simple, and can be modified early and quickly for use on later missions.

Rock Samples

Fragments of rock that litter the surface beyond the distal margins of the fresh ejecta blankets may be of two origins: (1) those that represent the local bedrock, and (2) those foreign to the site, from extralunar sources or other places on the Moon. The importance of obtaining adequate samples of the local rock, if any, has been stressed above. While less critical, the foreign fragments may provide valuable preliminary information about the composition of more distant parts of the Moon.

If there is a variety of lithologic types, or foreign rocks, the astronaut should estimate the relative abundance of each type, and collect one or a few small samples of each. As the lithologic variety increases, the difficulty of estimating the percentage of each rock type increases, but the estimates must be made. If a large number of rock types are present, the limited sample return will make it difficult to bring back a representative sample. Random sampling is justified only if the fragments are so altered or coated that lithologic differences are not readily apparent.

Fragments a few centimeters in diameter are adequate for petrographic study and many other types of analysis. Fragments 5 to 10 cm across are needed for special purpose analyses; fragments larger than 10 cm probably must be broken for packaging. Depending on the hardness or toughness of the rock, it may be possible to break chips from large blocks. It is very difficult, however, even with the gravitational force on Earth, to break hard fragments in the 10-50 cm size range embedded in yielding granular material; such fragments will probably have to be carried to a larger block, if any, for use as an anvil, or taken entire, or not taken at all. In this, as in every other aspect of the sampling process, the astronaut must use judgment based on a full understanding of the problem.

TRAVERSE OPERATIONS

The attached map (fig. 2) shows an example of several traverses from the LEM, arranged to examine features of special geologic interest. Such traverses will probably be planned in advance, on the basis of photointerpretation, essentially to field check the geology. The field-checking procedure is highly flexible, and, if time becomes a limiting factor, the amount of detail examined can be reduced from that shown to only a few of the most critical features. If the landing is not precisely on the intended site, a geologic map prepared from preflight information may not be available. Even if the landing takes place on a prechosen site, many of the features seen on photographs may be inconspicuous and difficult to identify on the ground. In these latter cases, the astronaut will have to solve as many of the geologic relations as he can as he proceeds along his traverse and plan the traverses as he goes along.

A critical question is how much of the astronaut's time should be spent in mapping, that is, in position-determining operations along the traverse lines. The controlling factor may be the random distribution of impact craters within reach of the LEM. Details of the shape, trends of linear features, and other pattern relations, which are essential elements in any study of structured bedrock, are not critical in early Apollo reconnaissance on the lunar plains. Most lineations and other pattern relations that may

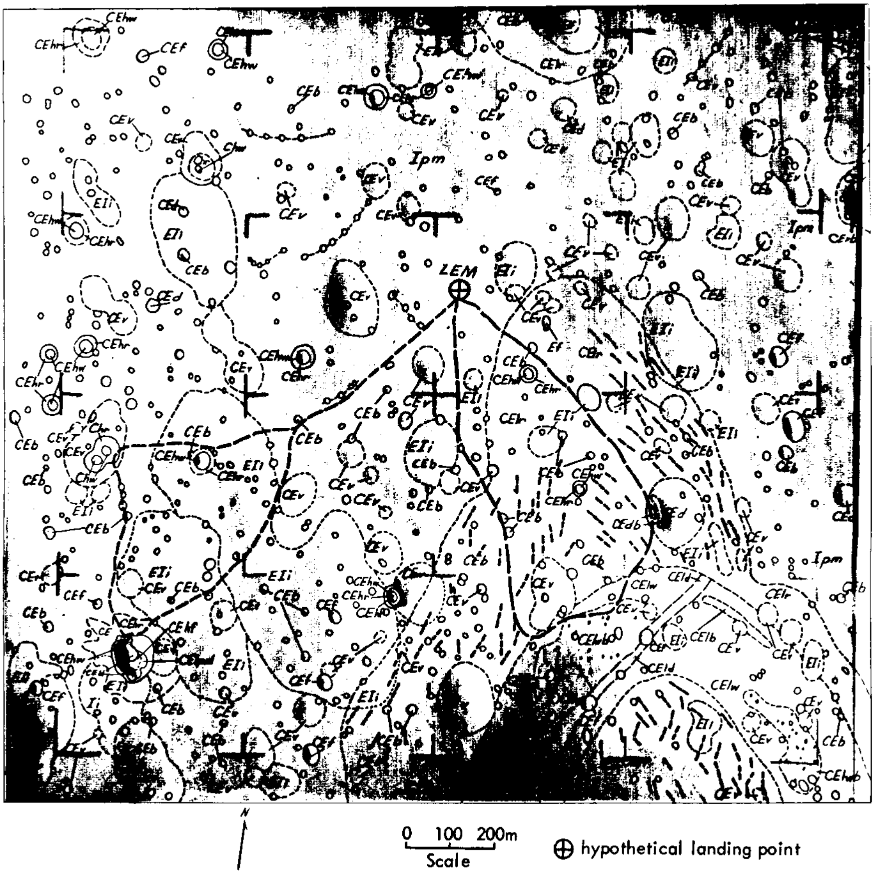

Figure 2.

Geologic map of area shown on B camera 570, Ranger VIII, illustrating foot traverses from hypothetical landing point of Apollo Lunar Excursion Module. Lat. 2.66 N. Long. 24.75 E at the center reticle. Geology by H. H. Schmitt, June 1965.

COPERNICAN SYSTEM

Chr

Crater rim material, sharp rim craters

Bright material on rims of sharp, generally circular craters. Outer rims are concave upward with steepest slopes greater than 15°. Rim crests are cusp-shaped in cross section. Craters probably formed by impact.

Chw

Crater wall material, sharp rim craters

Bright-appearing material on walls of sharp, generally circular craters with bright rims. Walls are concave upward with slopes greater than 15°.

CEhr

Crater rim material, sharp rim craters

Material on raised rims of sharp circular craters. Albedo is close to that of more surface material. Morphology of craters is the same as that of Copernican craters. Craters are probably of impact origin.

CEhw

Crater wall material, sharp rim craters

Material on walls of sharp circular craters without bright rims.

CEhf

Crater floor material, sharp rim craters

Material with relatively flat topography in floors of sharp, circular craters without bright rims.

CEhl

Crater lobe material, sharp rim craters

Hummocky material occurring in lobate patches on the lower walls and floors of sharp circular craters without bright rims. Probably crater rim and wall material that has undergone mass movement down the crater wall.

CEhwd

Crater wall material, dark, sharp rim craters

Relatively dark material in walls of sharp circular craters without bright rims.

CEf

Funnel crater material

Material of well-defined, circular craters that have no apparent raised rims and no rim deposits. Crater walls have conical shape with slopes greater than 15°. May be small maar craters or drainage craters over large fractures.

CEd

Dimple crater material

Material of well-defined craters with walls that are convex upward. Slope of walls varies from less than 15° to more than 15° with depth. Outer rim is poorly defined. Craters may be drainage craters over narrow fractures or openings, or sharp-rim craters that have undergone extensive inward slumping of their rim and wall material.

CEld

Linear depression material

Material lying in narrow, roughly linear depressions. Depressions probably caused by subsidence or volcanic activity along fractures in more surface material.

CEb

Crater material, undifferentiated

Material of small, steep-walled craters. Rim materials cannot be resolved at the scale of the photographic base. Slope of walls is greater than 15° on upper part and less than 15° on lower part. Probably mostly sharp-rim craters with unresolvable rims or small low-rim craters caused by high-angle secondary impacts.

CEdb

Crater bench material, dimple craters

Material on relatively flat areas between steeper slopes on walls of dimple craters. Probably downfaulted crater rim or wall material.

ERATOSTHENIAN SYSTEM

CEv

Crater material undifferentiated, convex rim craters

Materials in subdued craters with raised rims convex upward; albedo of rims is the same as that of the more surface material. Crater walls are concave inward with slopes of approximately 15° and less. Rim crests are poorly defined. Probably extensively eroded sharp rim, funnel and dimple craters.

CEvb

Crater bench material, convex rim craters

Same as CEdb.

CElr

Crater rim material, low rim craters

Material on wide, low rims of generally circular craters. Craters are probably secondary impact craters or partly eroded sharp-rim craters. Topographic rims are only slightly raised above surrounding more material and outer limits of rims are poorly defined. Albedo is the same as that of more surface material. Steepest slope on rims is less than 5°. Rim crests are well defined.

CElw

Crater wall material, low rim craters

Material on wall of low-rim crater. Walls are concave inward with slopes of approximately 15° or less.

CElf

Crater floor material, low rim craters

Same as CEhf.

CElb

Crater bench material, low rim craters

Same as CEdb.

CElwb

Crater wall material blocky, low rim craters

Low-rim crater wall material that is covered by blocks of apparently cohesive material less than 10 m average diameter. Black dots indicate position of individual blocks. May be allogenic breccia resulting from secondary impact.

IMBRIAN SYSTEM

Eli

Crater material, undifferentiated, indistinct craters

Material of indefinite craters and depressions with low topographic rims of the same albedo as the more surface material. Rims are convex upward. Walls are concave inward with slopes that are markedly less than 15°. Long axes of craters have a general northwest alignment that resembles the lineation of patterned ground. Craters may be eroded impact craters, eroded depressions on original more surface or depressions caused by structurally controlled subsidence.

Ipm

More surface material

Material making up the bulk of the more surface. Probably a heterogeneous layer of debris repeatedly stirred by formation of small unresolved craters and consisting of locally derived brecciated volcanic material, some extralunar fragments and fragments of material derived from distant impact events elsewhere on the Moon.

Contact, long-dashed where approximate, short-dashed where gradational or indefinite.

(CEv) Concealed contact. Buried formation shown in parenthesis.

Contact uncertain.

First two man traverse.

Second two man traverse.

Lineament. Shallow linear depression.

Craters that are too small to be classified. Joined by dashed line if several lie on smooth curve.

occur in the vicinity of the LEM should be evident on photographs taken before or after the landing. In general, traverses should be controlled as accurately as practicable, primarily so that observations and sample locations along the traverses can be tied to these photographs.

Positioning operations must be accomplished insofar as possible by a tracking device on the LEM, by shots of the LEM with a range-finding camera from points along the traverses, or other automatic or semi-automatic procedure that requires a minimum effort on the part of the astronaut. Where it is necessary for him to deal with directional trends, these can be described with reference to the direction of shadows, which will change less than 2 degrees during most field excursions.

Descriptions of topographic and geologic relations along the traverse lines should be supplemented by photographs, preferably stereoscopic. Good photographs are preferable to verbal descriptions of many field relations, such as shapes, size range, patterns of alignment or distribution of rock clasts, and all types of topographic features, from large craters to details of the fine structure of the surface. Because interpretation of the geologic significance of samples, after completion of the mission, may depend as much on their field relations as on the physical and chemical properties of the samples themselves; documentary photographs at each sample station will be nearly as essential as the samples.

Other things being equal, small fragments which may be readily available along traverse lines are preferable to chips of the same rock broken from blocks, because of the saving in the astronaut's time. Similarly, there is no point in digging a trench to expose a profile if the same profile is exposed in a crater wall, or in the depression, if any, produced by the blast of the LEM.

However they may be obtained, the most essential samples at each site are those that bear directly on the major problems of the lunar plains, namely, the character and origin of the material beneath the superficial blanket, and the processes responsible for the fine structure of the surface. If only two matrix samples can be obtained, they should include (1) a profile from the oldest surface in the vicinity—probably the flattest, darkest-colored surface, with the most strongly zoned profile—and (2) a profile from the youngest surface, which in most but not all cases, will be the outer slopes of the freshest crater. Other types of samples will have greater or less value depending on how closely they are identified with geologic units, the relative ages of which are known. The fact that the collecting time and weight of samples will be fixed, places a premium on the discrimination of the astronaut; this depends on his experience in geologic field work in general, and the depth of his understanding of the particular problems of the Apollo sites.

GEOLOGIC RELATIONS AT POSSIBLE APOLLO LANDING SITES

On the basis of study of the Moon by the U.S. Geological Survey and other groups, it is possible to distinguish lunar plains of three different ages, each floored by a named stratigraphic unit. The scientific objectives of the early Apollo program will be best served by one landing on each of these three units. Insofar as is now known, all provide favorable conditions for landings, but much more detailed information will soon be available, and the final site selection will be based largely on that information. For the bearing they may have on site selection, it is useful here only to state in general terms the geologic problems to be investigated; specific places are named merely as examples, not because they are necessarily better than other places on the same geologic unit. There should be time, after the final site selection, for the astronauts to engage in an intensive premission study of each landing area, so as to anticipate as far as possible the specific problems that may be encountered.

Mare Site (Sinus Medii)

The maria floors are thought to be the youngest of the major lunar plains considered here. Broadly speaking, they are underlain by materials, probably of volcanic origin, belonging to the Procellarum group; these materials filled in the maria basins long after they were formed. The surface in the vicinity of Sinus Medii can be expected to be similar to the mare surfaces shown in high resolution photographs of the Ranger VII and VIII series. A number of small primary craters are apt to be within traverse distance of any landing site, and it is likely that they will exhibit a range of erosional development or degradation from fresh to subdued that is favorable for studies of the type on which attention is focused in this report. There is a fair possibility that other types of craters, such as secondary impact craters, volcanic craters formed by eruption of lava, pyroclastic material, or gas, and collapse craters may be within traverse distance from the LEM; if so, these features will offer other lines of field study for which the astronaut should be fully prepared.

Highland Basin Site (Hipparchus)

Depressions in the highland parts of the Moon are floored by material which seemingly predates the maria; in the central region of the Moon most favorable for early Apollo landings, this material has been called the Cayley Formation. The Cayley Formation is typically developed in the craters Hipparchus and Flammarion; the topographic detail of the surface of the plains underlain by the Cayley Formation is apt to be similar to that shown in the high resolution Ranger IX photographs of the floor of Crater Alphonsus. The basic problems to be studied on the Cayley Formation are the same as those of the mare surfaces, but it is likely that the impact-shattered blanket is thicker and that it may locally show a stronger profile development. In some places domes suggestive of volcanic origin are present on the Cayley Formation—the landing site might be located as near as possible to features of this type. Equally attractive for scientific purposes are sites near the outer limits of rays or clusters of secondary impact craters associated with large fresh craters.

Site on a Smooth Part of the Fra Mauro Formation (Glyden)

A large part of the upland in the equatorial part of the Moon is mantled by a regional deposit named the Fra Mauro Formation. It has been interpreted as a regional blanket of ejecta associated with the Imbrium basin. The Fra Mauro Formation is older than the maria material and the Cayley Formation. As an example, Glyden is an ancient (pre-Imbrian) crater that has been covered or blanketed by the Fra Mauro Formation. The Cayley Formation nearby in Hipparchus rests stratigraphically on the Fra Mauro Formation.

Samples of the Fra Mauro Formation should represent materials which predate or date from the Imbrian event; in either case, it will be the oldest material likely to be encountered in the early Apollo program. For geologic purposes, the best landing sites are in a broad belt where the Fra Mauro has a thin and discontinuous cover of ejecta from much younger craters of Copernican age; the combination of an alteration profile on Copernican material, and a buried fossil profile on Imbrian material, would provide valuable data bearing on rate of surface alteration and possible changes in the nature of the alteration processes during a long span of lunar time.

GEOLOGIC TOOLS

Development should begin immediately for the equipment listed below. The tools and exploration systems are those that will meet minimum geologic requirements and are such that they can be developed should early Apollo missions be launched earlier than presently planned. However, the AES field geologic exploration system for use during foot traverses should be developed rapidly for possible use during Apollo missions. Of particular importance are the instruments of this system that perform tasks such as tracking and the orientation of images obtained by film and television cameras.

Sampling Trowel

Samples of fine-grained surficial debris can be obtained by a specially designed trowel having the following characteristics:

1. Tough, chisel blade-front with a distal width less than the width of sample bag openings.

2. Flat bottom with sloping flanges on either side.

3. Handle with malleable butt and overall balance compatible

with use as a hammered chisel. Handle should be extendable to meet sterile sample requirements for biological samples.

Sampling Tubes

The sampling of soil profiles in fine debris can be accomplished in many cases by use of driven or punched sampling tubes. Although telescopic data indicate there is a very fine-grained, porous surface layer on the Moon, it is not certain how thick or coherent this layer is or if it contains coarse fragments in sufficient quantities to seriously impair the use of sampling tubes. The scientific requirements for the sampling tubes are as follows:

1. Length compatible with LEM/CM sample container or any other available LEM/CM volume such as the space left by spent LiOH canisters; a desired minimum length is 1 foot.

2. Diameter 2 to 3 centimeters.

3. Composition of tube should be such as to provide a minimum nonidentifiable contamination.

4. Bit-end of tube should be designed so as to retain incoherent material.

5. Head-end should have a cap for hammer driving. Cap should be removable so that a second tube can be attached to obtain an extended sample.

6. Both ends of tube should have caps capable of maintaining the compositional integrity of the enclosed sample or the tubes should be placed in hermetically sealed containers.

7. An inner sleeve should be considered as a device for permitting rapid, sure extraction of the core.

Sampling Hammer

The chipping of samples from large blocks of rock will require either a hammer or a powered tool. To date, design studies of a powered sampling tool have not provided a tool concept that is compatible with either the weight, operational, or currently envisioned geologic constraints of Apollo exploration. Investigations of simple, lightweight, low-power sampling tools should continue; however, chipping operations during early Apollo probably will be best served by modified geologists' hammers. The general requirements for these hammers are as follows:

1. Length, grip and balance such that optimum accuracy and impact force can be obtained within the limits of suited mobility.

2. Head should have a hammer surface on one end and a flat, 2-cm-wide chisel blade on the other for scraping and picking.

3. Handle should have 1-cm-wide circular gray scale and color markings.

Sample Scriber/Brush

The collection of oriented samples for structural, paleomagnetic, and geochemical purposes requires a rock scriber which, for example, could be used to scribe a shadow line on the sample prior to photographing the sample in place. A small brush mounted on the same holder would be useful for removing any dust from rock surfaces to permit their close examination. The scriber/brush should have the following characteristics:

1. Diamond tip on one end, wire brush on other.

2. Length and thickness compatible with easy gripping and scribing or brushing under suited conditions.

Field Sample Bags

The prime requirements for general geological sample containers are that they can be easily filled, rapidly sealed against mixing, conveniently carried, and capable of compact packaging in LEM/CM sample spaces. The following general specifications will satisfy these requirements:

795-916 O-65-8

1. 100 bags per sampling man-hour of nominal surface excursion time.

2. Bags should be composed of flexible, tough, inert material.

3. The bags should be of two sizes, (1) 12 cm in opening width and 15 cm in depth, and (2) 8 cm in opening width and 10 cm in depth.

4. Bags should be prenumbered or lettered in large, easily read figures and should be compatible with mounting on dispensing and storing racks on a sample carrier.

5. Sealing of bags should be by a simple crimping mechanism.

6. In addition to bags, there should be a few sheets of covering material similar in composition to the bags which can be used for wrapping a few specimens that are too large for the bags.

Special Sample Container

In addition to the sample bags, the field geologic investigations require special sample containers with the following:

1. One sample container should be capable of maintaining the lunar atmosphere until samples are returned to the receiving laboratory.

2. One container should be designed to store the sampling tubes taken on any given mission.

3. Openings of containers should be as large as possible for ease of packing.

Hand Magnifying Glass

To aid the astronaut in the discrimination and interpretation of undisturbed small features of lunar materials, a hand magnifying glass should be developed having the following general characteristics:

1. 5 to 10 power magnification.

2. Optics and shape compatible with visibility and mobility constraints on the astronaut.

Stereometric and Surveying Film Camera

The Apollo film camera will provide detailed physical dimensions and color and photometric properties of lunar surface features in the near field. The near field is here defined as that between the identifying resolution of premission photographs and the dimensions that can be obtained from returned samples. It is anticipated that during most Apollo exploration the near field will lie between about 6 meters and 50 cm, the lower limit being determined by the degree to which fine textural detail can be preserved in returned samples. The film camera will also serve as an instrument for the location of data and sample points relative to the LEM.

The camera will take high resolution, dimensionally stable, stereoscopic and surveying photographs. The general specifications for the camera and its film are as follows:

1. Two matched lenses with a base separation of 160 mm or more.

2. Resolution on film of at least 100 lines per mm from the center to the edge of the frame.

3. Image stability on film of ±0.005 mm between any two points in the frame.

4. Low to medium contrast black and white film with calibrated sensitivity throughout the visible spectrum when scene luminance is 25 to 2,500 foot-lamberts, exposure time is constant, and one of three iris apertures is used.

5. Three calibrated, step variable apertures from f/3.5 to f/22, and a shutter which exposes all parts of the frame 5 milliseconds, ±0.06 millisecond.

6. Nominal field of view of 60° diagonally across the frame.

7. Data block on each frame, showing lens number and focus, iris setting, time, filter number, and camera orientation in tip, tilt to ±30' of arc.

8. Fiducial marks on the film image which define the principal point within 0.01 mm.

9. A depth of field of 0.5 m to infinity with a maximum of 0.02 mm diameter of any circle of confusion.

10. Focus achieved by using one of not more than 3 lens positions, for each of which the distance between the exit node of the lens and the principal point on the film plane is known to ±0.005 mm.

11. Telephoto lens centered between the matched lenses, with a nominal field of view of 20° frame diagonal, with focus and iris coupled to the stereometric lenses.

12. Film plane perpendicular to the optical axis of each lens, and so constructed that sensitized glass plates may be used for image recording for camera calibration. Plates normally used for such purposes are 1/4-inch thick. Other photogrammetric calibration procedures require unobstructed access to the film plane while the optics are mounted in normal operating positions. Calibration may be done before construction of the camera is complete, provided that emplacement of film drive mechanisms and other attachments after calibration do not disturb the geometric relationship between the lenses and the film planes. Calibration should be performed by the U.S. Geological Survey or by the National Bureau of Standards.

13. Three color filters, in addition to a clear position, which may be inserted if desired to filter the light forming either of the stereometric images, and the spectral transmission of the filters must be calibrated to the response of the film in order to approximately match the relative tristimulus values of the CIE color matching functions.

14. Three polarizing filters, in addition to a clear position, which may be inserted if desired to filter the light forming either of the stereometric images, with polarization planes 45° apart, $\pm 5'$.

15. Film magazine removable for return to the Earth.

16. Accommodation of 35 mm film with standard or square format.

17. Camera capacity on a single loading of 300 stereometric pair/telephoto combinations.

18. A single mechanism which advances the film, changes the iris, and cocks the shutter. All astronaut activated parts readily accessible and operable under spacesuited constraints.

19. Viewfinder readily usable by a suited astronaut.

Television Camera

A television camera should be developed for the collection of an extensive image record of geologic investigations near the LEM. The specifications for this camera should generally follow those outlined for high resolution mode of the Apollo Block II television camera, which are:

1. Small, lightweight television camera connected by a coaxial cable about 30 m long.

2. Camera characteristics are: 500 kc bandwidth; 0.625 frames per second; 1280 lines per frame; 5-2500 foot lamberts illumination sensitivity; 3°, 30° and 80° fields of view, and minimum discrimination of 8 gray levels at $\sqrt{2}$ intervals.

3. Simple camera orientation subsystems should be provided to data essential to the interpretation of photometric data.

Tool and Sample Carrier

Efficient operations on the lunar surface will require the transport and ready accessibility of the field tools and sample containers and cameras. A tool and sample carrier should be developed along the lines indicated by studies conducted by the U.S. Geological Survey and Manned Spacecraft Center. This carrier should have the following characteristics:

1. Lightweight and easily carried with one hand.

2. Provide easily accessible sample bag racks that permit the filling and storage of at least 300 field sample containers.

3. Provide easily accessible racks for a few special sample containers.

4. Provide a stand and carrying rack for the television camera.

5. Provide easily accessible mounts for the sampling trowel, tubes, and hammer; the sample scriber and hand lens; traverse plans and other instruments required by other working groups.

6. Provide carrying and panoramic mount for the stereometric film camera staff.

7. Provide mounting for a standard gray scale and color patch.

Summary

Table I gives a summary of the recommended geologic tools and systems and indicates the numbers and weights of tools required for various nominal operation plans.

TABLE I

MINIMUM NUMBERS AND PROBABLE WEIGHT OF GEOLOGIC TOOLS AND SYSTEMS FOR TWO EXCURSION APOLLO MISSIONS

Geological device	Only one man on surface at any given time		Two men on surface, each performing similar tasks		Two men on surface, one man sampling and photographing; one man describing and photographing	
	No.	Weight	No.	Weight	No.	Weight
Sampling devices						
sampling trowel	1	0.1kg	2	0.2kg	1	0.1kg
sampling tubes	3	0.3	3	0.3	3	0.3
sampling hammer	1	1.0	2	2.0	2	2.0
sample scriber/ brush	1	0.1	2	0.2	1	0.1
field sample containers	600		1000		1000	
hand lens	1	0.1	2	0.2	2	0.2
Film cameras						
stereometric and surveying camera	1	4.0	2	8.0	1	4.0
Television camera	1	--	1	--	1	--
Tool and sample carrier	1	4.0	2	8.0	1	4.0

GEOLOGIC MAPPING OF THE MOON FROM THE DATA ACQUIRED BY LUNAR ORBITERS

Geologic maps constitute tools for analyzing geologic relations and processes as well as providing graphic means of communicating geologic data and interpretations about the lunar surface. Thus a program of systematic geologic mapping of the Moon contributes significantly to all of the objectives for lunar exploration stated in the report of the 1965 Summer Study of the Space Science Board of the National Academy of Sciences.

Geologic studies already made indicate that the lunar surface is geologically very complex and that a wide variety of geologic processes have been responsible for producing these complexities. Geologic mapping will assist in defining these complexities and processes and will provide a context for interrelating studies and discoveries in geology, geochemistry, geophysics, and other disciplines.

Less than 1 percent of the lunar surface will be visited by man in the foreseeable future, thus the major volume of geologic knowledge must come from remote sensors supplemented by unmanned probes that can be emplaced from orbiters. Geologic analyses of the data acquired by orbiters will be essential for the early solution of landing feasibility and surface mobility problems. In addition, many of the remote sensors will provide data for purposes other than geologic analysis alone, such as information on the lunar atmosphere, and geodesy.

RECOMMENDED GEOLOGIC MAPPING PROGRAM

A program of systematic geologic analysis and mapping should include preparation of geologic maps at the following scales.

1:2 500 000-Scale

This scale will provide a synoptic map for general planning and for collating a wide variety of data about the gross features of the Moon. Preparation will require approximately six months (about 2 man-years of effort) and the map should be revised at intervals of a few years as new data are obtained.

1:1 000 000-Scale

Complete synoptic geologic mapping at this scale can be provided in a period of about 3 years. Efforts should be expended to make such a schedule possible.

1:250 000

Total coverage of the lunar surface at this scale is the long-range goal. Integration of observations at this scale by relating them on a geologic map is necessary to provide an adequate basis for interpreting lunar history, and to provide satisfactory interpretations of many features that can be generalized but not interpreted at smaller scales.

1:100 000, 1:25 000 and Larger Scales

Geologic mapping at these larger scales will be of a special purpose nature directed toward solution of selected topical geologic problems and detailed engineering and operational problems in areas of very limited extent.

It is important to note that an adequate geologic analysis will require a variety of geologic maps at each scale; for example, maps may be desired to emphasize the distribution of surficial materials, or of bedrock materials; or structural and tectonic features may be analyzed on still other maps.

Base Map Requirements

Early selection and standardization of a basic geodetic control net are needed so that standardization of map formats can be achieved as early as possible in the program. Rectified photographs will also be needed to provide preliminary base material for collating and early publication of geologic, remote-sensing, and other data.

Topographic base maps at a scale of 1:250 000 and with contour intervals of about 20-30 meters (with provisions for plotting of supplementary contours as required) should form the standard base for the entire lunar surface. These maps should have accuracy comparable to present U.S. national map accuracy standards. Special purpose topographic maps at 1:100 000 and smaller scales and having contour intervals less than 20 meters will also be needed as determined by special topical geologic problems of a local nature.

Photographic Support Needed

Basic photographic coverage should be at 6-inch focal length for the entire lunar surface. The photographic system used should provide photographs from which base maps at a scale of 1:100 000 and, if possible, 1:50 000 can be prepared for any part of the lunar surface. The photographic systems recommended by the NASA/OSSA/SM photographic team would provide the coverage needed. For geologic interpretations, total coverage should be obtained in the range of 5^{o} to 15^{o} of the terminator, and with both sunrise and sunset lighting. Photographic coverage at high-angle illumination is also needed to make possible the use of albedo differences to discriminate various geologic units and to measure slope. On equatorial orbital flights continuous photographic coverage should be obtained from terminator through the subsolar point to the opposite terminator in order to obtain the maximum spread in angles of illumination.

It is recommended that, in addition to the mapping camera systems, an ultra-high-resolution photographic system with resolution better than 1 meter be developed.

Photographic coverage from early unmanned orbiters and from the first Apollo missions will be needed for geologic analysis of the Apollo landing sites as well as for locating sample and observation sites of the astronauts.

Orbital Data-Gathering Systems Required in Addition to Photographic Systems

The following remote-sensing methods are potentially capable of providing significant geologic data about the Moon: X-ray fluorescence, gamma ray spectrometry, ultraviolet reflection and luminescence spectrometry, multispectral photography, infrared imagery, thermal infrared spectrometry, microwave imagery, microwave spectrometry, multifrequency radar imagery and scatterometry, atomic absorption spectroscopy, and electromagnetic pulse probing (table II). To some extent all methods are mutually supporting, and analysis of the results from each method will be significantly improved if as many sensors as possible are included on each mission until complete coverage of the lunar surface is obtained. There is a wide range in the state-of-the-art both in instrumentation and data gathering, and much remains to be learned about the interpretation of the data. Thus, studies should be supported to bring these systems into an equilibrium whereby maximum value may be obtained from each of them.

TABLE II

REMOTE-SENSING TECHNIQUES OF POSSIBLE APPLICATION TO GEOLOGIC MAPPING OF THE MOON

Proposed technique	Principal use in geologic mapping	State of development	Some space testing
X-ray fluorescence	Elemental composition	B2[a]	
Gamma-ray spectrometry	Elemental composition	A	X
Ultraviolet reflection and luminescence spectrometry	Petrology and mineralogy	C	

[a]Whether principal goal can be achieved on Moon is questionable because of conditions peculiar to Moon.

TABLE II. — Continued

REMOTE-SENSING TECHNIQUES OF POSSIBLE APPLICATION TO GEOLOGIC MAPPING OF THE MOON

Proposed technique	Principal use in geologic mapping	State of development	Some space testing
Multispectral photography, narrow angle	Discrimination and mapping of geologic units	B1	
Multispectral photography, wide angle	Discrimination and mapping of geologic units	B1	
Standard "six-inch" mapping photography	Discrimination and mapping of geologic units	A	X
Panoramic photography	Discrimination and mapping of geologic units	A	X
High-resolution photography	Discrimination of geologic units	A	X
Infrared imagery	Discrimination of geologic units and mapping of thermal anomalies	B1	X
Infrared spectrometry	Mineralogical composition	B1[a]	X

[a]Whether principal goal can be achieved on Moon is questionable because of conditions peculiar to Moon.

TABLE II. — Continued

REMOTE-SENSING TECHNIQUES OF POSSIBLE APPLICATION TO GEOLOGIC MAPPING OF THE MOON

Proposed technique	Principal use in geologic mapping	State of development	Some space testing
Microwave imagery	Discrimination of geologic units and mapping of thermal anomalies	C	
Microwave spectrometry	Measurement of thermal properties	B1	
Selected-frequency radar imagery	Discrimination of geologic units to some depth	B1	
Multifrequency radar imagery	Discrimination of geologic units to some depth	C	
Radar scatterometry	Surface roughness	D	X
Atomic absorption spectroscopy	Detection of near-surface atmospheric constituents	B1	
Electromagnetic pulse probe	Deep sounding (100 m-100 km)	B1	

TABLE II. — Concluded

REMOTE-SENSING TECHNIQUES OF POSSIBLE APPLICATION TO GEOLOGIC MAPPING OF THE MOON

State of development

A - Instrumentation in advanced stage of development; use for geologic mapping well understood.

B1 - Instrumentation in advanced stage of development; potential use for geologic mapping high but still to be developed.

B2 - Geologic use well understood, but space instrumentation only partially developed.

C - Instrumentation partially developed; potential use for geologic mapping high but still to be developed.

D - Instrumentation well developed; potential use for geologic mapping unknown.

Of the various methods, imaging techniques (visual, infrared, and radar) carry a high priority because they can be most readily applied to the problem of discriminating and mapping geologic units. X-ray, gamma ray, ultraviolet, and infrared spectrometry deserve emphasis because, in theory, these techniques can provide at least partial compositional analysis of the mapped units, although serious problems may confront each technique. The surface radiation temperature can be obtained from infrared spectrometry, and a subsurface temperature gradient to a depth of a few meters can potentially be obtained from microwave spectra. From the thermal data and radar reflections, lateral variations of a particular surface layer could conceivably be mapped to shallow depths. Electromagnetic pulse probing potentially can provide some data about structures at depths of from 100 m to 100 km. Atomic absorption spectroscopy may detect near-surface atmospheric constituents.

In the development of flight instrument payloads, clustering of mutually supporting techniques and modular development of these clusters should be planned for ease of adjusting to flight schedules. Some possible clusters include:

1. Imaging systems: photographic, multiband, infrared, and radar.

2. Infrared scanner, microwave and infrared spectrometry.

3. X-ray fluorescence and gamma ray spectrometry.

4. Ultraviolet reflectance and luminescence spectrometry clustered with comparative visual spectral photography.

The use of imaging systems for terrain identification is highly desirable on all missions for relating line trace or pulse information from some remote-sensing devices to recognizable lunar features; for the dark side of the Moon, infrared or radar imaging systems would be required.

The use of remote sensors in the study of terrestrial geology, currently underway, should be greatly accelerated in order to enhance the interpretability of remote sensing data to be obtained of the lunar surface. Some sensors, however, such as ultraviolet and X-ray fluorescence, can be tested fully only outside the Earth's atmosphere.

Calibration of Remote-Sensing Techniques

High priority should be accorded in early AES missions to obtain measurements on the lunar surface that will assist in the calibration of remote-sensing data. In order of priority they are:

1. Measurement of electromagnetic attenuation and reflectance coefficient at microwave and radar wavelengths in several lunar geologic environments. These measurements probably will have to be made by the astronauts. Indirect estimation of these parameters may be possible from regular geologic sampling and observation.

2. Goniometric measurements of reflected sunlight. These can be obtained from images acquired with cameras held by the astronaut provided the orientation of the cameras are accurately recorded. The measurements are needed to calibrate current photometric mapping procedures.

3. Goniometric measurements of spectral emission and reflectance of IR energy from several geologic environments should be made on the lunar surface. These measurements should be made simultaneously, if possible, with temperature measurements in the near subsurface zone (1 meter and less).

4. Porosity measured in situ. To some extent measurements of porosity can be derived from regular geologic sampling and observation, but development of new techniques applicable to the lunar surface should be studied.

5. Density gradations in depth measured in situ. To some extent this will be a part of the regular geologic sampling and observation program, but some special study is desirable. Shallow seismic refraction profiles may provide the data required.

6. Because geologic mapping will continue to be dependent upon remote-sensing techniques, serious efforts should be made to collect some specimens in a way that will make them most meaningful in the interpretation of remote sensor records. For example, samples should be taken that preserve the original surface, and the analyses made of these samples should include those analyses that are most meaningful to the interpretation of remote sensor data. Chemistry and structure of the surface and spectral emissivity of the surface are among the more important analyses to be made.

Scheduling of Remote-Sensing Missions

Activities related to remote sensing should be an integral part of both early Apollo and AES missions.

1. Early Apollo missions. High-resolution images should be obtained from the command module and, if possible, telemetered to Earth in order to identify the exact landing site and area investigated by the astronauts.

2. AES surface missions. Remote-sensing calibration investigations on the lunar surface should be scheduled at the earliest possible time.

3. AES lunar orbiter missions. The entire remote-sensing package should be flown on each orbiter mission until complete coverage of the Moon is obtained both at low-angle lighting and at high-angle lighting, and with sunrise and sunset lighting. One orbiter carrying the remote-sensing package should be flown prior to first AES landings. Polar orbiters of 28-day durations each are desirable at the earliest time for total examination of the lunar surface by remote sensors.

A minimum of three polar orbiting missions is necessary to obtain coverage of the Moon under the conditions of solar illumination listed above. More missions will probably be needed for the following reasons:

1. To study time varying phenomena of the lunar surface such as luminescence and emission of gas.

2. To follow up on discoveries made on earlier missions with specially designed experiments.

3. To use improved instrumentation developed on the basis of early-phase testing.

EMPLACEMENT OF UNMANNED PROBES FROM LUNAR ORBITERS

Unmanned probes can be effectively deployed on the lunar surface in AES orbiter missions in support of the geologic mapping and remote-sensing surveys and for other special purposes. The probes can be used to determine the surface composition and fine structure at many remote places and to delineate the most

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significant areas for subsequent, detailed investigations by manned surface missions. More specifically, the missions to which probes should be devoted are:

1. Reconnaissance surface study of geologic units delineated by orbiter and Earth-based mapping.

2. Emplacement of apparatus, such as seismometers, in a surface net.

The major advantages of utilizing probes for reconnaissance are:

1. The possibility of placing them at virtually any point on the lunar surface.

2. The relative ease of data collection brought about by the fact that several probes can be deployed during a single orbiter mission.

Reconnaissance Study of Surface

Unmanned probes can be expeditiously employed for reconnaissance surface investigations on the Moon in most geologic terrains. Certain geologic units may be predicted to be of critical importance for manned landings on the basis of other evidence such that reconnaissance surface investigation by unmanned probes is not necessary, and the need for detailed work by manned missions is warranted at the outset. In the early phases of manned lunar exploration, this will probably be true only in near-equatorial areas of the sub-Earth side of the Moon because of Apollo landing constraints. Probes should be widely deployed elsewhere on the lunar surface in early AES polar orbital missions.

Data needed from widely distributed surface probes to support the synoptic and systematic geological mapping of the Moon are:

1. Chemical and mineralogical analyses of the surface materials

2. Physical measurements for calibrating the remote sensor data acquired by the orbiters

3. Morphology and fine structure of the surface

In addition to support of the systematic mapping, probes should be employed for investigations of areas of difficult access for the manned missions, such as areas in permanent shadow near the lunar poles. Here the unmanned probes may be employed effectively for special investigation of the volatile substances that may be trapped in these extremely cold areas.

Surface Instrument Net

The ability of the probes to land at all points on the lunar surface and for a large number to be emplaced in one mission gives rise to the use of the probes for emplacement of instruments in a surface net. One of the most promising uses would be to emplace a seismometer net to record elastic waves from large seismic sources. The seismic sources could be either natural or artificial. Large artificial sources can be produced by explosives or by impacting the lunar surface with the LEM ascent stage or S-IVB.

Recommendations for Probe Systems and Equipment

We recommend that both rough-landing capsules and soft-landers be deployed in AES lunar orbital missions.

Rough-landing capsules should be developed principally for seismometer delivery and possibly to deliver an artificial source of elastic waves.

Soft-landing probes should be deployed for analysis of the lunar surface to support the systematic geologic mapping. The payload should be one which can sample the immediate lunar surface and near-surface (±1 meter deep) in the near vicinity of the probe. The instruments on the probe should have the capability of phase, elemental, and morphological and textural analyses of the samples obtained. High-resolution images should be obtained for definition of the local fine structure. Special payloads may be necessary for gas analysis and detection of ice and absorbed fluids in permanently shaded areas.

SPECIAL PROBLEMS AND RECOMMENDATIONS

Publication and Distribution of Data

Information distribution from a complex data-gathering mission such as an AES lunar orbital mission presents special problems. The interaction of data from various sensors and the need for experimenters in each technique to have available data from other sensors requires a special form of coordination and assistance in publication and distribution of data. For example, funds must be provided for adequate duplication of data, for distribution to cooperating investigators, for curating, storing, and retrieving data, and for final publication of results.

TABLE III

ESTIMATE OF TOTAL MANPOWER NEEDED
FOR LUNAR GEOLOGIC ANALYSIS AND MAPPING

Program	Man years	Years required for completion	Men per year at peak
1:2 500 000-scale geologic map	4	0.5	8
1:1 000 000-scale geologic map	75	3	25
1:250 000-scale geologic map	800	10	80
Special purpose geologic mapping and topical geologic studies	200	10	20
Site certification studies	300	3	100
Data reduction and handling of remote-sensing data	300	3	100
	1679		333

Scheduling should be such that peak manpower level will be reached within about 5 years.

Requirements for Scientific Manpower

The presently existing number of scientific personnel is inadequate to handle the large quantity of remote-sensing data to be obtained in the recommended lunar orbital missions. Significantly increased support of the participating scientific institutions will be required to develop the trained scientific manpower needed for this program (table III).

Security Classification of Remote-Sensing Techniques

The scientists engaged in evaluation of remote-sensor methods and techniques that may be applied in the exploration of the Moon and other planetary bodies are seriously handicapped by restrictions applied to the use and dissemination of understanding of these systems by security classification.

The large part of the knowledge to be acquired about the surfaces of the Moon and planets must come from these sensors. Limited or inefficient use of remote sensors can seriously impede the success of the lunar and planetary exploration program. We urge that this view be immediately brought to the attention of the National Security Council and the National Academy of Sciences.

Release of Data for Analysis

Interpretation of imaging data from one remote-sensing method is closely dependent upon correlation with imaging data from a variety of other imaging techniques; thus it is desirable that all imaging data be released to the general scientific community as soon as it has been reduced to suitable display form. Similarly, data from nonimaging techniques will have great value to a variety of investigators, and some means should be sought to promptly release calibration and certain procedural information as well as the data gathered.

GEOLOGIC INVESTIGATIONS DURING AES MISSIONS

It is expected that during early Apollo missions the operational difficulties of landing men on the Moon and returning them to Earth will have been solved. Moreover, observations and samples obtained by the astronauts will have provided direct evidence on the composition and age of some lunar materials, and will have established the nature of the fine structure in at least the upper meter of the Moon's crust near the landing sites. The significance of these Apollo findings, however, is not confined to the landing sites alone; they will provide a partial "spot-check" of geologic interpretations made from Earth.

Preliminary geologic maps of large parts of the Moon's surface have already been prepared. Construction of these maps and interpretation of the geologic units represented thereon, until now, has been based chiefly upon study of: (1) photographs obtained from Ranger spacecraft, and (2) photographs and visual observations through telescopes. Before the AES missions start, we will have additional evidence from photographs from Earth and lunar orbiters and results from a wide variety of remote sensors—some only recently developed. To check the validity of these maps requires identification of the rocks by actual sampling of the Moon's surface, and the direct observation by a geologically trained astronaut of the stratigraphic and structural relations. Apollo landing sites, however, will not be numerous enough, and may not be in localities most favorable to "prove up" the photogeologic interpretations. The real check of these interpretations made from Earth will come in the early AES missions and, together with the collecting of abundant samples, this should be the main objective of these missions.

Will the early AES missions prove the correctness of the early geologic interpretations? If they do—and we have every reason to believe that they will—the exciting prospect arises that within 5 years we may be able to compile a better geologic map, and know nearly as much about major events in the Moon's geologic history as was known about the Earth up to 1945—after two centuries of intensive geologic work. Clearly, AES landing sites must be carefully chosen, the specific problems each mission is to solve must be clearly stated, and the critical samples must be obtained from each site. The prize is within reach, but to attain it requires rigorous focusing of geological, geochemical, geophysical, and other techniques upon the specific problems to be solved, and upon the theoretical models to be tested.

AES MISSION OBJECTIVES

A sound program of lunar exploration must weigh the importance of the information sought against the capabilities of delivering that information within the operational restraints of the vehicles available. Delivery capability, as well as scientific information, may be expected to increase at a rapid rate with experience gained from each successive mission. Flexibility to take account of this increased capability and knowledge is essential, but planning must not be delayed. To make optimum use of new information and vehicular changes, the major scientific objectives must be identified well in advance, and plans for their solution framed following the most acceptable theoretical models as guides. Much of this early identification of objectives has been done and is available in many reports. We hold that one important aim of the early AES missions is to prove out in detail the present models of lunar structure and stratigraphy that have been developed mainly through photogeologic techniques, telescopic observations, and results from remote sensors. Still more specifically, the AES missions should concentrate on acquiring, by field work on the Moon, additional new information to answer as many problems as possible regarding three different kinds of geologic terrain of great importance on the Moon.

The Maria

Representative, but by no means complete, are the following questions about a specific mare that might be answered by an AES landing:

What is the composition and depth of the material that fills the mare? What is the absolute isotopic age, and the relative geologic age, in relation to other major stratigraphic units, of representative samples obtained from this fill? Is the fill lava, or is it an accumulation of fragmental material?

A second category of questions is directed more toward process than composition: Is the mare basin itself the result of a major impact event or of some other tectonic process? Is there tectonic significance in the pattern of fractures and of folds on the mare? Is the Moon seismically active? What is the present heat flow, and the source of this heat? Does the Moon have a molten core, and is there evidence of further radial differentiation as on Earth? If igneous rocks are present in the mare fill, what is their stage of differentiation and what do they reveal regarding the Moon's thermal history and the nature of its interior? Is there any evidence of degassing from the Moon's interior, either by volcanism or by other emission phenomena? Are there areas of concentration of sublimates and of water-bearing minerals, and, if so, how were they formed? If clastic rocks are represented in the mare, were any of them water-deposited and do they contain any evidence of former life?

A third category of questions relates to surface geologic features. We can expect that many of these questions will be answered in early Apollo missions, but additional new problems will arise that may be followed to conclusion during AES. What are the physical processes now at work on the Moon's surface, and how can we measure their rate or intensity? Is the fine structure of the uppermost meter or few meters fragmental, and if so, what is the source of the fragments and what is the rate of "stirring" of the fragmental layer? Is there an alteration profile (similar but of different origin than the Earth's soil profile)? Can buried alteration profiles be seen on the walls of craters, or recognized in ejected blocks? What magnetic and other physical properties may be unique to this surface crust? Are any nonlunar fragments (i.e., meteorites or fragments from Earth) recognizable in the surface debris?

The Cratered Highlands

An AES landing in a heavily cratered part of the highlands can help to solve many of the same questions asked for the maria, but special opportunities in the highland setting should be emphasized. The highlands supposedly contain the oldest geologic units exposed on the Moon's surface. Therefore isotopic ages, composition, stratigraphic sequence, and tectonic pattern of the rocks all may differ markedly from a mare. Are meteorites recognizable as constituents of these very old rocks, and how does their composition and age compare with those recovered from Earth? Are plutonic and metamorphic rocks present? Is there a recognizable primordial crust? Have the rocks of the highlands been shocked by impact so many times that their original textures and minerals have been largely reconstituted? Are seismic velocities and heat flow through these rocks comparable to those found for the maria? Do the rocks of the cratered highlands record a primordial stage in the evolution of a planet—long since obliterated by sedimentation and other processes on Earth?

A Thermally Active Major Crater (for example, Alphonsus)

Visual changes, possibly caused by emission of gas, have been reported within the craters Alphonsus and Aristarchus. Ranger IX photographs also show features within Alphonsus that some have interpreted as volcanic vents. There are many valid reasons to investigate an area of the Moon that is thermally active, and before AES surface missions are flown we should attempt to get data on possible thermal activity by means of infrared or microwave sensors. Alphonsus has additional features of interest such as a central peak, a complicated rill system, and lines of chain craters in reasonably close proximity to one another. According to impact theory the central peak should furnish material derived from deep within the Moon; the rills and chain craters may afford opportunity to collect and identify gases arising from the interior. The nature and origin of the deposits beneath the flat floor of the crater can be meaningfully compared with those that fill the maria. Enough problems of interest can be explored within a small distance to make it probable that preliminary investigation of Alphonsus during AES time would lead naturally to the development of a Lunar Base in this crater in a later phase of exploration.

These three geological terrains—maria, cratered highlands, and a thermally active crater—have been singled out as the most promising targets of AES missions. The major objective in all three cases is to test the prelanding geologic and theoretical models, and to simultaneously develop the largest possible fund of new knowledge about the Moon. The exact landing sites should be picked on the basis of our preliminary knowledge of the regional geology, after checking as to their operational feasibility.

ASTRONAUT TIME

A superficial study of experiments proposed and traverses planned on the Moon by participating scientists indicates that the use of astronaut time can be roughly classified into the following categories:

The Astronaut as Observer and Creative Scientist

Taking part in the original planning of the scientific mission, and having full responsibility for executing it on the Moon including the choice of changing the original plan to meet unknown or unanticipated conditions. With this goes the responsibility of cooperating with other scientists after return, and in many cases sharing as coauthor in the publications that result.

The Astronaut as a Technician

Setting up and monitoring communication equipment; observing and routine recording of simple physical phenomena; surveying activities.

The Astronaut as a Packer

Carrying experiment packages to favorable sites; transporting specimens collected to the LEM; carrying instruments and equipment that must be used on traverses.

In every mission there will be no escape from the astronaut having to perform certain tasks in all three of these categories, and in some scientific experiments they will be so intimately interwoven that they cannot be separated. But if we are to derive full benefit from the astronaut's time, every effort must be made to use automatic systems for recording data, thus minimizing the number of menial time-consuming chores he is to perform. No basic scientific reason to send a man to the Moon exists unless we make full use of his capabilities to observe and interpret, for even samples could be collected and returned by unmanned landers. A machine, however, cannot interpret geologic features such as folds, schistosity, or craters; nor can it use judgment in investigating them by selectively extracting the truly significant features. Only the human mind has the unique ability to evaluate from lifeless rock the subtle combination of physical features that reveal its origin and geologic history. Such statements are trite, but it cannot be emphasized too strongly that every bit of time the astronaut can use as a scientist greatly increases the chances for success of the mission.

EQUIPMENT TO BE DEVELOPED FOR AES MISSIONS

Immediate attention must be given to the rapid design and development or perfection of certain systems, vehicles, and instruments necessary for efficient field work on the Moon.

Automatic Position-Recording System

One of the most crucial and important systems to be developed is a precise tracking and recording system that will automatically keep track of the astronaut (or of a manned or unmanned roving vehicle) and telemeter this information back to Earth. Such a system should also be capable of automatically recording the orientation of a camera mounted on an unmanned vehicle or carried by the astronaut. The orientation of the camera at any point from which he takes pictures on his traverse should also be attainable from oral data supplied by the astronaut. Precision of position location to 1 part in 1000 is more than adequate for most work.

No other single development of equipment is as important for increasing the astronaut's output as a creative geologist. The heavy cumbersome equipment and time-consuming operations analogous to plane-table geologic surveying on Earth have no place whatever in lunar geologic exploration. New developments in laser, radar, and other optical techniques have made position finding much less formidable from an engineering standpoint. Contracts should be let at once to develop a position-finding system for the astronaut and for the roving vehicle, here referred to as the local scientific survey module.

Local Scientific Survey Module (LSSM)

One of the most promising concepts for geological exploration under AES is that of increased mobility on the surface provided by the LSSM. The LSSM should be capable of carrying either one or two men, and a scientific payload of up to 600 lb. An operational range of 8 km radius is minimal for lunar reconnaissance. Telescopic studies of the distribution of lunar geological units and features suggest that an operational range of 15 km radius would be much more useful if fuel and life support systems can be devised to permit this range. The vehicle speed must be such that a man can drive to a distance of 8 to 15 km for a LEM shelter and still have at least 2 or 3 hours in which to perform scientific tasks.

An automatic tracking and surveillance imaging system should be designed to operate from the LSSM, and the positional and image data should be relayed either directly to Earth or through a telemetry link in the LEM shelter to Earth. Remote control of the LSSM from Earth for extended periods both before and after the manned surface mission is very desirable. Image reconnaissance before arrival of the astronauts would not only provide site certification, but would also provide invaluable information for scientific mission planning. Features seen on orbital images could be studied closely through the LSSM imaging system to determine which features should be studied by the astronauts. An automatic sampling device would permit samples from these features to be waiting for the astronauts upon their arrival so that these could be closely observed or analyzed at the LEM shelter for determining the priorities of features to be studied.

The ability to remotely control the LSSM from Earth after the manned mission would allow correlation of features analyzed in that mission with features analyzed during previous missions, and provide both engineering and scientific site selection data for future missions. Extended geophysical instrument traverses could also be made, using the information telemetered to, and analyzed on, Earth.

All systems that are compatible with manned and remote operation should be designed for both operational modes.

Lunar Flying Vehicle (LFV)

The LFV is presently envisioned to have limited uses for extending the operational range of AES, and for studying features inaccessible to the LSSM due to topography. The rate of fuel consumption, and the inability to observe and collect samples from the surface close at hand during operation, limits the use of this vehicle as an exploration tool. Because of its possible application to visiting critical areas that are just out of range or otherwise inaccessible to exploration by the LSSM, we are interested in the continued development of the LFV. It should be designed to carry at least a 300 lb scientific payload. If it is to be used primarily as a rescue vehicle, it may not be available for scientific exploration except near the end of the mission because of fuel constraints.

Lunar Drills

We recommend development of a drill, capable of penetrating to a depth of three meters in either rubble or solid rock; the drill must be capable of being operated from the roving vehicle (LSSM). One inch core diameter is sufficient. We cannot justify a drill capable for penetrating to greater depths for geologic work in the AES missions but suggest attention be given to developing a 300 meter drill for use at a Lunar Base.

Analytical Instrumentation

Two types of geological instruments are needed for AES surface missions.

Geology hand tools. These would be largely inherited from early Apollo missions and should include hammer, hand lens, scoop, cameras, radiation meter and other aids.

Analytical equipment. This would be for all study of the composition, structure, and texture of rock materials. AES analytical instruments should be designed largely to discriminate between samples, to provide information on those samples which are not returned to Earth, and to provide near real-time information that will aid in guiding the field work. The analysis of chemical spectra is sufficient to answer most of the geologically pertinent questions on composition. The structure of the rock materials and the distribution of elements within the mineral compounds are easily determined by diffraction techniques. The textures of these materials and certain evidence on composition and structure are most easily analyzed by petrographic microscopy.

Analytical equipment for AES should include the following items for geological investigations:

1. Petrographic stereo-microscope
2. X-ray diffractometer
3. X-ray fluorescence spectrometer
4. Mass spectrometer
5. Natural radiation spectrometer
6. Materials testing equipment

Any of the analytical systems which utilize spectral data will require a data-handling system capable of comparing the spectrum generated from a sample with that from a standard or earlier sample. This capability is necessary for the astronaut to properly utilize his data and also to calibrate his instruments. A computerized system with memory cores on the vehicle and a library of spectra available by telemetry from Earth is recommended. Adequate sample preparation equipment must be developed for all analytical concepts.

ROLE OF ORBITERS AND PROBES IN AES SURFACE MISSIONS

Orbiters and unmanned probes have important roles both in the preparation that precedes AES missions, and in the investigations that will follow. Among the prelanding uses are: (1) certification of the landing site for safety of terrain, (2) photography and other remote sensing data for preparation of detailed geologic maps prior to landing, (3) probing of areas near the landing site with geochemical or geophysical instruments to set up specific experiments or gain specific information useful to the mission. (For example, a sterile biological sample might be taken by a probe prior to landing, and recovered during the landing operations.)

SUMMARY

1. AES missions should concentrate on testing the validity of geologic interpretations based on photographs, telescopic observations and data obtained from remote sensors, and in gaining new knowledge from sampling and direct observation, of three major kinds of geologic terrain on the Moon: (1) the maria, (2) areas of old rocks in the cratered highlands, and (3) a major crater with central peak and evidence of possible late thermal activity, for example, Alphonsus.

2. An essential system for the efficient conduct of the missions is an automatic tracking system capable of determining the astronauts' position (or that of a manned or unmanned roving vehicle) at all times during a traverse.

3. Development and improvement of vehicles to extend the astronauts' mobility—especially the LSSM—should be continued and accelerated. A drill capable of penetrating to depths of 3 meters should be developed for use from the LSSM.

USE OF A LONG-RANGE LABORATORY VEHICLE FOR POST-AES GEOLOGIC EXPLORATION OF THE MOON

OBJECTIVES

Traverses with a long-range surface vehicle will be needed to provide an integrated broad regional picture of the surface geology and crustal structure of the Moon. Long traverses are needed to tie together local detailed studies made during the AES program and at semipermanent lunar bases, and the long traverses are also needed for the complete interpretation of the data obtained by remote sensing from orbital vehicles and the data from lunar probes. A series of traverses across the general region of the equatorial belt will provide a continuous deep geologic and geophysical cross section to correlate with the topography and with the broad tectonic features. These traverses would also provide regional correlation of stratigraphic units and deep layering which would be impossible from widely scattered local areas studied in detail during AES missions or from fixed bases.

Some additional local detailed studies of specific problems encountered along the traverses will be necessary for the interpretation of the broad regional tectonic and stratigraphic pattern The traverses should be designed to intersect as many as possible of the significant structural and stratigraphic features that have already been recognized or will be discovered by the early Apollo and AES programs. Features of special interest include rilles, mare ridges, craters of several different types, volcanic fields, tectonic structures of the upland regions, and a number of different geologic units within mare basins. A series of traverses along the equatorial belt of the Moon will encounter most of the significant structural and stratigraphic features exposed on the Moon's surface.

PLANNING OF TRAVERSES

The final planning of specific traverses for the long-range laboratory vehicle should await the interpretation of the data from remote sensing by orbital missions, the data gathered by lunar probes, and the results of the AES surface missions. Such data will be of significant value in planning the long-range traverses and selecting various problems along the traverses that need further data to be solved. It is anticipated that such data will not only have significant bearing on geologic problems already being considered, but will turn up new problems on which the long-range vehicle investigations will have an important bearing.

Some of the presently identifiable geologic problems that should be investigated on the long-range traverses are as follows:

1. Mare basin-deep layering, nature of filling, broad compositional differences across the surface, overlapping of lava

flows or other layers, interlayering of various types of material, and the nature and structure of mare contacts along the borders of the basins.

2. Broad-range stratigraphic correlation and study of regional variations in composition of stratigraphic units.

3. Structure of the highland areas—patterns of faults and fractures, distribution of various igneous bodies, and regional metamorphic effects.

4. Rilles—nature, extent, width, depth and regional pattern; nature of material along fault scarps in the rille walls, displacement on bordering faults, nature of debris cover, classification of various types of rilles.

5. Mare ridges—underlying igneous material; associated faulting origin.

6. Craters—character and composition of outer rim, layering of crater wall, extent of ejecta blanket, ray material, volcanic material, origin.

No specific traverses should be selected at the present time, but the following traverse is offered as a model of the types of regional geology which should be investigated by the use of the long-range vehicle. This model utilizes four to six missions totaling approximately 3200 km range to establish a geologically controlled strip across the equatorial belt of the Moon. A nearly continuous strip is recommended because of the value of extrapolation to the rest of the Moon of the complex interrelationships investigated.

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REPRESENTATIVE LUNAR TRAVERSE

Major topographic points along traverse	Nature of feature studied
First section	
1. 38^{o} W 3^{o} S, Oceanus Procellarum	Mare material with intersecting Kepler and Copernicus rays, mare ridges
2. Lansberg crater	Imbrian crater
3. East of Lansberg	Fra Mauro Formation of Imbrian age and Eratosthenian craters, Procellarum Group dome, rille in Fra Mauro Formation
4. Lansberg P	Mare ridge crater, Highland morphology and structure north of Fra Mauro
5. Turner crater	Margin of Sinus Aestuum
6. East of Turner	Fra Mauro Formation, Copernican and Eratosthenian craters
7. Ptolemaeus crater	Deep structural cross-section of this large pre-Imbrian crater
8. Hipparchus	Deep structural cross section of Hipparchus and comparison with Ptolemaeus
Second section	
9. Southern Mare Serenitatis Northern Mare Tranquillitatis	Stratigraphic relations of the mare border area of Mare Serenitatis and Mare Tranquillitatis
10. Julius Caesar	Structural pattern and complex stratigraphy of deposits filling this pre-Imbrian crater
11. Hyginus Rille area	Complex structure of major rille and associated chain craters
12. Triesnecker crater	Copernican crater, Cayley Formation of Imbrian age

CHARACTERISTICS OF LABORATORY VEHICLE AND OPERATIONAL CONSTRAINTS

In order to meet the objectives outlined above, the long-range laboratory vehicle should have the following characteristics and be operated under the following constraints:

1. The vehicle should have a minimum range of 800 km without requiring refitting. In order to traverse this distance in a reasonable time, a three-man crew is recommended. Relief in driving the vehicle is an important factor and many of the laboratory analyses and experiments could be carried on by one man while the other two are making geologic investigations on the ground.

2. The mission duration should be from 2 to 6 weeks. Thus work during the lunar night is anticipated. The intensity of earthshine should permit such an effort.

3. The mission should not be restricted to operating under a command module.

4. The vehicle should not be constrained to return to a starting point, but should be able to operate from previously deployed caches of fuel and life-support supplies and be able to exchange crews at points along the traverse.

5. The concept of a long-range vehicle and that of a permanent shelter-base should be integrated as early as possible with the lunar exploration program.

6. To aid in the development of the long-range vehicle's sampling capability it should include as many aids to manned mobility as possible. These might include a flying vehicle, a small auxiliary surface vehicle, or a combination of both.

INSTRUMENTS

AES analytical instruments will be designed largely to discriminate between different types of rock and to provide information on those samples which are not returned to Earth. This concept becomes even more fundamental when the great sampling power of the long-range vehicle is brought into play. A variety of sophisticated analytical instruments must be employed to aid in this discrimination. The instruments suggested for the long-range traverses may be grouped in 4 main categories.

1. Geology hand tools and cameras. These would be largely inherited from early Apollo and AES missions. In addition, a mechanical sample collector deployed from the laboratory vehicle would be very useful to allow the astronaut to collect some samples without emerging from the vehicle.

2. Automatic tracking and navigation devices to provide accurate positioning at all times and a continuous topographic profile.

3. Analytical equipment for the study of the composition, structure, and texture of rock materials. It is anticipated that there will be a legacy of analytical equipment from AES equipment development which will include a system for providing relatively complete chemical and mineralogical analytical capability.

4. Geophysical instruments.

a. Active seismometer capable of detecting and measuring deep crustal structure to a depth of at least 5000 meters, and, if possible, tens of kilometers.

b. Magnetometer. Even though the Moon has low magnetism, a magnetometer would be useful in detecting local subsurface compositional differences in the mare and highlands regions, and might be effective in locating buried lava flows, dikes, and other igneous bodies.

c. Gravity meter. With the magnetic data, gravity data would aid in the detection and mapping of subcrustal compositional differences and structure. Specifically it will provide data on the degree of isostatic compensation of the broader features of the lunar relief.

d. Instruments designed to record the engineering physical properties of lunar surficial material will be most useful in interpreting geophysical information and for evaluating possible shelter sites. Properties of both displaced and <u>in situ</u> materials should be determined.

e. Instruments for measurement of natural radiation will be of great assistance in differentiating rock units. A practical system should be adapted for use in the long-range vehicle.

5. In addition to the above analytical instruments, the following ancillary equipment is recommended for the long-range traverses.

a. A drill capable of drilling 3 meters would facilitate the geophysical experiments.

b. A power-driven trenching machine is needed, capable of trenching to a depth of 3 meters, to expose stratigraphic layering in critical areas, and to expose bedrock where cover is thin.

c. A high resolution video system is recommended for studying features at a distance and for tracking the astronauts when they make local short-range traverses from the laboratory vehicle.

The design specifications of the various instruments should not be determined at the present time, but must depend on the evaluation of instrumental concepts and their effective use in the early Apollo and AES missions.

ASTRONAUT TRAINING REQUIREMENT

For successful long-range traverse missions, it is essential that the astronauts be selected far in advance and be specifically trained for the operation of the scientific instruments and the interpretation of the results. They should have enough experience to be able to determine what experiments to use and how to integrate them with other data obtained on the mission. At least one of the three astronauts should be an experienced geologist.

GEOLOGIC INVESTIGATIONS FROM A LUNAR BASE

A lunar base is defined here as a lunar surface complex which will allow a total stay time longer than 2 weeks; it may remain in use for a period of years with scientists in attendance during all or part of the duration of that period.

ROLE OF A LUNAR BASE IN AN INTEGRATED GEOLOGIC EXPLORATION PROGRAM

The geological missions for which a base is required are those that need extended stay time in one locality. The basic difference between a base and other lunar exploration concepts is the length of time that can be devoted to measurements at one place. Long stay times allow investigations that require extreme detail in observation of geologic relations or high precision and accuracy of measurement. Apparatus requiring long assembly time, calibration, and monitoring can also be used at the lunar base. Four prime geological objectives that require a lunar base are as follows:

Measurement of Time-Dependent Phenomena

Optimum investigation of time-dependent phenomena requires a sufficiently long integration time for precision of measurement and for intelligent monitoring of instruments to account for aberrant or nonphenomenological data. The time-varying measurements described below could be done best at a base.

Passive seismology. Measurement of induced and natural elastic waves over a wide range of periods with high directional resolution is required to meet the basic objectives given in the geophysics report. Sophisticated instruments and monitoring that can be achieved at a base will allow the more refined and precise seismic work that will be needed in order to correlate potential zones of lunar seismic activity with observed surface structure and to extend surface structure to depth by seismic observations.

Magnetic fields. Measurement of the intensity and direction of the total field vector over a long time period with concomitant measurement of charged particle influx on the lunar surface may allow a separation of the induced field, an internal field, the plasma field and any remanent magnetization of surface rocks. The rate of decay of the induced field over a lunar day may indicate the deep internal temperature gradient.

Meteoroid flux. It is of great importance for quantitative understanding of lunar surface processes to increase the precision in our knowledge of the mass spectrum and influx rate of meteoroids striking the lunar surface. Either long counting time and/or vastly increased detector sizes are required for precision measurements.

Electromagnetic spectrum. A base will provide the optimum opportunity to increase precision in measurements of the electromagnetic radiation intensities and to observe the unmeasured gaps in the spectrum. Such measurements are critical to an understanding of the role of radiation in the modification of the fine structure and the composition of the lunar surface at the present and in the past. A wealth of data on past environments and events may result.

Study of Lunar Surface Processes

The precise interaction between the lunar surface and processes acting upon it can be studied in detail over a long period of time at a base, and the predominant mechanisms and rates of erosion, transport, and deposition of surface material can be determined. These processes can be investigated by periodic observations and measurements at natural lunar test areas, close to the base, that contain a sufficient range of compositions, geometries, and mechanical properties for clear evaluation. Artificial surface models for testing these variables can also be erected. The data so derived will be basic to interpretations of the sequence and nature of events which have modified the lunar surface throughout the history of the Moon.

Deep Drilling

Several of the major lunar scientific problems concerning the early history of the Moon, crustal composition, and surface processes of the past can be best approached by deep penetration below the Moon's surface by drilling. The depth that should be reached is difficult to specify at this time but should probably exceed 300 meters. The drilling apparatus and time required to drill to depths of 300 meters or more will clearly require the capabilities of a base. Measurements on the core and in the drill hole should include examinations of the drill core for differentiation and for evidence of the conditions of formation of the material in each layer penetrated as well as the time and nature of subsequent events such as hydration or brecciation of the material. The deeper parts of a hole drilled in an appropriate part of the Moon may provide the best source of material which can indicate the radioisotopic age of consolidation of the Moon. Deep samples will also be of use in further biological studies. The deep hole will be optimum for logging of the physical properties of lunar materials for interpretation of geophysical measurements. The opportunity for highest accuracy in heat flow measurements also will be provided by a deep hole.

Detailed Study of a Critical Field Area

Careful field and laboratory studies should be made of fine scale stratigraphy, structure, and petrology of a small critical field area at which the base has been located. These areas will provide keys to the understanding of less quantitative observations taken elsewhere on other missions. The site should be chosen, on the basis of previous knowledge, at a place where critical problems can be studied. In some cases, considerable time may be required for the astronauts to work out the problems, collect sufficient field and laboratory data, and recheck certain observations and the consequences of their interpretations. The quality and efficiency of the study will probably be enhanced by considerable supporting apparatus and integration of techniques. Such field studies will provide the geological context for interpretation of the chemical, structural, and temporal nature and history of the surface where other base measurements will be made (i.e., seismicity, heat flow, magnetic measurements, drill hole petrology and stratigraphy).

SPECIFIC EXAMPLES OF LUNAR BASE INVESTIGATIONS

Following are some specific lunar problems that serve as examples of investigations which fall under the four geological objectives of a lunar base given above.

Structure of Lunar Mountains

The surface and subsurface structure of the mountain ranges of the Moon are critical field problems which will probably require the capabilities of a base for solution. The Earth and the Moon represent extremes in the range of mass and density of the terrestrial planets, and the mechanical properties and thermal history of the two bodies may have been very different. Comparison of the way in which positive masses form on the lunar spheroid, and the way the body of the Moon supports them, with mountain-building processes on Earth, and the way mountains are supported on Earth, will be a major key in understanding the mechanical forces and reactions affecting both the Moon and the Earth through geologic time.

Analysis of the structure of the Apennine Mountains represents a specific problem which can be outlined at this time as an example of a lunar investigation which will probably require the capabilities of a base. The Apennines form the southeastern rim of the Imbrium Basin and contain strong lineaments radial to the Imbrium Basin. Lunar base investigations should show whether the Apennines are an enormous pile of surface debris, and if so, whether they were created from ejecta produced by a collision that created the Imbrium Basin or whether they have been formed by some other mechanism. If the mountains have roots, what is the subsurface configuration of the roots? Have the Apennine Mountains been uplifted, and what is the tectonic relation of the Apennine lineaments and the Imbrium Basin? Most importantly, are these mountains compensated by roots of low density material so that the Moon is in local isostatic balance, or do the mountains form a mass which is supported by the internal strength of the Moon? Solutions to these problems will provide an important insight into the internal character of the Moon and the mechanics of mountain-forming processes on a terrestrial body which has rather different properties from the Earth.

Investigation of the Apennine Mountains problem from a lunar base should consist of detailed mapping of the fabric and structure of the Apenninian rocks over a representative area and of gravity and seismic examination of the subsurface structure.

Study of the Early History of the Moon

Current investigations of the stratigraphy and structure of the lunar surface indicate that the surface is largely composed of blankets of crater ejecta, laterally transported dust, and perhaps, volcanic rocks. Studies of these blankets are critical to the understanding of most of the history of the Moon, but they may not reveal the conditions and processes which predominated in the early history of the Moon. Investigations in and below the oldest rocks exposed on the lunar surface may indicate whether surface processes have been uniform in time, and provide evidence on the possible existence of past lunar atmospheres and oceans, the composition of the primordial surface, and the age of first consolidation of the Moon. Knowledge of these factors will contribute significantly to our understanding of the early development of the Earth, a subject on which direct observations are virtually impossible.

Investigations of the early history of the Moon will require the stay time and deep drilling capability that a base can provide. Specific lunar sites for these studies must be determined from regional geologic mapping. On the basis of present knowledge of lunar geology, as an example, the early history of the Moon might be investigated in a relatively old geologic unit west of Mare Humorum, away from the mare rim, which is believed to predate the formation of the Imbrium Basin. A part of this unit should be mapped for its lithologic and structural relations to later geologic units; ejecta blocks on this unit or volcanic rocks derived from depth should be sought for the information they provide on the subsurface lithology. If geophysical data indicate subsurface vertical differentiation in this area, it would be a favorable site for deep drilling.

Studies of Lunar Volcanism

The Moon may provide substantial gains in our understanding of volcanic processes by comparative studies of lunar and terrestrial volcanism. These studies will also be fundamental for determining the thermal and petrologic history of the Moon. Among the problems that need study are: (a) the composition of adsorbed and evolving gases, (b) the nature of seismic and tectonic activity associated with lunar volcanism, (c) the products of lunar volcanism, i.e., rocks, sublimates, and rock-forming minerals, and (d) the mechanics of intrusive and extrusive igneous activity on the Moon.

In order to get answers to these problems, a base will be required at a site of active volcanism such as may be present in the Aristarchus region. Standard field geologic mapping techniques integrated closely with data from remote sensing, geophysical measurements, and geochemical sampling will supply most of the relevant geologic data.

Post-Impact Crater Mechanics

Some geologic data on large lunar craters suggest that some of the crater floors have risen in response to isostatic adjustments. The extremely complex geology of these floors merits study from a lunar base. Among the problems that require study are: (a) the present nature of seismicity and rock movements, (b) the distribution of rock mass, (c) the heat flow and possible volcanism associated with crater floor adjustment, (d) the structural relationships of adjoining rock masses, and (e) the mechanics of isostatic movement. Data of this type could be obtained by establishing a lunar base in or near a crater such as Ptolemaeus or Alphonsus. Extensive geophysical monitoring of such a crater combined with extensive and detailed geological field work are required to solve the problems.

Processes of Erosion, Transport, and Deposition on the Lunar Surface

The lunar surface is covered by deposits of material that range in size from extensive blankets of crater ejecta to local small deposits of diverse origin. Among the important questions to be studied concerning erosion, transport, and deposition of material on the lunar surface are: (1) What is the present flux of eroding particles and particulate energy, what is its origin, and in what way does this flux modify the large-scale features on the lunar surface? (2) Through a comparison of deposits and landforms of a variety of ages and degrees of modification, what are the principal agents of transport and at what rate do they act? (3) What is the response of the surface to depositional loading? (4) What is the history of erosion, transport, and deposition?

These questions can only be resolved by controlled experiments and observations on the Moon. Studies of rates and processes can be evaluated in situ or by study of models placed in the lunar environment. Excavation of trenches for study of the stratigraphic column of local deposits and use of a wide variety of geophysical and geochemical exploration techniques will be needed. The scope of these activities calls for a lunar base.

REQUIREMENTS OF A LUNAR BASE

Number of Astronauts

The maximum number of astronauts needed at the base at one time to perform any one of the scientific missions given above is estimated to be four to six. Because the investigations can be carried out sequentially, except for the long-term monitoring functions, the number of astronauts need be no more than those required for the single mission requiring the most manpower.

The task with the highest manpower requirements is drilling. It appears that four to six men can maintain a core-drilling rate of 5 meters per day, which would be sufficient to put down a 300 meter hole in 2 months.

The estimated manpower and time requirements for various types of missions are given in table IV.

TABLE IV

ESTIMATED MANPOWER AND TIME REQUIREMENTS FOR LUNAR BASE INVESTIGATIONS

Sequence	Investigation	Minimum number of astronauts	Time[b] (Earth days)
1	Surface processes		
	Initial setup	2	20
	Monitoring[a]	2	360
2	Time-dependent phenomena		
	Initial setup	2	10
	Monitoring[a]	2	360
3	Drilling	4	60
4	Downhole measurements		
	logging and initial setup	2	15
	Monitoring	2	60+
5	Geological field studies	2	80

[a]Continuous measurement; instruments may require periodic attention from astronauts, say 1 day every 10 days of operation.

[b]For minimum astronaut staff.

If a larger number of astronauts were employed to man the lunar base, certain tasks could be finished in less time than shown in the table. The times estimated for instrument setup and field studies given in table IV are probably inversely proportional to the number of astronauts, so that what would take four men about 60 days to do, eight men could do in 30 days. Of the two alternatives (few men for long time versus many men for short time), the former is scientifically preferable because of the importance of long-term monitoring in addition to the active tasks in the missions at a base.

Duration

Our estimate of the time required to gather adequate statistics for the time-dependent studies and surface process observations is 1 year, as shown in table IV. For a staff of four astronauts, about 120 astronaut days are required for tasks other than monitoring. If the astronauts directly attend to monitoring for 1 day in every 10 days, an additional 40 astronaut days are required; this frequency of direct monitoring is likely to be required only for the surface process investigations, because the other instruments can probably be monitored remotely, in large measure, from the base interior. On the basis of these estimates, four astronauts must occupy the base around 35-45 percent of the minimum total lifetime of the base. The schedule of astronaut attendance at the base will depend upon the nature of the long-term experiments. Conceivably, the active tasks could be performed during the initial few months and the base could be operated remotely thereafter; alternatively, short periodic visits by the astronauts could be scheduled.

We estimate that careful field mapping in complex terranes on Earth can be done by experienced observers at the rate of 1.5 to 2.0 square km per day. The daily work period on the Moon may be about half as long and, perhaps, half as efficient. This suggests the rate of field mapping will be 1/2 square km per day or less on the Moon. A conservative estimate of the maximum radius of action of the astronaut on foot is 1/6 km (500 ft). On this basis, the area reached from a single point of departure, say from a lunar vehicle, would be about 0.1 square km. Several of these small areas might be investigated in a single day. Thus, about 80 square km could probably be investigated in detail under the manpower and time limitations shown in table IV.

Mobility

Though the geological investigations at a lunar base should be focused on problems of a local extent, these investigations will require a means of transportation. The number of critical lunar field areas that can be clearly worked out within a radius of less than a kilometer of a base is likely to be very small. Further, a larger attainable area about the base is required for satisfactory selection of optimum points to emplace instruments such as seismometers and magnetometers and to make observations and measurements of surface processes. The optimum radius of action should not be less than 10 km and might well be somewhat greater.

Location

On the basis of the geological objectives given for a lunar base and our present knowledge of lunar problems and processes, it is possible to suggest several criteria for base sites. These criteria and lunar sites are given as possible examples as follows:

1. The objective of deep drilling into the oldest rocks in a vertically differentiated part of the Moon indicates that a base should be placed where the oldest lunar formation crops out. The oldest units mapped to date are in the highlands west of Mare Nectaris.

2. Studies with a deep hole of the petrology, stratigraphy, structure, and heat flow of lunar areas where volcanic or strong tectonic activity has occurred can provide an understanding of past and present internal lunar processes that may not be clearly interpretable from surface observations or geophysical measurements. Possible examples of such areas are in the Aristarchus or Marius regions.

3. A major goal of the lunar base is the study of critical stratigraphic sequences, both vertically and laterally over a small area for the purpose of improving the relative and absolute lunar time scales. Three major stratigraphic sequences, pre-Imbrian, Imbrian, and post-Imbrian, are currently well established and each

will probably require studies from a lunar base for definitive analysis. These three sequences will probably have to be studied at separate locations.

Number of Bases

The foregoing list of locations suggests that at least five bases may be required. This number should be the minimum because it is highly likely that future exploration will present many new problems which will come within the scope of base investigations.

Drilling Depth

The optimum depth of drilling from a base cannot be specified at this time and should await the results of planned investigations. We suggest that 300 meters should constitute a minimum drilling capability for a base; the maximum depth would depend on the time available and the priority of drilling relative to the other scientific missions of a base. We estimate that 60 days, or 15 to 20 percent of the minimum base lifetime, will be required for four astronauts to drill 300 meters. At a drilling rate of 5 meters per day and use of 50 percent of the base time over a year, about 1000 meters depth could be reached.

Base Equipment

Stationary field devices. A number of instruments for passive seismology, magnetometry, and fields and particles measurements should be part of the base equipment. These instruments are specified in the sections on geophysics and fields and particles. Equipment for controlled observations of the predominant processes and rates of surface erosion should include devices for possible construction of test areas where lunar rocks of different composition and geometry are exposed to external phenomena. Means of periodic measurements of change in gross size and shape of the specimens as well as changes in elemental and phase composition and grain-to-grain relations are required. Devices are also needed to measure the momentum and size of flying particles and the way they come to rest. The equipment to be employed in surface process measurements could be either permanently installed or could be transported to and from the base laboratory.

Geological field devices. The geological hand tools employed in previous early Apollo and AES missions should also be used in the detailed field studies around a base. In addition, the astronauts should have at their disposal a wide range of equipment for active field work and excavation that have not been permitted on early Apollo and AES missions because of weight restrictions. Such devices should include active seismic sources, detectors and recorders, a hand magnetometer, trenching machines and gas analyzers. Direct measurement of physical properties of undisturbed surface material can be made near the base, and instruments to determine bulk density, porosity, and induced and natural radioactivity should be available.

An instrument for rapid petrographic analysis might be needed to expedite field work if previous missions have shown that visual discrimination of rock types is difficult.

Base laboratory measurements. Surface geological investigations at a base should be complemented by a wide range of laboratory analytical tools so that field problems can be fully developed during the occupation of the base. Petrologic equipment should include means for phase and elemental analysis, textural observations, and density and porosity measurements. If feasible, simple radioisotopic analyses could be done at a base. The work at a base should not be aimed primarily for return of specimens to Earth; rather, full analytical capabilities should exist at the base for measurements which are necessary for the smooth progress of field studies.

Abundant core will result from the drilling mission, and it seems preferable to return this material to Earth, since analysis of this material is unlikely to be critical in fulfilling the on-site mission of the base.

Facilities for systematic compilation and analysis of field relations during mapping should be available.

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Drilling and logging equipment. Facilities for penetration, coring, and, if needed, casing of a drill hole are required. Logging of the hole for physical properties such as elastic wave velocity, magnetic susceptibility, electric and thermal conductivity, density, and porosity should follow completion of drilling. Downhole temperatures should be measured with precision after the walls of the hole have attained thermal equilibrium.

GEOLOGIC TRAINING OF THE ASTRONAUTS

The program of geologic training of the astronauts may be divided into two major stages: (1) training of the present astronauts in the fundamentals of geology, with specialized geologic training for Apollo missions; and (2) continued training of present and future astronauts for systematic exploration of the Moon. The goals and plans for the first stage of training are clear and relatively simple; the problems of training in the second stage are complex and diverse.

PRE-APOLLO GEOLOGIC TRAINING

Pre-Apollo geologic training has been divided into three phases:

1. Lectures, laboratory work, and demonstrations in the principles of geology and in mineralogy and petrology, conducted by the U.S. Geological Survey and the National Aeronautics and Space Administration geologists at the Manned Spacecraft Center in Houston, with participation by other specialists from the universities.

2. A joint U.S. Geological Survey and National Aeronautics and Space Administration program of supervised field training in a wide variety of geologic terrains, but with special emphasis on impact and volcanic geology, followed by limited participation in field research projects. Specialists from other institutions and universities have aided on many of the field trips. The U.S. Geological Survey, as contractor to NASA, has been chiefly responsible for

selection of the field sites and planning of the field training.

3. Special mission-directed training at sites and in procedures developed by the U.S. Geological Survey.

The first two phases have gone through a steady progression from training in fundamentals and in basic field techniques to increasingly mission-oriented training in techniques and field exercises. At present, about half of the present astronauts have completed essentially all of the program through phase 2; the rest of the astronauts, owing to flight assignments, have participated to lesser extent in the program.

POST-APOLLO GEOLOGIC TRAINING

The nature of the second stage of training will depend to a large extent upon the background and requirements of astronauts to be selected in the future. The training program should be flexible enough so that it can be adapted to the needs of different groups and individuals; it should provide for the following specific requirements:

1. Advanced training in geology for astronauts who have been through the pre-Apollo training course.

2. Training and research opportunities for astronauts selected for their qualifications in geology, geophysics, and geochemistry.

3. An opportunity for training in the geological sciences for astronauts whose scientific background has been in other fields.

4. General geologic training for astronauts selected for other than scientific qualifications.

CONCLUSIONS AND RECOMMENDATIONS

Training Program

The training program conducted to date has been successful; about 15 astronauts have been brought to a high level of qualification necessary to undertake the scientific responsibilities in the early Apollo missions; the rest of the astronauts, because of flight assignments, have participated to varying degrees in the training program. We recommend that the program be continued, and, if necessary, expanded along the following guidelines:

1. The classroom experience at the Manned Spacecraft Center should be repeated for future astronauts who need to acquire training in the rudiments of geology. With smaller classes, however, an increased amount of specialized tutorial work is planned, particularly in petrology and stratigraphy, and on problems concerning the origin of craters.

2. Continued group participation in field investigations of a few days duration should be available to astronauts who have completed phase 1, or are qualified by previous training.

3. Additional field exercise at an advanced level (one or two each year) should be scheduled in areas of particular geologic significance. Trips to geochemical and geophysical laboratories may also be arranged.

4. Participation of some astronauts in the manned lunar exploration studies and in other research activities of the U.S. Geological Survey Branch of Astrogeology at Flagstaff, Arizona. Similar professional experience in the form of joint investigations with scientists planning experiments for Apollo and later missions should also be encouraged. Such participation should also take place in fields other than the geosciences.

5. Operations training and dress rehearsals for actual flights. This or phase 4 will also include training for any specialized sampling procedures, or delicate experimental operations required during the mission.

Scientific Adviser

We recommend that during the actual missions there be available at the Integrated Mission Control Center of the Manned Spacecraft Center a research scientist—preferably one well known to the astronauts—from whom they can request advice during the course of the mission if they wish.

Debriefing Conferences

We recommend that during scientific debriefings those investigators having experiments on the mission be allowed to question and confer with the astronauts while details are fresh in their minds.

Crew Selection

No one questons that flight-operations ability is the first criterion for selection in Apollo missions. Beyond this, we strongly recommend that, from the pool of operationally-qualified astronauts, ability in field geology, as demonstrated during the training program, be an important factor in the selection of the astronauts who will land on the Moon in the early Apollo missions.

We strongly urge that on the more sophisticated scientific missions of late-Apollo and post-Apollo, it is imperative to the scientific success of each mission that at least one astronaut be chosen who has actually performed field investigations and/or research in one of the fields of prime scientific importance to that particular mission.

We call attention to the fact that after the first successful manned landing and return, the justification of additional lunar missions must be judged on the success of the scientific results.

CAREER PROFICIENCY MAINTENANCE FOR SCIENTISTS

Assuming that the scientist who has become an astronaut will have approximately a 10-year career as a flight-qualified astronaut, a serious problem arises in maintaining his proficiency as a research scientist. Unless means can be found to permit him to continue in a productive research program his qualifications as a scientist after a few years will deteriorate rapidly.

The lack of a predefined plan to take care of this situation probably resulted in a greatly diminished number of applications for the astronaut program by scientists of high caliber.

Each of the small number of scientists in the program will necessarily have to be treated as a special case. The need for research time and how this time is programmed varies greatly from one profession to another, and from one individual to another within the same profession. For example, a geochemist might satisfactorily do research in a laboratory at the Manned Spacecraft Center on a schedule involving half days of free time scattered through the week. This would be easy to satisfy. At the other extreme might be an astronomer whose research needs might require leaves of absence for a few months a year to continue an observing program with a telescope. Similarly, a geologist might have need to continue a field project at some distant site. It is not a trivial problem but may be crucial both in acquiring very capable scientists as astronauts and maintaining their skills once acquired. This is a difficult but not an insoluble problem. Every effort should be made to solve it. Some readjustment of time assignments within the whole astronaut program may be required to do it.

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REPORT OF
GEOPHYSICS WORKING GROUP

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INTRODUCTION

The working group concerned itself with the overall design of a lunar exploration program directed toward revealing to first order the physical properties of the Moon from the surface to the center. Major emphasis was given to the early Apollo missions and the AES because the constraints were either fixed or reasonably well defined and the lead times for development of experiments were becoming critically short. Although some effort was expended on longer range lunar programs (ALSS, LESA and beyond), it was felt that, in view of the costs and scientific manpower commitment, a review in depth could be made only in the context of priorities associated with an overall program of planetary exploration.

We assume that the reader is familiar with the main justifications of a lunar scientific program and that he is somewhat knowledgeable about the several lunar missions, including the strengths and weaknesses of the preceding unmanned ones.

The meeting represented the first opportunity for specialists to assemble and view the geophysical program as a whole. Our deliberations covered the interaction of experiments, the common needs such as power supply and telemetry, the establishment of priorities using the criteria of scientific significance, weight, volume, power, telemetry requirements, and feasibility. Conclusions of a general nature emerged as well as specific recommendations with regard to the geophysical components of the several missions. Experiments from lunar orbiters were discussed from the standpoint of how they could contribute information on physical properties of the near surface and deep interior.

The report is divided into an introductory section which defines the overall geophysical problem and indicates what the several experiments can contribute to the solution. It is followed by a discussion of the geophysical aspects of the early Apollo and AES missions. General recommendations are finally made regarding telemetry requirements, spacing of missions, and role of experimenters.

THE LUNAR GEOPHYSICAL PROBLEM AND EXPERIMENTS WHICH CONTRIBUTE TO ITS SOLUTION

Measurements of physical properties of the lunar surface and interior are not ends in themselves. They are important only to the extent that they reveal the structure, composition and state of the Moon's interior and explain its surface features. In a larger sense, studies of the Moon gain significance when viewed in the context of an evolving program of planetary exploration directed toward the basic problem of the origin and development of the solar system. From a more provincial point of view, lunar studies may well lead to major new insights if not to revolutionary developments in the geology and geophysics of the earth.

The mass and radius of the Moon are now known to a sufficiently high degree of precision, and its mean density is well established at 3.34 g/cm^3. However, its principal moment of inertia, C/Ma^2, is inaccurately known. Knowledge of C/Ma^2 is exceedingly important because it determines the gross degree of radial differentiation of the Moon and places specific bounds on the construction of lunar models

$(C-A)/Ma^2$ may be obtained from analyses of the perturbations of an artificial lunar satellite. This value may be combined with $(C-A)/C$, which is believed to be well known for the Moon, to obtain C/Ma^2. A lunar satellite is, therefore, of prime importance to the lunar geophysical program.

For a homogeneous Moon, the pressure at the center is about 46 000 bars, although it is possible to construct a model for the Moon having a small iron-rich core in which the central pressure is somewhat higher. A model cannot be constructed for the Moon containing a chemically distinct core without violating compositional identity with the Earth. Knowledge of the presence or absence of a core in the Moon is of primary importance for understanding its gross properties and its relation to the other terrestrial planets. Since it is generally believed that hydromagnetic mechanisms in the Earth's metallic, fluid core are responsible for the Earth's main magnetic field and since the Lunik II space probe indicated the nonexistence of a lunar magnetic field larger than the 100 gamma noise level of the experiment, it is an obvious step to conclude that there is no fluid metallic core in the Moon. Assuming a dipolar field, the indicated magnetic moment of the Moon is no larger than about 2×10^{-5} times that of the Earth. The indicated magnetic moments for Venus and Mars, as a result of the Mariner II and IV flights are also small. However, the magnetic fields of Venus, Mars and the Moon may not be dipolar, and straight analogies to the Earth concerning the existence of planetary cores from magnetic measurements alone might be risky. The answer to whether the Moon has a central core analogous to that of the Earth cannot be answered by magnetic measurements alone.

A lunar magnetic field may also be related to an ancient remanent field or the interaction between the Moon and the solar wind. Its most important aspects are its spatial and temporal variations as revealed by orbiting magnetometers, an array of magnetometers on the surface and observations of magnetic anomalies along surface traverses.

An equally important part of a lunar exploration program is examination of physical properties of lunar materials, in situ or on returned lunar samples. Comparison with corresponding properties of Earth materials and studies of the effects of pressure and temperature provide data which interact with every experiment.

Calculations on the thermal history of the Moon, assuming a uniform chondritic composition and uniform distribution of radioactivity, suggest that much of the Moon would be in the molten state even if the assumed initial temperature is very low. The most important parameter for the understanding of the internal thermal regime of the Moon is its surface heat flow. Observations of heat flow probably will not allow unique conclusions regarding the thermal history of a body but they will allow us to severely restrict our speculations. Observations of heat flow on the Earth have demonstrated that the mean heat flow from the oceans and from the continents is the same. It is important to learn what differences in heat flow, if any, will be measured between the lunar highlands and maria. Because of the Moon's small size, a measurement of heat flow "samples" a larger percentage of the volume of the Moon than does a similar measurement on Earth. Most important, of course, is that measurements of heat flow can yield valuable clues concerning the bulk composition and internal energy regime of the Moon and complement other geophysical and geochemical measurements.

Intimately related to the problem of the internal energy regime of the Moon is its seismicity. Lunar seismicity, the statistics of moonquakes, is an index of strain accumulation and release which ultimately relates to the thermal history and current thermal-tectonic regime of the Moon. Seismicity is an index of the origin of surface features, such as faulting, volcanism and meteoritic impacts.

The most direct means for determination of the internal structure of the Earth has been by seismic methods. Similar techniques will be useful for lunar work. The elastic and anelastic properties can now be extracted from seismic data. The presence of a crust, core and velocity reversals in the Moon can be found from seismic analyses. The density variation with depth can be recovered if the compressional and shear velocity distribution is first determined. The variations in seismic velocity and density are important for understanding the bulk composition of the Moon.

Measurement of the temporal variation of gravity at a point on the Moon is of marginal value for determining its mean elasticity. Similar observations on the Earth have told us only that the mean rigidity of the Earth is that of steel. Further refinements on variations in the elasticity of the Earth have come from seismic measurements. Because of the Moon's smallness, the additional magnification in the lunar solid body tides over the rigid body tides is extremely small. For a Moon of rigidity similar to that of the Earth the amplification of the tide is only a few parts in a thousand. This requires an extremely precise measurement. Only a Moon containing a fairly large fluid core would give a substantial magnification to the rigid body tides.

Knowledge of the spatial variation of gravity is important and leads to direct inferences concerning lateral inhomogeneities within the Moon. This can best be attacked by lunar orbiters and mobile gravity surveys on the lunar surface.

Using the Moon as a base for the detection of gravitational waves is an important cosmological experiment but is not pertinent to the study of the lunar interior.

Magneto-telluric measurements can be made by combining magnetic variations with variations in the horizontal electrical field. In view of the state of this work on Earth it may be justifiable to defer magneto-telluric measurements to post-Apollo missions.

Electrical resistivity measurements also appear to be best deferred until experimental techniques for the Moon can be perfected. Some indication of its electrical properties can be deduced from studies of the spatial magnetic variations. AC measurements, involving at the higher frequencies antenna impedance and reflection coefficient determination and at the lower frequencies radio transmission measurements, may be feasible at an early stage in the lunar exploration.

Surface sampling may give clues concerning only the rubble on the lunar surface. The "original" lunar surface may be buried to an extent not penetrable by the astronaut. An active seismic experiment could give valuable information concerning the surface and near-surface layers of the Moon. Fundamental geologic problems such as subsurface layering are best attacked by a combination of seismic refraction and gravity observations. If initial passive seismic experiments demonstrate that the Moon is a cold, dead body, then active seismic surveys must be used to obtain information concerning the lunar interior.

High frequency electromagnetic measurements not feasible on Earth because of the high conductivity of moisture laden materials within the upper kilometers of the Earth's surface may be possible on the Moon. If the conductivities are as low as reported for over-dried igneous rocks, an electromagnetic pulse probe using relatively low power may be able to penetrate a useful distance into the lunar surface materials. Combining electromagnetic and seismic data taken on the same path should permit considerably improved deductions about the properties of the subsurface materials. Since electrical conductivities become high when the temperature exceeds a few hundred degrees, this technique cannot be used to learn about the deep interior.

GEOPHYSICS ON EARLY APOLLO MISSIONS

The early Apollo missions represent a major opportunity for performing all of the experiments called for in the preceding section. The LSEP is an observatory whose capabilities in many respects exceed those achievable on Earth. Overlapping LSEP experiments represent the beginning of an array of observatories so important to the synoptic data acquisition which geophysicists require. The short walking traverses by astronauts open the possibility of active seismic measurements, whose penetration capability is shallow, but greater than that afforded by geologic observations alone. Heat flow—an observation of major significance—may well be feasible on these missions.

In considering the early Apollo missions we have attempted to define as comprehensive an experiment as is consistent with the mission constraints as now known. To our surprise these constraints were not overly restrictive in the sense that every basic observation could be carried out. Some of the experiments were listed in a variable weight mode; the greater the weight the greater the information returned or the greater the feasibility. Other experiments (such as lunar atmospheric determinations) may be competitive with the heavier weight modes of the variable weight experiments. In any case the priority assignments at this time are not considered frozen. Development is recommended of all of the listed experiments. It cannot be emphasized enough that the design of LSEP in modular form allowing for rapid interchange of experiment packages is highly desirable. It allows for changing priorities governed by such factors as scientific results of preceding missions and instrumental failures.

In assignment of priorities, a mix of criteria was established. Scientific significance, weight, volume, data transmission rate and power requirements, and feasibility were all considered.

Several recommendations pertaining to the early Apollo missions were singled out for special emphasis.

1. Two or more missions should overlap so that the LSEP's operate concurrently for 4-8 months.

2. Changes in the LSEP experiments should be permissible between missions 1 and 3 if not 1 and 2 or 2 and 3. Modular design could make this possible.

3. Telemetry capability sufficient to recover all data generated by the LSEP is required in the early mission if not all of them. Real-time data recovery is not required except possibly as a backup mode if a data storage system should fail.

4. The tidal gravimeter, because of the limited information it returns about the lunar interior and its weight, is recommended for deferment to the AES missions.

5. The lunar atmosphere, micrometeoroid and other experiments may well be competitive with the heavier weight modes of heat flow or active seismic. Sufficient information was not available and a judgment was deferred without prejudice. If the LSEP carries 60-75 lb of scientific experiments (excluding power and telemetry), then one or more of these experiments can also be included.

6. The heat-flow experiment is of major significance but problems arise because of the need to emplace the probes to depths of at least 1 meter. The minimal weight is estimated at 5 lb if the astronaut can emplace the probe without auxiliary tools. The 15 lb mode includes a special drill, which greatly enhances the experiment. The drill is recommended for mission 2, since drilling feasibility can be assessed after mission 1.

7. If a high priority experiment fails to be included in a given mission by virtue of considerations beyond the control of the experimenter, it should be included in the next mission without loss in priority.

Table I summarizes the experiments and priorities for which sufficient data were available to make judgments. Except for the short-array active experiment, the experiments are all components of the LSEP. The individual experiments and recommendations are discussed in greater detail in the following paragraphs.

PASSIVE SEISMOLOGY (INCLUDING TIDAL GRAVIMETRY) STUDIES

Introduction

Earthquake seismology has provided the most detailed information available regarding the distribution of physical properties with depth in the Earth. The variations of compressional and shear-wave velocities, density, pressure, compressibility, rigidity, anelasticity and temperature, as functions of depth are derived from or constrained by seismic data. In addition, the distribution of earthquakes in terms of location, depth, time and energy released is a direct indication of the tectonic deformation presently occurring in the Earth's crust and upper mantle. Assuming a seismic activity in the Moon roughly equivalent to that in the Earth, it can be expected that a single instrument will detect an average of five or more seismic events per day. However, from a single observing point it will be possible to locate only a relatively small percentage of such events. By using a single three-component instrument it is possible to get a rough location from an event of sufficient size to produce clear arrivals of

TABLE I. — CHARACTERISTICS AND PRIORITIES ASSIGNED TO GEOPHYSICAL EXPERIMENTS CONSIDERED BY THE GEOPHYSICS WORKING GROUP FOR INCLUSION ON THE EARLY APOLLO MISSIONS

[All experiments are considered to be of major scientific importance and recommended for inclusion in the missions. All experiments are for inclusion in the LSEP except for the short array mode of the active seismic experiment which the astronaut will complete during his stay time on the lunar surface, and the gravity meter experiment which is recommended for the AES Missions.]

Experiment	Weight (lb)	Power (watts)	Size (cu ft)	Information rates (bps)	Astronaut time (min)	Mission 1	Priorities mission 2	Mission 3
Magnetometer/ particle detector	13	5	0.5	35	Small	2	2	4
Gravity meter	30	15 int @ 30% 5 cont	1.0	Small	Small	AES	----	----
Passive seismic (long period)	20	1 cont	0.7	350-800	Small	1	1	5
Passive seismic (short period)	5	1 cont	0.3		Small	Both modes	Both modes	3
Active seismic[a] (long array)	20	3-20 min	2.0	7000 real time recorder, slow read-out	Small	(b)	(b)	2
Active seismic (short array)	7	20 int LEM power supply	0.5	Return tape	45 max	3	3	----
Heat flow (without drill)	5	2 cont	0.5	Small	10	2	----	----
Heat flow[c] (with drill)	15	2 cont LEM power to drill	1.0	Small	30	3	2	1

[a]Readout variable; consistent with available telemetry.

[b]Long and short modes if weight is available, otherwise short array mode.

[c]One meter holes drilled by astronaut.

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compressional, shear, and surface waves. With a single-component instrument (e.g., vertical) it is not possible to determine azimuth. A net of three or more instruments, properly spaced, greatly facilitates the accurate location of an earthquake and makes it possible to use a larger percentage of recorded events for detailed studies.

In addition to the arrival times of discrete phases, the spectral content and dispersion of body waves (compressional and shear) and surface waves (Love and Rayleigh) can be used to study the physical properties of the Moon. Generally, lower frequencies contain information averaged over a greater depth. Free oscillations, which can be considered as the low-frequency limit of free-traveling Love and Rayleigh waves, may be generated by the largest moonquakes. If the lower modes of the free oscillations are observed, they can be used to determine the properties of the whole Moon. Such modes should have a lowest frequency of about 1/15 cycle per minute. Tidal forces, principally from the Earth, produce forced deformations of the Moon whose largest amplitudes have a period of about 28 days. Accurate determination of the amplitudes and phases of tidal tilts and variations in gravity can, in theory, be used to determine the average elastic properties of the Moon (Love numbers) and the tidal dissipation. Predicted values of these amplitudes for reasonable lunar models indicate that such measurements would require very high precision and stability to differentiate among the various models, and it will be difficult to achieve this in the lunar environment.

Under favorable circumstances with respect to epicenter locations, a single instrument located near the border between a mare and a highland can identify a possible lunar crust and crustal differences between these regions, principally through the use of surface wave dispersion.

In the event that there are no large moonquakes (this observation in itself would be of fundamental importance), meteorite impacts, spacecraft or booster impacts, or large explosions can be used to provide seismic energy.

Proposed LSEP Passive Seismology Experiment

A single short-period (1/2 to 1 sec natural period) vertical seismometer weighing about 5 lb and a three-axis, long-period (10 to 15 sec natural period) seismometer of about 20 lb total weight are proposed for the LSEP. These instruments should have as high an ultimate sensitivity as can be obtained within weight and power constraints. The short-period instrument should be independent of the long-period system to provide a backup for the more complicated long-period system in addition to giving high-sensitivity short-period data. Remote caging of the inertial masses and remote calibration should be provided. The long-period instruments will have sufficient sensitivity at ultra-long periods to detect tidal gravity and tilt variations although it is unlikely that useful geophysical information will be obtained from them because of limited sensitivity and temperature control. At 15 minutes (gravest free mode) the long-period instrument will have a minimum detectable signal of 10 mm or less. For shorter periods the minimum detectable signal will decrease at 12 db/ octave or more, making the detection of low-order modes quite feasible.

The bit rate required is 350 bps. However, with this bit rate it is possible that a significant amount of high-frequency data will be lost. A desired bit rate of 800 bps would permit signals up to 20 cps to be recorded from the short-period vertical.

Following is a list of suggested seismometer parameters:

Free period: 3-axis system seismometers, 10-15 sec; short-period single-axis seismometer, 1/2-1 sec.

Damping: (near) critical for long-period; critical or over-damped for short-period.

Transducers

Displacement for signal from three-axis system with damping and mass position feedback servo through velocity transducer; velocity transducer for single-axis seismometer.

Frequency Response

DC - 2 cps, divided into two bands for three-axis system; 20 cps to 5 cps low-pass for single-axis system.

Dynamic Range and Distortion

80-db range analog with amplitude distortion less than 10%. Resolution (minimum detectable ground motion):

Short-period band: 1 millimicron or less (displacement)

Mid-period band: 10 millimicrons or less (displacement)

Long-period band: about 50 microgals or less (acceleration)

Each band to be fitted with a magnification control, available on command, and a threshold indicator.

Calibration

Step-force calibration signal available on command.

Power Consumption

1 watt or less continuous; 3 dc levels regulated under 28 volts.

Approx. 1 watt-hour for initial leveling (e.g., 1/4 amp 12 volts, for 20 sec).

Distance for power transmission: 10-20 ft.

Peaks: Pyro battery one time only, if needed.

Level Accommodation

Three-axis system: Servoed leveling screws are preferred to gimbals, if feasible, to accommodate 10^{o} or less. Automatic rough level probably is not required since instrument will be rough-positioned manually. Masses will be continuously servoed to zero by feedback of processed transducer 'error signal'; gross corrections by mechanical adjustment actuated by error signal or by command.

Single-axis system: 15°

Caging

Instrument cage and uncage available on command for protection during transport and noise check.

Temperature and Environment Tolerance

Long-period system: Thermal shielding and, if necessary, active internal temperature control must be provided so that internal temperature variation is within tolerance required by mechanical and electronic components. Operation in vacuum or near vacuum preferred.

Short-period system: Must be capable of operating over ambient lunar temperature cycle with little or no passive thermal insulation.

Radiation tolerance as dictated by future studies.

Weight and Volume

Using the already developed Lamont and Caltech models as a basis, it is estimated that the entire passive seismic package would weigh less than 25 lb and be about 1000 cu in. in volume, exclusive of heat screens and power supply.

Telemetry

Central multiplexer-AD converter for all experiments is desirable.

Range - three-axis system: 80-db analog
single-axis seisometer: 80-db analog

Sample rate - three-axis: 3 channels, 5 samples/sec, each sample 10 bits; 3 channels, 1 sample/sec, each sample 14 bits
single-axis: 1 channel, 40 to 10 samples/sec, each sample 14 bits; engineering channels, less than 18 bps total

total system: 800 to 350 bps.

HEAT FLOW MEASUREMENTS

The measurement of heat flow from the interior of the Moon provides one of the most important numbers that can be obtained from geophysical experiments at a single site.

The heat flux from the interior of a planetary body depends on the past thermal history, the distribution and strength of heat sources and the mode of heat transfer inside the body. Hence, a measurement of heat flow sets limits on compositional and physical models of a planet's interior. Heat flux measurements on the Moon will be of particular interest for two reasons:

1. The Moon has a smaller volume than the Earth so that a heat-flow measurement will "feel" deeper into the Moon.

2. Comparisons between the average heat flow for the Earth and the Moon will yield important information about the similarity of internal composition, the relative ages of the two bodies and their origin.

If samples collected from the surface are representative of the near-surface layers of the Moon, then measurements of the radiogenic heat production in these samples combined with heat-flow measurements may decide the important question of whether the material in the lunar interior is now differentiated. Lastly, comparisons between measurements in the maria and in the highlands may indicate significant differences in the composition of the rocks beneath these features.

An early start on heat-flow measurements is desirable, since the validity of the determination will ultimately depend on measurements at other sites. Therefore, an experiment to measure heat flow from the Moon's interior is given high priority among geophysical experiments to be carried out on the lunar surface in early Apollo missions.

Sydney Clark and Marcus Langseth have concluded, from a study, that the best approach to the problem is to use essentially the same technique as that used on the Earth's surface, namely to measure the temperature as a function of depth and time to determine the steady-state vertical temperature gradient. In situ conductivity measurements are to be made at several depths. The steady-state heat flow is the product of the gradient and the conductivity.

The subsurface temperatures and conductivities would be measured at regular intervals throughout the observation period. In this way the propagation of surface fluctuations downward as well as the dissipation of any thermal disturbances caused by implanting the temperature probe can be monitored. These transient disturbances will not only have to be removed from the observations to obtain the steady-state heat flow but will also yield thermal diffusivity in situ. Variations of conductivity with temperature will be determined in situ by making periodic measurements.

The drilling capability anticipated for the early Apollo missions limits the measurements mentioned above to a depth of about 1 meter below the surface. The validity of a heat-flow measurement at such a shallow depth must be examined later because of several possible disturbances. Some of these disturbances are known from Earth-based radiometric measurements, and their effects can be estimated. Pertinent observations are:

1. Large amplitude fluctuations of the surface temperature (120° K to 400° K) occur during a lunation.

2. The lunar surface cools very rapidly when solar radiation is cut off. The rapid cooling indicates the surface material

has a very low thermal inertia (about 5×10^{-6}), which implies a low thermal conductivity. With reasonable assumptions it is estimated that only 1 percent of the incident solar energy is transmitted inward as heat; therefore the very large fluctuations at the surface are rapidly attenuated with depth. These fluctuations can be removed from the observations.

There are several possible disturbances of the steady-state heat flux which we cannot estimate at the present time: (1) lateral inhomogeneities of conductivity in the near-surface material; (2) lateral variations in surface heat flux caused by changes in emissivity, thermal inertia or topography. The recent photographs of maria by Ranger indicate rather uniform surface conditions. Other data brought back from the Apollo missions will help toward a better evaluation of the effect of these disturbances.

A second method to measure heat flow has been considered in which a disc, or blanket, thin in relation to its radius, with known thermal properties is placed on or below the surface. The heat flux is obtained from a measurement of the temperature gradient through the disc. The ideal material for such an experiment would have properties that match those of the lunar surface materials. However, for materials with conductivities of 10^{-4} cgs, or greater, steady-state temperature gradients expected from estimates of the lunar heat flow (3×10^{-7} cal/cm^2 sec) would be 3×10^{-3}° C/cm or smaller. The very large transient noise will make this value hard to measure with precision over a thin blanket. For conductivities less than 10^{-4} cgs, the time required for the disc to approach thermal equilibrium is greater than a year — the planned period of observation. Regardless of these apparent difficulties, studies should, however, continue on this method of measurement. If the surface is not suitable for easy implantation of a vertical array of sensors, then an alternative technique would be available.

The conclusion of the working group was that the heat-flow experiment, as envisioned, has sufficient prospect of success to be included among the first geophysical measurements attempted on the Moon. Furthermore, the determination of the temperature gradient will be an invaluable aid for the interpretation of both the ground-based and lunar-orbiter passive microwave observations.

It has been emphasized by the group that the probability of a successful measurement would be greatly enhanced if a drill capable of making a 1 meter hole in solid rock, specifically for heat flow, could be carried on some missions. This drill would be operated by the astronaut using power from the LEM vehicle. 1200 watt-hours of dc power have been proposed for the descent stage of the LEM for surface operations. This would be ample power for a drill. The working group strongly recommends that the 1200 watt-hour capability be left in the design of the LEM. The development of a drill to make holes specifically for heat-flow measurements would be easier than the development of a drill to obtain samples (already under development). The present state of drilling technology is sufficient to develop such a drill for use in early Apollo missions.

The inclusion of a drill in the heat-flow experiment would increase the weight to 15 lb and the demand on astronaut's time to 20 minutes. After considering the value of the heat-flow measurement in relation to other geophysical experiments, the special heat-flow drill was given a relatively low priority for the first mission. However, on the last two missions of early Apollo, the drill was given a higher priority to insure getting at least 1-meter measurement.

Lastly, it was noted that a drill may not be required if sufficiently deep cracks in the lunar surface could be found near the site. The astronaut should be instructed to utilize such opportunities.

Specifications for the early Apollo missions are:

Weight:	5 lb without drill
	15 lb with drill
Power:	2 w continuous
	1400 w for 10-20 min with drill

Volume:	0.5 cf without drill 1.0 cf with drill
Information rate:	1.5 bps
Astronaut time:	10 minutes without drill 20 minutes with drill

MAGNETIC STUDIES

It is desirable that measurements of the magnetic field and related phenomena be made early in the schedule of lunar investigations. Direct measurements by Lunik II indicate that the lunar magnetic field cannot exceed 100 gamma at 55 km, but the observations of IMP-1 show a magneto-hydrodynamic wake of the Moon's interactions with the solar wind and suggest a compressed lunar magnetic field of several hundred gammas or more.

The existence and nature of the lunar magnetic field must be known to design subsequent magnetic exploration experiments and to predict the interaction of the solar wind with the Moon and thereby predict the particle and field environment to be expected on its surface. It has been proposed that if the Moon has no inherent magnetic field it can accrete one from the solar wind and that this field would "leak" from the dark side. Measurement of this "leakage" can give a measure of the gross electrical conductivity of the Moon.

Measurement of the magnetic field from IMP satellites orbiting the Moon will give some indication of its gross nature, but because the shock wave and magnetopause produced by the Moon are likely to be below the IMP perigee, it is suggested that the lunar magnetic field be measured within a few tens of kilometers of its surface, perhaps on Lunar Orbiter flights or from the Command Module during the stay-time of the early Apollo missions. The low-altitude stipulation would also allow measurement of a field which originates in some multipole mechanism of a higher order than a dipole, and might therefore decrease much more rapidly with distance from the center of the Moon than we expect. A polar flight would provide the most complete coverage.

Surface magnetic observatories spaced widely along the equatorial belt are needed to determine the interaction of the solar wind and the magnetic field. The operating periods of at least three observatories should overlap, requiring lifetimes on the order of one year.

All the above measurements can be performed by an instrument similar to the IMP magnetometer, a triaxial vector instrument with a dynamic range of several hundred gammas and a sensitivity of fractions of a gamma with appropriate analog-to-digital conversion subsystems. This instrument weighs 7 lb and uses 5 watts of power. The bit rate will depend on the requirements of the Particles and Fields studies, but will be low (not more than a few hundred bits per second).

The magnetic properties of samples returned from the Moon should be measured. It is probable that some or all may exhibit permanent magnetism and that from this "magnetic memory" some idea of lunar magnetic history can be obtained. Ideally all such samples should be oriented and returned to Earth in containers which would shield them from all ambient magnetic fields including that of the Earth. In our opinion these constraints are impractical on early Apollo missions but can be incorporated in AES studies after the early results define the necessary limitations. Lunar magnetic history can be determined best from oriented drill core or oriented samples from outcrop, but some significant information on recent magnetic history might be obtained from remanent measurements on oriented samples of surface rubble.

In summary, we recommend the following:

1. Measurement of the lunar magnetic field from Lunar Orbiter or Apollo Command Module flights.

2. Lunar magnetic field measurements from surface observatories incorporated in the LSEP package.

3. Measurement of magnetic properties of returned samples. Although orientation and magnetic shielding of the samples are desirable, they do not seem practical for early Apollo missions.

ACTIVE SEISMOLOGY STUDIES

Determination of physical properties of the lunar surface and interior to varying depths is the basic scientific objective of an active seismic experiment. (An active seismic experiment differs from a passive experiment in that the seismic source and receiver are controlled.) The scale of an active experiment depends on the depth of penetration desired which is approximately proportional to the distance between the seismic source and most distant receiver. We shall discuss two active seismology arrays for early Apollo missions which vary from a scale of several meters to hundreds of meters. Most instrumental and some operational aspects are common to both.

Since the original lunar surface may be buried to an extent not directly accessible to the astronaut, an active seismic experiment may provide the only data to properly interpret the surface and near-surface features of the Moon. Data on the thickness, strength, and variation of physical properties with depth in a possible surface fragmental layer is pertinent to a full interpretation of the fine structure of the lunar surface and the processes which have led to its formation. It is quite possible, of course, that exposures of subsurface strata might be directly visible to the astronaut in crater walls or on long scarps on the Moon but an active seismic experiment allows an extrapolation to inaccessible regions.

Refraction velocity data are interpreted in terms of layer thickness and the variation of elastic constants with depth. On a finer scale, the degree of induration of the near-surface materials and the surface bearing strengths may be inferred from refraction data. Active experiments must be used to obtain information concerning the lunar interior if passive seismic experiments indicate that the Moon is seismically dead. The engineering characteristics of the lunar surface are important because of their effect on future systems designs and execution of post Apollo missions.

As presently conceived, the short seismic refraction array experiment proposed for use on early Apollo missions will consist of a minimum of three detectors forming a linear array about

300 feet in length. The anticipated depth of penetration is about 75 feet. The energy sources will be a small squib- or spring-activated piston deployed and activated by the astronaut. The data will be recorded on magnetic tape to be returned to Earth. However, it is also possible to record the data for later slow playback and direct transmission to Earth. This experiment will weigh about 7 lb, but could require up to 45 minutes of astronaut time on the lunar surface.

The larger scale active seismic experiment proposed for early Apollo missions differs in that the seismic sources would be deployed automatically in varying distances along a linear array up to 1.5 km from the detectors. The experiment will weigh about 20-25 lb; the apparatus for automatically deploying the seismic sources accounts for about 15 to 18 lb of the total weight. A minimum use of astronaut time (2-4 minutes) is required.

It is recommended by the Geophysics Working Group that the active seismic experiments be given third priority on the first two flights of the early Apollo missions. If weight and astronaut time permit, it is further recommended that both the long- and short-array experiments be conducted on Missions 1 and 2. If weight is at a premium, only the short seismic array should be executed. On Mission 3 of the early Apollo program, the long active seismic array is ranked priority 2. Because many of the features of the long- and short-array experiments are common to both, it is recommended that development continue on both experiments.

During the meeting of the working group, the modular concept of experiments within the LSEP was stressed. In the context of modular design, long and short arrays can be considered as different modes of a single experiment operating singly or in concert, depending on constraints of weight and astronaut time. In particular, detectors (geophones or piezoelectric accelerometers), recording amplifiers, cables, magnetic tape recorder for recording and/or slow playback, seismic sources, and relative time generator can easily be utilized by both the short- and long-array experiments.

To implement the modular concept of two active seismic array modes for the early Apollo missions, it is recommended that the short-array experiment be also placed in Category I by the Planetology Subcommittee of the Space Sciences Steering Committee.

The instrument specifications and power requirements of the short- and long-array modes of the active seismic experiments are given below:

Common Instrumentation

Amplifiers:

Dynamic range	60-100 db
Input noise	0.01-0.1 microvolts maximum
Pass band	1/2-300 cps
Weight	8 oz (estimated)
Power	2 watts for 20 minutes (estimated)

AVC or logarithmic compression required down to 40 db

Tape recorder:

Dynamic range	40 db
Weight	2 lb
Number of channels	4
Playback speed	1-7/8 ips
Power	16 watts start
	12 watts record; 30 seconds per shot

Transducers:

If geophones are used:

Weight	2 oz
Natural frequency	5-15 cps
Damping	0.6 of critical
Sensitivity	0.5 v/in/sec

Environment: lunar

If crystal accelerometers are used:

Weight	1 oz
Bandpass	4-15 000 cps

Environment: lunar

Control unit:

The control unit module would contain a programmer, a range signal generator, a time break radio receiver, and a relative time clock. The relative time recorder can be excluded if the recorded seismic data are transmitted in real time. Estimated weight of control unit is 1 lb. 3 watts of power for approximately 20 minutes are required.

Three hundred feet of approximately 28 gauge cable, possibly shielded, are required. Estimated weight is about 2 lb.

Special Instrumentation for Long-Array Profile

A mortar package for automatically deploying the explosive charges is used.

Weight	15-18 lb
Power	28 volt, 2 amp for a few milliseconds
Dimensions	4 x 8 x 18 inches (estimated)
Environment	lunar

Short-Array Energy Source

A thumper, consisting of a mechanical or squib actuated piston which strikes the lunar surface, is enclosed in a staff which the astronaut presses against the lunar surface to insure good coupling. Total weight is 2 lb.

Telemetry Requirements

If the seismic data are transmitted in real time, 7000 bps per shot for 30 seconds of recording are required. This assumes one channel at 40 db dynamic range and 500 cps bandwidth. More channels can be used if greater compression and/or more smaller bandwidth are acceptable. For the long array the data will be stored on magnetic tape for later transmission at a much lower bit rate (200-300 bps). It is currently anticipated that the data obtained from the short array experiment would be recorded on magnetic tape to be returned to Earth by the astronaut, although this is not a stringent requirement and the data could also be later transmitted at a lower bit rate.

PHYSICAL PROPERTIES

Data on the physical properties of lunar material are needed for the interpretation of field observations. Densities of the near-surface rocks are required for the reduction of gravity traverses. Velocities of elastic waves will be needed to interpret the seismic data of the lunar interior. The dielectric constant and emissivity of surface materials are needed to make the best use of available "field data" on the electromagnetic characteristics of the Moon. Similar statements hold for the other physical properties.

The necessary backup data may be obtained by measurements in situ or in the laboratory on either actual lunar samples or Earth materials that simulate lunar materials. Measurements of many properties are best made in situ—e.g., dielectric constant, albedo, thermal conductivity, and density. For others, such as the elastic and anelastic properties, measurements under controlled conditions in the laboratory are best. Because much can be learned in the laboratory, even for those properties best measured in situ, we recommend that physical properties be measured in the laboratory on Earth materials that simulate lunar materials and on returned lunar samples, and that some properties be measured in situ. A list of the important properties is given in table II.

Measurements of the physical properties of the returned lunar sample that are important to geophysicists require (1) that representative samples be obtained from both the debris and solid material (if any), (2) that at least the top piece of any core be oriented, (3) that a few oriented samples be obtained for measurement of magnetic properties, and (4) that the surface of a few samples be preserved (if possible). Depending on the strength of the lunar magnetic field, it may be desirable in the AES program to return to Earth a few samples in a magnetically shielded box. Size requirements are shown below:

Property	Ideal size (inches)	Minimum size (inches)
Elastic	4×4×4 Solid	1-1/2×1-1/2×1 Solid
Thermal	1-1/2×1-1/2×1 Solid	1×1×1/2 Solid
Magnetic	1-1/2×1-1/2×1 Solid	Powder
Electrical	1-1/2×1-1/2×1 Solid	Powder
Optical	4×4×4 Solid	Powder

Methods used to measure these properties are nondestructive (in the usual sense) except that the material must be shaped for some measurements. It is recognized that the shaping operations will ruin the material for some experiments, e.g., measurement of content of rare gases. Therefore the following recommendation is made: that a group be established within the structure of NASA,

TABLE II

MEASUREMENTS OF PHYSICAL PROPERTIES

Property	*In situ*	In lab on Earth material	In lab on returned lunar sample	As function of pressure	As function of temperature
THERMAL					
Conductivity[a,b]	x	x	x	x	x
Diffusivity[a,b]	x	x	x	x	x
Expansion			x	x	x
Radioactivity	x	x	x		
Specific heat		x	x	x	x
Emissivity[c]	x	x	x		x
ELASTIC					
Velocity (P)[b,c]	x	x	x	x	x
Velocity (S)[b,c]	x	x	x	x	x
Compressibility[b,c]	x	x	x	x	x
INELASTIC					
Q[b]	x	x	x	x	x
Creep[d]		x	x		x
Mechanical strength[d]		x	x	x	x
ELECTRICAL[c]					
Dielectric constant	x	x	x	x	x
Resistivity	x	x	x	x	x
Emissivity	x	x	x		x
Attenuation	x	x	x		x
Velocity	x	x	x		x
MAGNETIC					
Remanent Magnetization	x	x	x		x
Susceptibility	x	x	x		x
Curie point		x	x		
B-H curve		x	x		x
OPTICAL[c]					
Albedo	x	x	x		x
Emissivity	x	x	x		x
MISCELLANEOUS					
Density	x	x	x	x	
Porosity	x	x	x	x	
Permeability	x	x	x	x	

[a]Including thermal radiation.

[b]Including effect of composition and water content.

[c]At various frequencies.

[d]At various rates of loading.

consisting of one representative from each of the working groups of the Manned Space Coordinating Committee, to schedule measurements by the various experimenters on the returned lunar samples.

GEOPHYSICS ON AES MISSIONS

The working group emphasized the AES missions in its deliberations because of the narrowing lead time for this program and the reasonably well defined constraints. Missions with greater capacity were discussed briefly from the point of view of what could be done with a greatly enhanced weight (and traverse) capability. These require different delivery systems and modes involving major commitments of resources. Before recommending such programs the working group felt it needed to review priorities for lunar exploration in the overall context of a rational program for planetary exploration.

The AES missions offer a much augmented capability for lunar exploration. ESS (emplaced scientific stations), traverses to distances of the order of 10 km, satellite observatories at the end of traverses—these are all possible with AES. The emplaced observatories have a weight and data rate capacity which permits inclusion of essentially all station type geophysical observations. Heat-flow measurements are not only assured (because of the drilling capacity), but their precision is extended by the greater depths at which temperature observations are made and the larger number of holes that are available for logging.

Traverses in "golf cart" type vehicles make possible the study of gravity and magnetic anomalies associated with local and regional geophysical structures. Regional boundaries can be crossed and the associated anomalies studied, especially if the traverses are normal to structural boundaries. Active seismic experiments with profiles 10 km long (penetration of several kilometers) are possible. "Horizontal logging," i.e., the simultaneous and automatic measurement of many physical properties, and natural and induced fields can be carried out by towing a comprehensive logging package behind the vehicle.

At the end of the traverse a satellite ESS which survives for one or more years can be off-loaded and set up by the astronaut. Each AES landing site can thereby become a triangular array some 10 km on a side. This greatly augments the capability of passive seismic experiments to define the interior, allows for reversed active seismic profiles, and strengthens the heat flow, magnetic, and lunar atmospheric experiments.

The following list is a preliminary priority ordering of the AES mission so far as the geophysical experiments are concerned.

1. Central ESS package (all can be done, no ordering of component experiments needed)

   Absolute gravimeter
   Tidal gravimeter
   Passive seismic
   Magneto-telluric-particle-field
   Heat flow in 10 ft hole
   Lunar atmosphere
   Micrometeoroid and other experiments

2. Drilling and borehole logging of 20 ft hole at central site

3. Traverse 1 with

   Surface logger and electromagnetic sounding probes
   Sample collection
   Gravimeter

4. Satellite ESS package no. 1 with

   Passive seismic
   Magneto-telluric-particle-field
   Heat flow in 10 ft hole
   Lunar atmosphere

5. Drilling and borehole logging of 10 ft hole at first satellite site

6. Traverse 2 with

   Equipment of traverse 1
   Active seismic

7. Traverse 3 with

   Equipment of traverse 1

8. Satellite ESS package no. 2

   Same as satellite ESS no. 1

9. Drilling and borehole logging of 10 ft hole

10. Traverse 4 with equipment of traverse 1

11. Satellite ESS package no. 3

    Same as satellite ESS no. 1

12. Drilling and borehole logging of 10 ft hole

The following notes pertain to the ordering of AES mission.

1. If overall mission is curtailed, satellite ESS packages should be off-loaded rather than individual experiments.

2. The central ESS package has highest priority. Next priority goes to traverse with logging, sampling and gravimeter but no active seismic. This also carries first satellite ESS package.

3. Active seismic has priority over second satellite package which it replaces on the second traverse.

4. Surface logger and borehole logger are compatible, so output of each uses same amplifiers, recorders, etc.

A discussion of the component experiments for the AES mission follows. It is incomplete in that lunar atmospheric, micrometeoroid, and astronomical experiments are not discussed.

PASSIVE SEISMOLOGY-GRAVITY STUDIES

The AES should provide the capability for a much broader and more detailed program in passive seismology and tidal gravimetry than that possible for early Apollo. As mentioned in the report for early Apollo, the tidal gravimeter was recommended for inclusion in later missions, partly because of the difficult nature of the experiment and partly because of its large weight. The possibility of using the Moon and Earth as detectors of gravity waves by monitoring free oscillations and other gravity perturbations makes the long period seismometer-gravimeter an attractive experiment. Although a tidal gravimeter and a long-period vertical seismometer with a displacement transducer are, in principle, the same instrument, design details of present instruments are somewhat different because of the high shorter-period sensitivity required of the seismometer and the extreme stability required of the gravimeter. It is not unreasonable that for AES an instrument combining the best features of both types of instruments can be developed and, in fact, presently available instruments are now approaching this goal. It is feasible that a matched three-component seismometer-gravimeter-tiltmeter can be developed that would weigh not much more than the seismometer proposed for LSEP and require only a little more power for precise temperature control.

Three-component short-period instruments, similar to the vertical instrument recommended for LSEP, would provide data for particle motion studies at short periods and give azimuthal information on high-frequency body waves. Such instruments would be especially useful for studying near moonquakes, meteoroid impacts, and artificial events from an active experiment. Such an instrument might weight about 15 lb.

The traversing capability of AES can be used to establish an array of three or four seismometer packages. Such an array, in the form of a triangle (perhaps with a mid-point sensor) about 10 km on a side could be used to obtain the surface velocities of body waves and the phase velocities of surface waves. Such data can be used to obtain precise travel-time curves, to differentiate between body waves having different propagation paths from source to receiver and, eventually, to determine the detailed crustal structure in the vicinity of the net and a velocity-depth function for the Moon. Five or six of the arrays operating concurrently and distributed at sites carefully chosen in relation to geological provinces and active seismic zones would provide quite satisfactory synoptic coverage of the whole Moon.

Careful choice of instrument sites and firm implantation of the instruments can assure good coupling to the lunar interior, reduce the amount of active thermal control required, and reduce the likelihood of large thermally induced tilts. For example, the instrument package could be implanted in a permanently shaded area and/or covered with a thick layer of lunar rubble.

All band-pass, sensitivity, and dynamic range specifications should equal or exceed those given for the LSEP. Especially, the short-period instruments should have a high-frequency cut off of 20 cps or greater; and the tidal and free oscillation sensitivity should be much greater than that for LSEP. The weight and power required should be similar to that for LSEP with the additional weight, power and bit rate required for the two additional short-period instruments, somewhat better thermal control, and perhaps, a separate gravimeter.

MAGNETIC OBSERVATORY STUDIES

The magnetic observatory measurements proposed in early Apollo can be upgraded markedly in AES by a four-point installation at each site with coordinated measurements of the electric field. These magneto-telluric studies can detect coarse lunar subsurface layering of magnetic and electrical contrast. In addition they will supply the time-dependent magnetic variations needed to correct the magnetic traverse measurements. It is proposed that a three-component IMP-type magnetic observatory be implanted at each AES landing site and at the ends of three 8-km traverses approximately 120° apart or at least at the ends of two 8-km traverses at approximately right angles. Telluric current measurements should be made on a grid at all observatories and perhaps on the major grid formed by the observatories. The design of these grids can probably be selected best after the early Apollo results have been analyzed.

If samples from early Apollo exhibit permanent magnetism, oriented drill core and other oriented samples should be collected. These should be shielded from artificial ambient fields and from the Earth's field by storage in mu metal or similar containers. A series of such containers should be designed to meet different specifications of lunar magnetic field and magnetic rock properties and the appropriate container selected after the early Apollo mission has determined these values.

HEAT-FLOW MEASUREMENTS

Heat-flow measurements made on AES missions can be considered as an extension of the early Apollo experiments. The increased scientific payload delivered to the surface and longer astronaut stay time will permit more precise heat-flow measurements at four locations at each landing site. The objectives of the AES heat-flow measurements are:

1. Improve the determination of the average heat flow from the Moon as a whole. Local and regional variations of heat flow can be expected because of compositional variations, topography and subsurface structure. The precision of the value for the mean flux will become better as the number of measurements from different geologic environments increases.

2. Detect regional differences in heat flow between sites on the lunar surface. The heat flux from a mare site could differ from a highland site if underlain by rocks of different composition. Radically asymmetrical distribution of deep interior material would also cause regional variations in the surface heat flux. The detection of these differences, if they exist, would be of prime importance in studying the origin of the Moon and its major surface features.

3. Study areas of special geophysical interest. Based on results from early Apollo missions such areas might be: (a) sites of real or suspected contemporary thermal activity (volcanoes, outgassing zones or lava flows); (b) seismic belts; (c) a recent fault or meteor crater.

Continuous surface-temperature measurements along a traverse are also of interest. The results from these measurements give information on local variations in emissivity, conductivity and heat capacity. In a crude way they can be related to the porosity of the surface material.

It is feasible to measure the thermal inertia of the surface in several locations from the Local Scientific Survey Module (LSSM). Measurements of the rate of temperature loss after an area is shaded will give this parameter, which is a function of conductivity, heat capacity and density.

Small probes with temperature sensors can be used to measure the temperature gradient and thermal parameters in penetrable surface material such as dust or rubble. Results from these measurements can be used to (1) determine the mean temperature as a function of depth over a broad area and hence to determine heat flow; (2) provide ground-truth data for earthbound or orbiting microwave measurements; (3) determine average diffusivity at each location; (4) study local anomalies in the surface thermal regime.

The AES missions will have the capability of drilling several 10 ft holes. In holes to these depths, precise measurements of the heat flux can be made by placing temperature sensors and heaters for conductivity measurement in the hole. The elements are closely spaced (6 in. for the 6 ft hole). Temperature of these sensors would be telemetered to Earth at 3 hr intervals for a period of several lunations. These sensors would be incorporated in a logging cable or expendable probe which can be easily inserted into the hole and would be part of an instrument package (satellite ESS) which is to be set up near the hole.

At a single landing site it would be advantageous to have four holes, three at the end of traverses and the fourth near the landing vehicle.

To measure the surface temperature continuously the best technique appears to be a radiometric measurement of the optical temperature of the surface. This device would be carried by the LSSM and would measure temperature of the surface ahead of the vehicle. The thermal inertia measurements could be made with the same thermometer by utilizing the shadow of the LSSM.

The small probes to be used in the dust and rubble on the surface would be similar to the probes proposed for early Apollo. They would require a small self-contained detector, power supply and transmitter. The temperature data from these probes can be transmitted by line-of-sight telemetry to an ESS or to the landed vehicle.

Generalized specifications are as follows:

Experiment	Number of experiments planned per lunar landing site	Weight per experiment lb	Information rate bps	Astronauts time[a]
10 ft hole	4	5	6	Less than 5 min to install
100 ft hole	1	7	1	Less than 20 min to install
Small temperature probe	10	1	20	Less than 5 min to install
Surface thermometer	2	1	10	----

[a]Not counting drilling time.

ACTIVE SEISMOLOGY

Active seismic experiments on the Moon should form an important and integral part of the AES missions. Because it will be possible to drill at most a few sample holes on the Moon, we must rely on geophysical techniques to extrapolate to greater depths. Refraction velocity surveys can be used to study many important geological problems on the Moon, such as the subsurface relations between the maria and the highlands, internal layering within the maria, the existence and nature of isostatic compensation of topographic features, and the subsurface relations of wrinkle ridges, linear scarps and other tectonic features. The active seismic experiments recommended for the early Apollo missions are limited as to the areal and vertical extent of terrain examined. In the early Apollo missions, the depth of penetration attained is limited by the range of the mortar apparatus automatically deploying the seismic sources. The traverse capability on the lunar surface offered under the AES missions allows seismic refraction profiles to be conducted on the Moon which will form the bridge between the relatively short profiles planned for early Apollo (up to one mile) and extremely long range refraction profiles (100-1000 miles) which should ultimately be accomplished.

With the ability to execute traverses up to 8 km from the LEM Shelter, the surface and subsurface coverage can be greatly extended. The traversing capability would even allow continuous shallow refraction profiles to be executed. Rather than attempt continuous seismic reflection or refraction profiling the Geophysics Working Group recommends emplacement of one or more expendable geophone spreads out from the LEM Shelter and physical emplacement (shallow burial) of radio-controlled explosive charges along the traverse line for later controlled detonation. Within the AES framework, penetration depths up to 5 km could possibly be obtained.

The long-array active seismic experiment, as presently recommended by the working group, would be carried out in the following manner. As the LSSM (Local Scientific Survey Module) traverses away from the LEM Shelter, a cable (1200-2400 ft long) with attached geophones would be unreeled behind the roving vehicle. Six to twelve geophones spaced 200 feet apart appear to be optimum. This would give good subsurface coverage within the overall weight constraints of the LSSM, and allow good correlation between individual detectors. The amplifiers, recorder, time-break radio receiver and other ancillary electronic equipment would be located in the Emplaced Scientific Station (ESS). Explosive charges will be detonated at varying intervals beginning at the end of the spread out to the end of the 8-km traverse. This technique of refraction profiling will be used because it allows partial reversal information to be obtained by shooting in only one direction. The charges would be emplaced by the astronaut whenever he debarks from the LSSM. Expendable radio-controlled detonators would be used to detonate the explosive charges on command, once the LSSM has returned to the LEM Shelter. Since it is further planned to emplace short-period passive seismometers with telemetry capability at the ends of individual 8 km traverses from the LEM Shelter, these seismometers could also be used to record the artificial detonations. This would give limited subsurface coverage over distances of 16 km if charges were emplaced at the ends of individual 8 km traverses. Any holes drilled for core collection and geophysical logging and measurement purposes could later be used as shot holes once any desired geophysical measurements are made. Individual explosive charge weights would be in the range from 1/4 to 50 lb. Up to 250 lb of expendable explosives would be carried in the LSSM.

It is also recommended that shallow seismic profiles be conducted along individual traverses. Basically the same instrumentation developed for the short array active experiment on early Apollo missions would be used. However, different modes of operation appear feasible depending on the nature of the surface at the landing site, the length of traverse and the amount of astronaut time available. The detectors could be towed behind the roving vehicle or deployed by the astronaut when he debarks from the LSSM. The detectors might conceivably be attached to the vehicle to monitor extravehicular seismic energy when the vehicle has stopped. The seismic energy sources could be located in a walking staff module actuated by the astronaut or a thumper source could be affixed to the vehicle. It is also possible to do continuous thumping while the vehicle is in motion and to record the surface waves generated by the motion of the vehicle.

The basic equipment for the long array seismic experiment, i.e., geophones, cables, amplifiers, and miscellaneous electronics, would weigh about 50 lb. 250 lb would be allotted for explosives. The shallow (short-array) seismic equipment would weigh about 10 lb. The data would be stored within the ESS for later slow playback and telemetering to Earth at a low bit rate. The instrument specifications are generally the same as described in the active seismic experiments for early Apollo.

Because seismic reflection surveys require extensive subsurface coverage and subsurface velocity data for best interpretations, it is recommended that as of now no major effort be devoted to this technique during the AES missions.

TRAVERSE GEOPHYSICS

Surface Measurements of Gravity

Because the purpose and problems of measuring spatial gravity variations on the surface of the Moon do not seem to have been considered previously in adequate detail, this section attempts to provide the necessary background. Studies of tidal and other time variations of gravity are not included. The Geodesy/Cartography Working Group has adequately covered measurements made by means of an orbiter. We strongly endorse the orbiter measurements, which should define the figure of the Moon in considerable detail and resolve questions of broad-scale departures from equilibrium.

As stated by the Geodesy/Cartography group, analyses of orbital perturbations of lunar satellites can give the gravitational field of the Moon to harmonics of the 12th degree or higher. Roughly, this means that the limit of resolving power will be several hundred kilometers. In addition, gradient measurements, if they can be successfully made from orbiters, might extend the resolving power sufficiently so that surface features or anomalies about 100 km in diameter could be analyzed. Some of the most interesting gravity anomalies on the Earth, such as those of oceanic trenches, with a breadth of about 50 km, or the anomaly gradients at the edges of continents, would require more resolution than is obtainable from lunar orbiters. Furthermore, the scale of interesting features on the Moon extends to craters less than a kilometer in diameter and to riftlike valleys only 5 km in breadth. So the need to make surface gravity measurements is clear. The problems and possibilities are discussed in the following pages.

Lunar Gravity and Gravity Anomalies

Absolute Gravity: At least for purposes of instrument design, we need to consider the level of absolute gravity. Approximating the Moon as a sphere with a mass of 7.35×10^{25} g and a radius of 1735 km, we calculate that the gravitational field on its surface is 162.8 gals, about one-sixth that of the Earth. The steady tidal attraction of the Earth on the near side of the Moon reduces lunar gravity by about 3 milligals and increases it by a like amount on the far side. This tidal attraction will vary during the month because of the difference between the Earth-Moon distances at perigee and apogee and because of the librations in latitude and longitude. There are other perturbations from the Sun. Evidently the time variation will have to be monitored or calculated to eliminate it from the measurements of spatial variations. Because the main variation is slow it should present no serious problem; moreover, the tidal gravity experiment, if carried on during the same period, will provide excellent control.

A direct measurement of absolute gravity at an early stage of lunar exploration is not essential, but some means of obtaining relative gravity at distant, isolated landing sites is critically important. Inasmuch as it will not usually be possible to transport a gravimeter between such sites for making relative measurements, two possibilities emerge: (1) absolute measurements with a pendulum or falling body apparatus should be made at each site or (2) a gravimeter capable of referring gravity at each site to a reference base on the Earth should be developed.

Vertical Gradient and the Elevation Reductions: More important than the absolute gravity on the Moon is the vertical gradient just above the lunar surface. To obtain meaningful gravity data the relative elevations at all points of measurement must be determined with high precision, a task on the Earth requiring more effort than making the gravity measurements themselves. Again approximating the Moon as a sphere and taking the derivative of its gravitational field, we obtain 1.88×10^{-4} gal/m or 0.188 mgal/m, as the vertical gradient, compared to 0.309 mgal/m on the Earth. Thus the requirements for elevation control will be slightly less stringent on the Moon.

The other term in the elevation reduction is the Bouguer term and it depends on the density of topographic masses. Obviously, density measurements of a variety of samples will be needed. If Moon rocks have about the density of rocks on the Earth's surface, the combined Free Air and Bouguer reduction will be about half as large as on the Earth; in no case will the reduction be larger than on the Earth.

Relative elevations to a precision of 1 meter at points of measurement would allow gravity reductions to a precision of about 0.1 mgal; a 10-meter precision would permit reductions to about 1 mgal. We recommend a capability for 10-meter elevation control in general and 1-meter capability for relative elevations at points along a traverse.

The precision of terrain reductions is a little harder to define. Topographic maps even at a scale of 1/250 000 allow most Earth stations to be terrain corrected within about 1 to 2 mgal.

Gravity Anomalies: A gravity anomaly is the difference between measured gravity and a normal value; it reflects the difference between subsurface distribution of density and some density model. The Free Air and Bouguer anomalies calculated on the Earth refer to a normal value with a large latitude variation. Because of the slow rotation of the Moon the situation there is quite different. Pending the establishment of a reference figure for the Moon, however, Lunar Free Air and Lunar Bouguer anomalies could be established relative to an arbitrary fixed base and reduced by Lunar Free Air and Lunar Bouguer reductions, without regard to latitude and longitude.

Magnitude of Anomalies: Obviously, equal masses at equal distances will produce equal anomalies on the Moon and on the Earth. However, it is reasonable to expect that contrasts of density and of mass are even greater on the Moon than on the Earth. For example, some of the largest anomalies and steepest gradients on the Earth are caused by accumulations of porous sedimentary and volcanoclastic rock. The pore spaces are filled with water except very close to the surface, above the water table. Because of the lack of water, lunar ash or dust would have an even lower bulk density; the lack of ordinary sedimentary processes and a much smaller absolute gravity tend to work in the same direction, to make the bulk density lower. If ashy deposits have accumulated locally in depressions to depths as great as a kilometer or more, gravity anomalies of tens to hundreds of milligals may be expected in association with the deposits. Conversely the lack of anomalies indicating thick accumulations would be significant.

Other very large anomalies on the Earth are caused by nonporous rock bodies of contrasting mineral composition and density, such as granite and gabbro. If Moon rocks are equally heterogeneous on a similar scale, either because of differentiation or accretion, anomalies of tens of milligals should reveal that fact.

At the boundaries of maria and continents, at mountain ranges, and at vast breaches like the Alpine Valley in the lunar Alps, large anomalies of tens to hundreds of milligals may reasonably be looked for and would yield much information on the internal structure and origin.

It is worth pointing out that lunar masses weigh only one-sixth as much as the same masses on the Earth, and this means that stress differences at comparable topographic or geologic boundaries are also only one-sixth as large as on the Earth. This suggests that gravity anomalies associated with masses supported by unrelaxed stresses may be much larger on the Moon than on the Earth.

The relaxation of stress by movement of atomic dislocations in crystalline material is highly temperature sensitive. If the temperature gradient in the outer hundred kilometers of the Moon is greatly different than in the Earth, correspondingly larger or smaller departures from fluid equilibrium are possible. There is thus some interdependence of gravitational and thermal models.

These lines of reasoning, and also the nonequilibrium figure of the Moon, indicate that we should not be astonished to find gravity anomalies an order of magnitude greater than those on the Earth. On the other hand, there are evident differences in the geologic processes—in erosion for example—that might work in the opposite direction.

Requirements for Instruments

Gravimeter

1. It should operate in a field of about 162 gals.

2. It should have a range of several thousand milligals.

3. It should be capable of measuring gravity differences to 0.1 mgal, assuming local elevation control of 1 to 10 meters can be obtained. For special purposes a precision of 0.01 mgal may be desirable, as outlined below under detailed gravity surveys.

4. It should have a stable, verifiable calibration. What is really needed is a capability to measure in two widely separated areas during separate landings and be able to refer the measurements to each other. A gravimeter capable of doing this might utilize added weights like a chemical balance and be calibrated on the Earth. Alternatively, absolute measurements on the Moon might be necessary.

5. It should be drift free or have linear drift.

6. It should be automated for lowering, leveling and reading.

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7. A stable base suitable for lowering from the lunar vehicle while it is stopped should be provided.

8. Power requirements, size, and weight should be minimal but not at the sacrifice of other requirements.

We strongly recommend that development of one or more alternative instruments with capabilities similar to those tabulated here be started as soon as possible.

Absolute or Earth-Reference Instrument: The necessity for establishing relative gravity between distant sites isolated from each other dictates the development of an additional gravity instrument for the Moon. Such an instrument would also be valuable for measuring or verifying the calibration of a gravimeter in the lunar field, if calibration emerges as a serious problem.

Pendulum and falling-body devices have been suggested. Desired accuracy is about 1 milligal. The possibilities inherent in the great range of vibrating string gravimeters should also be investigated to see if they might be designed to operate over the entire Earth-lunar range and still retain a precision of 1 milligal.

We strongly recommend that feasibility studies and instrument development be undertaken at once.

Problems for Investigation

It is probably not worthwhile to discuss all of the potentially valuable gravity studies, because gravity data should be collected on all traverses. The problem of first importance is to find relative gravity between large features such as the maria and highlands, and to define the gravity gradient across the boundaries. On the Earth, gravity tells us clearly and unambiguously that the total masses per unit area beneath continents and ocean areas are the same—it is the density that is different. The gradient tells us that the density difference is largely confined to the upper 50 to 100 km. What is the comparable situation on the Moon? Are the major topographic masses isostatically compensated, and if so, at what depth?

Examples of each of the major topographic features are also targets for gravity exploration: subsurface structure of maria, craters, mountains, and valleys, for example. In conjunction with the boundary conditions at the surface, i.e., the geology, rock densities, etc., gravity puts important constraints on the interpretation of subsurface structure and therefore on the origin of these features.

Detailed Gravity Surveys: The question arises, what is the smallest scale of topographic or structural features to which gravity might be applied? This can be illustrated in connection with the lunar dust problem. If the dust is only 1 meter thick and has a density contrast with underlying material of 1 g/cm^3, its gravitational effect will be 0.04 mgal, which can be measured but is negligible for most purposes. On the other hand, if the dust varies in thickness by an amount as great as 10 meters, a corresponding variation in gravity anomaly of 0.4 mgal may be expected, and therefore gravity may be useful for detecting this variable thickness.

In areas of low surface relief detailed gravity surveys with measurement accuracy of 0.01 milligals may make significant contributions to the study of geologic features buried at shallow depths on the lunar surface. With vertical control to 10 cm, which can be attained locally by hand levels, gravity anomalies of 0.01 milligals can be defined.

Spacing of Measurements: Spacing of measurements on a traverse may be close, say at 100 meters for the smallest features if adequate elevation control is practicable (1 meter). For most purposes a one-kilometer or one-half-kilometer spacing would be adequate. Vehicles must stop to make measurements.

Summary of Problems for Investigation

1. Highland—maria borders: subsurface structure, isostatic compensation, existence of a crust.

2. Internal homogeneity of density—are there large bodies of buried metal or differentiated rocks, for example?

3. Valleys, ridges: tectonic or superficial, accumulations on floors.

4. Subsurface structure of maria—depth and possible buried topography, edges.

5. Craters—superficial or deep, structure of central peaks.

6. Depth of lava or debris accumulations in depressions bordered by rocks of contrasting density, on all scales down to a few meters.

7. Engineering applications to "dust" layer, cavities, etc.

Summary and Recommendations

It is recommended that high priority be assigned to surface gravity measurements to investigate geologic structures and internal homogeneity of density on a scale that cannot be reached by a lunar orbiter.

For this purpose the development of a suitable gravimeter should be undertaken at once. Concurrently an instrument for absolute measurements or Earth-lunar relative measurements should also be developed.

It is important that the capability for elevation control to a precision of 10 meters or better be developed, and we endorse the recommendations of the Geodesy/Cartography Working Group to that end.

For local, detailed measurements along traverses, relative elevations of points of measurement may be needed to a meter or better. We recommend that a study be made of ways to achieve this precision.

The instruments, mapping capabilities and automated vehicles should all be compatible with requirements of longer traverses of 100 to 200 km or more if these become feasible in the future.

SURFACE LOGGING ON TRAVERSES AND BOREHOLE LOGGING

Continuous logging of both boreholes and surface traverses yields information on physical properties of rocks and some geophysical quantities that are obtainable in no other way. Borehole logging will use a sonde on the end of a cable; the surface logger will consist of an instrument head pulled along by a cable behind the astronaut's vehicle. It is desirable to examine the feasibility of combining these two sets of equipment.

On surface traverses, measurements that should be made with the logger include the following: temperature, magnetic susceptibility, magnetic field, electrical resistivity, neutron activation analysis, electrical impedance, self-potential, velocity of elastic waves, passive neutron, gamma-gamma scattering, and gamma-ray spectroscopy. A recording gravimeter with sensitivity and drift rate specified in the preceding section should be aboard the vehicle. The gamma-ray spectroscopy will be done only when the vehicle is stopped along a traverse for as much as 5 minutes. Continuous recording of the other quantities along traverses, together with the geologic data obtained from observation and point samples, will give control on the spatial distribution of physical properties. Simultaneous mapping of several fields (temperature, gravity, electrical, and magnetic), desirable for the interpretation of geophysical anomalies, will be done by the surface logger. Worth noting is the fact that the interpretation of geophysical data extends the depth of geologic observations. Continuous surface logging of parameters which require intimate contact of probe and the surface will be quite difficult. Construction of a many purpose logger should be attempted, recognizing that it may not be feasible.

An electromagnetic pulse probe, probably using a quite low frequency coaxial antenna dragged behind the surface vehicle as part of the logging package, may make possible automatic monitoring of subsurface discontinuities from depths of hundreds of meters to tens of kilometers depending upon the conductivity encountered. In addition to this "logging" type function, such a device with suitable separate receivers can be used in conjunction with seismic profiling to enhance the information obtainable from both types of experiment individually.

Another electromagnetic device also has promise for profiling the immediate subsurface. This is a UHF or VHF short pulse or chirping radar. Such a system has demonstrated on Earth the capability of measuring ice thickness of meters to a precision of centimeters and is likely to be able to profile the immediate subsurface of the Moon to a depth of some tens of meters. Besides its geophysical value, it might also be a useful detector of possible dangerous travel regions if its antenna were mounted forward of the vehicle, working much as a crevasse detector in the Antarctic.

Borehole logging of any holes that are available on the Moon should normally include measurements of temperature, thermal conductivity, magnetic susceptibility, electrical resistivity, electrical impedance (i.e., induction log), self-potential, neutron activity, gamma-gamma scattering (for density), and gamma-ray spectroscopy. Measurement of these parameters as a function of depth not only will be intrinsically valuable but will provide the basic data for use in correlation of possible stratigraphic units. This correlation will be valuable among the various boreholes at a particular landing site. Correlation between landing sites, although more uncertain, should be attempted.

At each borehole some "permanent" equipment, complete with telemetry link to the central station, will remain after the astronaut leaves. Temperature sensors will monitor temperature at several depths for several months to obtain data from which thermal diffusivity and heat flow can be determined. Small seismometers and explosives will be sealed also in each borehole. After the heat flow experiment is completed, the holes will be used not only as shot-holes for the active seismic experiment but also as detector sites. Development and special techniques will be required in order to use the same hole for a shot hole and detector site. The acoustical coupling is expected to be better at higher frequencies for borehole detectors than for equivalent instruments set on the lunar surface. Consideration should be given to use the surface vehicle on unmanned traverses after the astronauts have departed.

PHYSICAL PROPERTIES

During the AES studies there will be a continuing need for measuring physical properties in situ as well as in Earth-based laboratories. The same statements and recommendations made above in the section on physical properties in the early Apollo program apply equally well to the AES program.

Measurement of the attenuation coefficient and dielectric constant of the lunar surface material is quite important to interpretation of orbital and Earth based radar data. Experience in making such measurements on Earth indicates the desirability of in situ measurements to supplement the laboratory measurements on the returned samples, since the environment can have a major effect on these properties.

AES ORBITAL GEOPHYSICS EXPERIMENTS

Manned spacecraft orbiting the Moon give a significant opportunity to measure surface and near-surface geophysical parameters of the Moon. Proposed experiments may be divided into two general classes: (1) those providing information about structural variations at depths of kilometers and beyond, and (2) those providing information about structure and composition of the surface from depths of microns to a few meters. Because of the limited extent of lunar surface exploration possible in the near future, these measurements will provide the only means of studying these regions on a planetary basis for many years. Thus, they can provide useful additions to the deeper studies from passive seismology and the more local studies from fixed and traversing surface experiments. Because of their nature, however, they cannot provide information with the same precision and detail as the surface measurements. Orbital investigations offer the potential of defining local areas of the lunar surface with unusual properties which might be of interest for future exploration by landing parties.

ORBITAL INSTRUMENTS FOR DEEP PROBING

Three orbital instruments give promise for probing to depths of kilometers and beyond: magnetometer, gravity gradiometer, and electromagnetic pulse probing instrument. Each is treated in a separate section below.

Magnetometer

The Geophysics Working Group recommends feasibility studies on the geologic applications of magnetic field measurements from manned orbiting platforms. Recent studies have shown the existence of magnetic field anomalies having broad spatial wavelengths and large amplitudes which probably originate in the deeper portions of the Earth's crust or in the upper mantle. These amplitudes are still appreciable when extrapolated to altitudes as great as 200 nautical miles above the Earth's surface. Assuming that the external part of the magnetic field can be separated from the internal part, an orbiting spacecraft mapping the magnetic field would yield important information on the geology of the lunar crust.

Gravity Gradiometer

A gravity gradient experiment on an orbital spacecraft would yield some details of the variations in the Earth and lunar gravitational fields, yielding total coverage in a rapid and economical manner. We are not convinced that the estimated accuracy of $\pm 3\times10^{-11}$ gals/cm can be attained.

Electromagnetic Pulse Probe

Electrical conductivity of extremely dry igneous rocks, at least at moderate temperatures, is low enough so that one might expect penetration of an electromagnetic wave to depths of kilometers and tens of kilometers at frequencies in the region a decade or so on either side of 1 megacycle. A pulsed carrier at such frequencies, therefore, has the potential for probing to this depth and differentiating the various layers present. Such a measurement might be made continuously from an orbiter, so that profiles of the subsurface contacts could be prepared over the regions covered by orbiters. Interpretation of these would depend on adequate assumptions for the velocity of propagation, as with seismic waves.

The instrumentation for such a probe is quite simple, and the estimated power requirements are low, provided that the conductivities are indeed low enough for successful operation. Values for electrical conductivity of igneous rock on Earth are quoted from 10^{-3} to 10^{-9} mhos/meter. It is difficult to determine the value applicable to the Moon, but the lower values are normally associated with moisture-free rock measured in the laboratory.[1] The conductivity increases with increasing frequency, but values in the range 10^{-5} to 10^{-7} mhos/meter may be reasonable on the Moon. If so, the penetration will vary between a few kilometers and a few hundred kilometers, provided no layer with a near-unity reflection coefficient is encountered.

A suggested system would use a series of frequencies stepping from about 100 kc up to about 10 mc, with shorter pulses for the higher frequencies permitting better resolution of adjacent contacts. The lower frequencies, however, may be necessary for really deep penetration—in fact, frequencies well below 100 kc may be needed. This system is, except for the lower frequency end of the spectrum, similar to that flown for ionospheric sounding on the S-48 and programmed for the ISIS series of Earth satellites.

ORBITAL INSTRUMENTS FOR SURFACE OBSERVATIONS

Various instruments are currently being developed to examine the lunar surface at wavelengths from hundredths of an angstrom to about a meter. Passive instrumentation is proposed for all wavelengths in this range, and active radar is proposed for centimeter and decimeter wavelengths. Combining several of these

[1] G. V. Keller, "Electrical Properties of the Earth's Crust, Part 4, Electrical Properties of Dry Rocks at Elevated Temperatures," U.S. Geological Survey, Denver, 1962. A. D. Watt, Matthews, E. L. Maxwell, "Some Electrical Characteristics of the Earth's Crust," Proc. IEEE (June 1963)

sensors should permit determination, or at least inference, of many physical properties of the surface and near-surface layers. This information will be available over much, if not all, of the lunar surface. Furthermore, the various imaging sensors will permit determination of relationships pertinent to studying the origin and mechanics of surface features and the underlying structures.

Infrared and microwave radiometers may permit study of both detailed and planetary-scale heat fluxes through measurement of the temperature and its variation at and near the surface. The latter is particularly interesting in the terminator region where variations as a function of illumination give a key to the thermal properties of the surface materials.

Imaging radars at the longer wavelengths are sensitive to the region within a meter or so of the surface, and may be especially valuable in detecting buried features.

Gamma-ray, X-ray, and alpha-emission sensors are intended to determine various surface properties, especially chemical composition and natural radioactivity. In orbit these experiments can only give averages over wide regions (30-300 km) because their detectors are essentially nondirective. If sufficient intensities are encountered, resolution can be improved. IR spectral emission studies can give similar results over smaller regions of a square kilometer in area.

Microwave radiometers and radar scatterometers, especially when used together, can give information about the dielectric and thermal properties and roughness of the surface and near subsurface layers and these can be interpreted in compositional terms as well.

RECOMMENDATIONS

Deep-Probing Orbital Instruments

The working group recommends that high priority be assigned to magnetic surveys as a tool for studying the geology of the Moon.

This could be done by a low-orbit spacecraft provided that the magnetic field of the Moon proves sufficiently strong.

The Geophysics Working Group is in accord with the recommendations set forth by the Geodesy/Cartography Working Group regarding the gravity gradiometer. We recommend that instrument development be initiated to determine if sufficient sensitivity can be attained. In any event, development of an orbital gravity gradiometer would not eliminate the need for detailed surface gravity observations. (See comments in preceding "Traverse Geophysics on AES" section.)

Orbital use of the electromagnetic pulse probe can provide significant geophysical information, provided the conductivity of the Moon is sufficiently low. Further study of this concept is recommended; inclusion in an early orbital payload is recommended if the study results make success appear reasonably probable.

Surface-Observing Orbital Instruments

Imaging instruments, including UV imagers, cameras, IR imagers, and high-resolution radars, are now of demonstrated value for surface and near-surface structure and composition studies and for the study of thermal anomalies. Images with these instruments covering essentially the entire Moon are recommended for early flight. Once adequate coverage has been obtained, continuous repetition of the flights does not seem in order, although special coverage of interesting areas may be required. Thermal information from the IR imager available at different times of the lunar day may require additional flights with this instrument, and further study is recommended.

Nonimaging remote sensors, such as the passive microwave, radar scatterometer, IR, X-ray, gamma-ray, and alpha-particle emission experiments, are recommended for inclusion in lunar orbital payloads pending the results of the current Remote Sensor Feasibility Study. Some of the sensors (passive microwave, radar, and IR) have a long history of Earth-based use in lunar studies and the increase in surface resolution afforded by orbiting lunar vehicles makes these sensors prime candidates for early lunar orbiting payloads. Consideration should be given for inclusion of the temperature-sensitive sensors, particularly the passive microwave and infrared, on several payloads launched at times chosen to allow study of the lunar surface and subsurface at several phases of the solar insolation cycle. Gamma-ray experiments of a more sophisticated nature than those included on the Ranger vehicles are in an advanced state of readiness and should be included in an early lunar orbital mission.

Preliminary Calibration and Development

Development of many of the orbital sensors will require ground, aircraft, and Earth-orbital testing. Furthermore, extrapolation of interpretation to the Moon requires additional calibration tests using aircraft and subsequent development of interpretive techniques. Support on a continuing basis is recommended for such efforts.

GENERAL RECOMMENDATIONS AND COMMENTS

RECOMMENDATIONS RELATIVE TO SCHEDULES OF POST-APOLLO SCIENTIFIC LUNAR MISSIONS

Many factors influence mission schedules, including the fundamental quantities of timing, frequency, and number of flights. We addressed ourselves to consideration of basic scientific needs, such as lead time for the conception of ideas and experimental planning. Without such consideration, scheduling could limit utilization of knowledge gained in earlier missions to increase the success of the later ones. This situation may lead to (1) inappropriate and/or redundant experiments, (2) use of spacecraft hardware not fully tested or of less-than-optimum quality, and (3) conduct scientific experiments in a less than optimum sequence. Therefore, the Geophysics Working Group wishes to recommend the following:

1. For all post-Apollo lunar missions it is important that liaison with the scientific community be continual and thorough so that experiments will have maximum lead time for conception of equipment.

2. Schedules of post-Apollo lunar missions, beginning with the latter phases of the presently designated AES program and including new programs, such as ALSS and LESA, should be formulated after giving consideration to the results of scientific investigations performed by prior missions.

3. Spacecraft scientific payloads should be designed in modular form so that advantage can be taken of the preliminary scientific results of previous missions, except for the case of overlapping missions. By this means, interchangeable packages of flight-certified experiments would be available to make possible last-minute changes in keeping with the latest scientific advances.

4. The presently conceived AES flight schedules appear to represent a reasonable balance between orbiting and landing missions, as far as can be determined at this time. An upper bound to the spacing of missions is the requirement that the missions be separated in time to allow changes in the modular experiments dictated by information generated by a preceding mission. A lower bound is set by the requirement that missions be spaced frequently enough to allow for overlapping life times of the ESS.

REQUIREMENTS FOR DATA STORAGE AND EARTH-BASED TELEMETRY SUPPORT DURING LSEP OPERATION AND BEYOND

At least three distinct demands for data storage on the lunar surface during the period of LSEP operation have been considered. The Geophysics Working Group suggests that while two of these demands may be satisfied without data storage capability, the third demand warrants consideration of a tape recording unit of multi-megabit capacity as an integral part of the LSEP data subsystem.

The following arguments are predicated on the desire for full-time monitoring (at least in the early stages) of the experiments which constitute the LSEP. This coverage does not have to be in real time.

First we consider the high bit rate associated with the active seismic experiment (7 kbps). If an 85-foot Earth-based receiving dish can be employed at the time of this experiment (for a period of about 0.5 hour, at a time when there is no manned mission in progress), a data rate of 10.2 kbps is attainable and should satisfy the demands of this experiment. If this large dish is not available and some means of data recording must be used, a storage capacity on the order of 7-10 megabits would be required (7 kbps for each of 5 shots for 20-30 seconds each). Considering the flexibility in the time of initiation of the active seismic experiment, it seems reasonable to expect availability of the 85-foot dish.

A second consideration is the possibility that during the period of LSEP operation, real time examination of results might suggest that during observable periods of unusual activity, data be recorded at a higher rate which could exceed the capacity of the 30-foot Earth-based antennas. In such an event a buffer storage unit for excess data might be required. The Group feels, however, that the possibility of this demand being realized is small for those experiments considered in table I.

The third consideration is for some technique to help insure the full time monitoring capability for LSEP in the likely event that Earth-based antennas are not available on such a demanding schedule. Assuming an average bit rate of 500 bps, approximately 2 megabits would be accumulated by the LSEP in a single hour. One hour is important if it helps complete full time coverage; it is probably not too important if it changes the coverage time from 50 percent to 54 percent. The Group recommends consideration of a magnetic tape unit as part of the LSEP data subsystem. The capacity of such a unit should be consistent with the schedule of the Earth-based monitoring network in an effort to achieve full-time coverage.

The magnetic tape unit would be of considerable value even if it only survived some fraction of the total package lifetime. Obviously there would be a design requirement that in the event of failure of the data recording unit, the system would revert to the real time transmission mode. If engineering studies should reveal that such a unit is feasible but that its weight would account for a considerable portion of the LSEP payload, we would then consider the tradeoff of experiment payload versus real time monitoring.

It is further suggested that NASA give considerable thought to the establishment of an independent science network (3 stations) on Earth to support the increasing demands for bandwidth and time coverage during AES. The current bit rate limitation of 1280 bps will in the near future represent an unrealistic constraint on the design of scientific payloads. The prospect of sharing time on a network faced with the competing demands of an expanding program of manned and unmanned planetary exploration will soon lead to the untenable situation of the lunar and planetary scientific programs being molded to the constraints of the Earth-based reception system.

If one adopts the premise that increased telemetry capability will be needed in the 1970's, as seems inescapable from the above considerations, then planning and construction of the necessary facilities should begin immediately. A minimum of three 85-foot antennas would be required for continuous monitoring of lunar scientific stations. The economic considerations of erecting three 85-foot antennas are quite favorable when viewed in the light of (a) the present and future level of spending in the Apollo and the various follow-on programs, and (b) the increase in scientific data and experiment capability by a factor of 8 derived by changing from 30 foot to 85 foot antennas. Estimates of the expected bit rate for the Emplaced Scientific Station during the AES program seem entirely compatible with the near full-time 85-foot antenna coverage.

To set things in proper perspective it should be realized the construction of an 85-foot antenna in no way represents a major engineering challenge. Radio astronomers and NASA have been using such antennas since 1958. NASA is currently completing a 210-foot antenna for the Goldstone (California) DSIF station.

In view of the above, the following recommendation is proposed for consideration:

The Geophysics Working Group of the Manned Space Science Coordination Committee recognizes the limitations of the current data telemetry network for unmanned payloads left by astronauts on the lunar surface and sees future needs of both the manned lunar and planetary programs exceeding the current telemetry capability. Accordingly, the Geophysics Working Group strongly recommends the construction of a minimum of three 85-foot antennas to be placed and operated for continuous monitoring of lunar surface payloads, and that consideration be given to expanding the network beyond the minimum of three antennas.

A LONG VIEW

The geophysical yield from the early Apollo and AES missions will have major impact and will provide a fairly accurate picture of the Moon as a planetary body. However, major questions will remain unanswered (as is the case with Earth geophysics now). In the absence of results from early Apollo and AES, it is not prudent to plan a detailed follow-on program. Furthermore, large scale follow-on programs can only be evaluated in the context of the overall program of planetary exploration. However, some general ideas can be put forth in a preliminary fashion.

If the Moon is as seismic as the Earth, the observatories established during the early Apollo and AES missions will have provided information on the gross features of the lunar interior such as whether the Moon has a core and a crust and the approximate distribution of velocity and density with depth. Heat-flow probes will have determined the average heat flux at the Moon's surface and magnetic measurements will have revealed the nature of the Moon's magnetic field. The geologic observations together with geophysical measurements on the short profiles will have revealed many features of the lunar surface and the processes that are acting near the surface.

Between the two extremes of gross features and fine detail in limited areas, there are a number of important questions that may remain unanswered or partially answered: What is the structure and the origin of the lunar maria? How do the maria differ from the highland areas? What is the nature and the mechanism of isostatic balance on the Moon? What is the origin, distribution and structure of crystalline rocks? Are there batholiths on the Moon and, if so, what is their structure and composition? Does the Moon have radial symmetry? Does the back side differ from the front side?

In addition to their importance for understanding the Moon, the solution of these lunar problems will have a direct bearing on the solution of similar problems on the Earth.

Long range refraction profiling, integrated with gravity and magnetic profiling, will help to answer some of the questions above. If the Moon is aseismic, these measurements may be the only source of definitive information on the lunar interior.

SPECIFIC AREAS OF INTEREST

Seismic Refraction Studies

The answers to two basic questions are needed for the planning of refraction profiles on the lunar surface: What is the maximum sensitivity attainable by seismometers on the Moon and what is the efficiency of explosive and impact sources of seismic energy on the Moon. If we take the most optimistic guess based on our experience on Earth, the impact of a Saturn V payload would provide enough energy to study the Moon as a planet and the impacting of expended delivery modules would provide sufficient energy for profiles several hundred kilometers in length. At the other extreme, the source efficiency and background noise at the seismometers could make the experiment completely impractical.

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Studies of the seismic efficiency of impact sources in various media might be undertaken, together with the design of an appropriate seismometer package. The package would be distributed by traverse vehicles or dropped in probes from orbiters. Initial sources could be provided by impacting exhausted S-IVB stages. If these experiments were successful, a final shot into an extensive array of seismic stations might involve an entire Saturn V payload. These experiments would provide lunar travel-time data that would permit us to determine the structure of the Moon with a precision approaching that attained on the Earth.

Long Gravity and Magnetic Profiles

It is expected that a good definition of the large-scale features of the Moon's gravity and magnetic fields will be obtained from satellite data and the Apollo landings. However, we will not obtain details of the gravity and magnetic fields necessary to study the problems mentioned above. Information obtained from Apollo missions might enable us to design vehicles for long, remote-controlled traverses on the lunar surface.

Heat Flow

Early Apollo and AES missions will determine average heat flow at the lunar surface. Regions of anomalous heat flow on the Moon should be located and studied, if possible. These measurements might be relatively easy if suitable traversing vehicles are developed, or it may be feasible to implant large numbers of heat-flow probes from orbiting satellites.

Observatory Measurements

It may be desirable to increase the number and the life-time of observatories of the type established in the Apollo missions and to add more sophisticated instruments to these observatories. For example, we may wish to add instruments that measure change in strain, strain seismometers and local geodetic networks.

Detailed Studies of Specific Features

It may be desirable to conduct intensive studies of specific features such as major craters, volcanoes or mountain ranges. Dense networks of passive seismic stations coupled with seismic refraction profiles, gravity surveys and magnetic surveys would be involved in these investigations. Close coordination with geologic and geochemical studies would be necessary for solutions to these problems.

Recommendations

The experiments listed above are too complex to be undertaken in the first stages of lunar exploration, but they should be considered for the future.

Feasibility studies should be initiated and supported by NASA to determine if these experiments are appropriate for a later stage of lunar exploration.

N66-14830

REPORT OF BIOSCIENCE WORKING GROUP

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INTRODUCTION

The report and the recommendations by the Bioscience Working Group for the period July 23-30, 1965, constitute in part a reemphasis of the information and recommendations submitted in two previous reports (July 17, 1964 and February 26, 1965). It also includes new findings and additional recommendations with particular emphasis on areas in which there was some degree of agreement between the Bioscience Working Group and other working groups present at the conference. Most of this report is directed toward the bioscience objectives, methods and needs for Moon exploration beginning with the early Apollo missions. No clear distinction has been made or is intended between the Apollo program and AES program, except that at the end of this report a discussion specifically concerning the AES program is presented. The fact that no other clear dichotomy is indicated between Apollo and AES is intentional on the part of the working group in order to emphasize the difficulty in predicting the magnitude of bioscience involvement as the exploration of the Moon continues. In general, we can only predict that as long as different types of lunar samples from different locations will be available for examination, they should be studied by the bioscience disciplines.

BIOSCIENCE AREAS OF INTEREST

Specific identification of the areas of interest of the bioscience disciplines with regard to the lunar exploration program is appropriate in order that clear objectives and methods be established. For the purpose of this report we have chosen to classify these areas of interests as follows:

RESEARCH INTERESTS

These interests relate to basic or fundamental scientific studies to be done with returned lunar samples after release from quarantine, or to basic experiments carried out on or near the Moon's surface. They include research in the general area of organic or proto-organic chemistry and biological research dealing with intact living systems or identifiable segments of living systems, and evidence for the presence of past living systems.

The Bioscience Working Group wishes to emphasize and to make it clear that all possible bioscience fields and subfields are not represented by the membership of the present working group. We are particularly interested in increasing the representation of microbiology and are seeking to do so.

CONTAMINATION CONTROL ACTIVITIES

The contamination control activities considered by the working group included methods of minimizing biological contamination of the Moon and returned sample quarantine for the unlikely event that a back-contamination problem exists.

BIOSCIENCE OBJECTIVES AND METHODS

SCIENTIFIC OBJECTIVES AND METHODS

The general objective of the bioscientists during the exploration of the Moon is to employ their disciplines to the greatest extent justified in order to gain the maximum knowledge about the Moon and its relation to the Earth and to the universe. This objective derives from previously approved objectives set down by Apollo Science Planning Teams.

The specific objectives of the organic chemical exploration of the Moon involves the search for molecules of possible biological or prebiological origin. Detailed knowledge of the amount, distribution and exact structure of the organic compounds — if any — present on the Moon is of extreme importance in the search for answers to questions relating to the origin and history of the Moon, and to the relationship of the Moon to the Earth and to the universe. Specifically, such knowledge is essential for determining whether life on the Moon exists, ever did exist, or could develop. Since the organic chemical investigations used in attempts to answer these questions would be on a molecular level, the conclusions would not be dependent on the assumption of life and life-related processes as we know them. They, therefore, represent a broader and more general approach to the problem of detection of "extraterrestrial life" than is presented by direct culture or by wet-chemical, yes-no, life detection devices.

The analysis for organic compounds in the detail required for these studies involves the separation of minute quantities of organic constituents from the inorganic lunar matrix, separation of the ensuing mixtures by repeated processes (mainly by various types of chromatography) first into groups of components, such as acidic, basic and neutral constituents, polar and nonpolar ones, etc., followed by separation of each subgroup into the individual components. Since it is likely that many different compounds will be isolated by these methods, regardless of whether the organic material of the Moon originated with or without involvement of living cells, the amount of each individual compound will be extremely small, probably on the order of less than 10^{-6} grams per kilogram of original lunar material. Very sensitive techniques must be used to detect and determine the detailed structure of these components.

It should be understood that we employ the term "structure" to mean the exact arrangement of the atoms in the molecule rather than only the type of compound. For example, discovery of components with carboxyl and amino groups is interesting as such, but in relation to the problem of living matter and its likeness or difference in comparison with terrestrial life, it is necessary to determine if this particular compound is one of the usual amino acids. If not, it becomes important to determine the exact structure of this molecule and how closely it is related to terrestrial amino acids. (If suitably related one might suspect that lunar life could have originated from the same Primordial Sea after the first amino acids had been produced.) If compounds of a very different structure but still capable of peptide-bond formation are found (e.g., tertiary amines not found in terrestrial life), one could conclude that peptide-like macromolecules can be, or have been, involved in lunar living systems.

It appears that the state of the art in structure determination is reaching the level of sophistication required for this task. Mass spectrometry, in combination with other spectroscopic techniques such as ultraviolet spectroscopy, UV-fluorescence and infrared spectroscopy, is evolving as the method of choice. Both the sensitivity and general applicability of mass spectrometry (anything that can be vaporized at even very low pressures gives a characteristic mass spectrum which is related to the molecular structure of the compound) make it a particularly useful technique. Moreover, the interpretation of data does not require any prior knowledge concerning the nature of the material under investigation. For example, if organic compounds from lunar samples should turn out to be so dissimilar to terrestrial products as to not even be based on carbon, hydrogen, nitrogen and oxygen, but, to be extreme, to be based on silicon and fluorine, the mass spectrum would reveal this at a glance. The high reproducibility of the characteristic features of mass spectra provides an excellent opportunity to support initial interpretations by finally comparing them with the spectrum of the authentic substance.

If any organic material found in the lunar crust should at all resemble terrestrial compounds of biological origin then it would be of interest to compare the compounds found on the Moon with those encountered in geological formations of various eras in the Earth's history, such as early Precambrian sediments (ca. 2.7×10^9 years). This is a field presently being intensively investigated. In principle, such studies are similar to those to be done on lunar samples and are presently providing the testing grounds for further development of the techniques to be employed on lunar samples.

Several series of organic molecules of biogenic origin (biological markers) are currently employed to trace the origin and development of terrestrial life through geologic time. For example, (1) a number of isoprenoid alkanes, including pristane and phytane, have been isolated from ancient shales by chromatographic procedures and subsequently identified and characterized by mass spectrometry; (2) a series of steroid hydrocarbons, including the C_{23} and C_{29}-tetracyclic steranes, have similarly been isolated and characterized. The isoprenoid alkanes have served to provide the molecular fossils of their diagenetic precursor, the chlorophyll side chain (phytol) as evidence of the photosynthetic process. Steroid hydrocarbons must certainly demand enzymatic templates for their biosynthesis, thus confirming the implications of finding the acyclic hydrocarbons, pristane (2,6,10,14-tetramethylpentadecane) and phytane (2,6,10,14-tetramethylhexadecane).

Obviously the organic chemistry of the lunar crust should be analyzed with the same degree of sophistication as the Earth's crust but without confining such analyses to terrestrial models. It is hoped that the quantity and quality of the material brought to the Earth by the first Apollo mission will permit these investigations.

Examples of the types of analyses to be performed for the detection, identification and study of protobiological and organic compounds include:

1. Mass spectrometry

2. Capillary gas chromatography

3. Spectrophotometry (infrared, ultraviolet and visible radiations)

4. Electron probe and secondary ion emission microanalysis

5. Other physical methods such as electron microscopy, electron diffraction, X-ray diffraction, analytical ultracentrifugation and light scattering

The biological objectives for the lunar exploration program involve the search for evidence of viable or nonviable organisms and the search for any types of life systems that may be present or may have been present on the Moon. The life systems need not be recognizable by comparison with known Earth forms but probably at least would be identified as specially organized systems in which material is processed and energy is utilized for growth and reproduction, for means of survival (e.g., adaptation and mutation), and for maintenance of internal system integrity. Obviously identification and study of life so defined must be based on characteristics in addition to those of a morphologic nature. The most obvious of these are the biochemical and biophysical characteristics.

The objectives of a search for organized life must also take into account the probable environmental conditions of the Moon. For example, the Moon probably lacks a solvent system for the support of life. Also the stresses of the environment resulting from the radiation flux, the cycling temperature and the high vacuum make it difficult to envision how any coherent growth processes could take place. On the other hand, the probable conditions of low temperature, high vacuum and low radiation that might exist in subsurface protected areas can be regarded as favorable for the preservation by freeze-drying of micro-organisms on Earth. Thus, as compared to reproducing "life" entities, it is more probable that the Moon may harbor organisms in a dehydrated state which upon exposure to the proper environment can be made to exhibit the true characteristics of a living entity.

The biological objectives would also include search for life-associated macromolecules and their constituent moieties such as nucleosides, bases, sugars, lipids, hydrocarbons, etc.

The methods used in connection with the above objectives would include exhaustive attempts to isolate and culture "micro-life" systems by inoculating standard culture media, tissue cultures, embryonated eggs, and plant and animal hosts. These tests would differ from those performed in the Lunar Sample Receiving Laboratory in that they would be more exhaustive and would be conducted as research projects with appropriate follow-ups, rather than as standard screening tests. X-ray probe microanalysis also would be used as required, as well as analytical methods such as light optical histochemical straining, electron microscopic histochemistry and ultrastructure and cathodeluminescence microanalysis.

Some examples of other types of microbiological tests that could be performed on lunar sample material are:

1. Animals stressed by physical, surgical, chemical or radiation means could be challenged with lunar materials. Similar tests could also be done with stressed plants.

2. Pregnant animals could be challenged with lunar samples. The fetus is often unusually susceptible to terrestrial infectious or toxic agents.

3. The possible influence of lunar material on bacteriological transformation could be studied. Genetic material (DNA) extracted from donor cells could be exposed to lunar material before absorption by recipient cells. Similar tests could involve the bacterial processes of transduction, in which genetic material is transferred from donor cells to recipient cells by bacterial viruses, and the processes of conjugation, in which there is a direct transfer of genetic material from donor cells to recipient cells.

CONTAMINATION CONTROL OBJECTIVES AND METHODS

The first objective relates to a general desire to minimize the biological contamination of the Moon that might result from our explorations. There has long been general agreement that any introduction of micro-organisms from the Earth onto the Moon should be avoided as far as possible. There is little reason to repeat here all of the previous recommendations, but they can be summarized as follows: Introduction of Earth organisms on the Moon will make more difficult, both now and in the future, investigations into whether the lunar environment does now, or ever did, harbor viable organisms. The Bioscience Working Group would like to extend this objective to include minimizing contamination of the Moon with organic compounds from the Earth. The working group is aware that complete prevention of Moon contamination is not possible, however it strongly recommends that such contamination be sufficiently studied and characterized so as to assure that valid biologic and organic determinations will be obtained during subsequent study with lunar samples.

The confusion and disadvantages that could result from the failure to collect biologically and chemically clean samples can be illustrated by the following possibilities.

1. Microbial contamination of the lunar samples resulting from the astronaut's collection techniques could result in considerable difficulty during the quarantine process. It could be, for example, that the release of the sample from the quarantine laboratory would have to be held up until various microbial contaminants isolated from the samples could be identified and shown not to possess pathogenic or toxic properties. If an astronaut-contributed contaminant happens to be a pathogen, such as hemolytic streptococci, this presents an even more complicated problem whose solution in regard to quarantine time is impossible to estimate.

2. Chemical contamination of lunar samples, especially with organic compounds, could also result in considerable confusion during the processing of samples through the Lunar Sample Receiving Laboratory and might even result in an illogical apportionment of samples to the interested investigators.

3. Finally it should be remembered that the presence of Earth contaminants in lunar samples, if they are mistakenly taken to be a normal constituent of the lunar material, could lead to erroneous conclusions regarding the history of the Moon or the presence of life on the Moon.

There are three principal sources of contamination that should be controlled in order to minimize contamination of the Moon during early Apollo flights. The first is the LEM itself, including its vented gases and other discharges. The second is the leakage from the suits of the astronauts when they are on the surface of the Moon. The third possible contamination source is the products of fuel combustion that may be deposited on the Moon during descent and ascent operations. Moon contamination from these sources can be minimized in a variety of ways. The working group feels that the outside of the LEM presents little or no problem. The solar radiation to which the surface of the LEM will be subjected during the trip to the Moon would probably insure the inactivation of any bacteria except those in protected fissures. During the LEM's sojourn on the Moon surface bacteria in such fissures would probably not be transferred away because of the absence of a lunar atmosphere.

The atmosphere inside the LEM and any material and equipment that is moved from the LEM down to the surface of the Moon represent a potent source of microbial and organic contamination for possible deposition on the Moon. To minimize contamination from the interior of the LEM we strongly advise the following:

1. Venting of the LEM's atmosphere through an ultra-high efficiency biological filter prior to exit of the astronauts from the LEM.

2. Earth sterilization with ethylene oxide or heat of all equipment and apparatus to be moved later from the LEM to the surface of the Moon. Apparatus and equipment such as the sterile sampling tool and the lunar sample containers could be maintained in a sterile condition while in the LEM by encasement in a thin film of teflon.

3. Out-gassing from the astronauts' suits presents a probable means of contaminating the lunar surface. Moreover, in this instance, it is probable that unless adequate precautions are taken, the out-gassing may contaminate the samples being collected. Study of the amount and extent of contamination from an astronaut's suit in order to determine what steps must be taken to prevent sample contamination is one of the most urgent problems impinging on the interests of the bioscientists.

The second contamination control objective relates to possible back-contamination of Earth with harmful lunar materials. The overall objective in this case is to assure that no catastrophic event or events occur on this planet as a result of the return and experimental use of the lunar samples. There has been much discussion of the many aspects of this problem. On the one hand there is the low probability of the existence of any form of life on the Moon. Added to this would be the probability that even if life of some form were detected it would be nonpathogenic and nontoxic when brought to this planet. There is even evidence to suggest that there is a continual deposition of lunar material on the Earth by natural means. On the other hand, even as remote as the catastrophe may be, its possible consequences could be so serious that it is unthinkable not to recognize the probability. In short, the Bioscience Working Group believes that although the probability that viable organisms will be found on the Moon is very small and that the chance that they would be dangerous if they do exist is even smaller, when one considers how much is at risk on this planet (men, animals and plants, and the ecological balance among them) it becomes mandatory to make the prevention of this unlikely event a necessary requirement of the Moon exploration program. The working group also recognizes the fact that the prevention of back-contamination will probably be a required approach, with the exact procedures being prescribed by the U. S. Public Health Service and/or the U. S. Department of Agriculture. Therefore such procedures are not specified in this document.

The clearance of safety testing of the returned lunar samples should be done in a laboratory designed especially for this purpose and designated as the Quarantine Laboratory of the Lunar Sample Receiving Laboratory. The prime purpose of the laboratory would be to provide a formal mechanism for testing appropriate representative lunar samples for the possible presence of agents that might be infectious or toxic for man, animals and plants. It should be the goal of this laboratory to provide safety clearance for lunar samples, if possible, within a period of approximately 30 days. It is important to underscore that quarantine clearance will have to be obtained for each type of sample returned from the Moon or each particular mission. That is to say that the clearance of one or several samples representing only a very small portion of the Moon surface cannot serve as a mechanism for declaring the Moon itself safe for all future exploration or sample returns. It is impossible at this time to state with any assurance when the quarantine restrictions will be able to be dropped for returned lunar samples.

The definition of a Lunar Sample Receiving Laboratory (LSRL) has resulted in an opportunity to combine several other needed functions within the same facility. These functions require exact definition since the design of the laboratory should be aimed at fulfilling the objectives of these functions and no expansion of the facility should be allowed. That is to say that the LSRL is not a facility for basic research in any discipline but only designed to carry out the following functions:

1. Performance of necessary quarantine tests

2. Permanent repository for the storage of lunar samples

3. Central point for gross characterization and distribution of sample material

4. Conduct of gas analysis and low-level radiation counting on lunar samples

5. Mass spectrometry measurements of the pyrolyzed lunar sample (650-100 mg) for organic compounds

The overall design concept to be employed for the LSRL is that of a double barrier system similar to that which has been shown to be effective in containing the most hazardous types of Earth pathogens. The first barrier consists of a series of gas-tight chambers and cabinets in which the sample is kept at all times. Manipulations of the sample are done by the use of manipulators, attached arm-length rubber gloves, etc. The secondary barrier is the laboratory building itself. All vapor, liquid and solid effluents from this building are appropriately treated by incineration, filtration, etc. Moreover, the entire facility is to be maintained at a negative air pressure. The purpose of the secondary barrier (the building itself) is to provide a positive separation of the laboratory work from the world at large.

Detection of pathogenic or toxic substances in the LSRL should be done in primary isolation and barrier units of the following types:

1. A Bioprep laboratory for: initial gross examination of biological samples, preparation of sub-samples for inoculation, microscopic examination and sterile pass-out to the units below

2. Anaerobic culture laboratory

3. Aerobic culture laboratory

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4. Normal animal inoculation laboratory

5. Germ-free animal inoculation laboratory

6. Egg and tissue culture laboratory

7. Invertebrate inoculation laboratory

8. Soil and water exology laboratory

9. Biochemical analysis laboratory

10. Sterility control laboratory

The LSRL will be designed to handle approximately 20 lunar samples at one time.

APOLLO SAMPLING REQUIREMENTS AND PROBLEMS

The working group considers that the highest priority of work time on the lunar surface should be given to the collection of samples for return. If work time on the lunar surface is limited by a partial abort of the mission, the astronaut should attempt to bring back samples in whatever condition and in whatever amount is possible. However, to the extent that adequate stay-times on the lunar surface are realized, the following requirements and problems are identified:

TYPES OF SAMPLES FOR BIOSCIENCE USE

Samples for bioscience use should be collected as far from the LEM as realistically possible. If aseptic collection of all samples is not possible, then separate samples must be collected in an aseptic and chemically clean manner for (1) bioscience research after release from the LSRL, and (2) for quarantine purposes in the LSRL. It should be emphasized that aseptic collection of all samples simplifies the collection techniques by reducing the number of types of samples and by providing more flexibility for later distribution use of these samples. Whether collected separately or not, the bioscience disciplines would prefer both surface and subsurface samples, both meteoritic and volcanic samples (if both exist), and small aggregate material as well as rocks. The group did not establish a requirement for core samples, but wishes to have representative parts of a core if a hole is to be drilled.

AMOUNTS AND DISTRIBUTION OF SAMPLES

For bioscience purposes the amount of information derived from research with lunar samples will increase very considerably with increases in the amount of sample available. For the types of research described in this report a minimum of 5 to 10 kg of sample would be needed. This estimate reflects the amount that will be needed to make specific molecular identifications, based on the assumption that the organic content of the lunar material will be comparable to that found in old terrestrial sediments. In this regard, however, it can be pointed out that mass spectrometry screening determinations on lunar material while in the LSRL should be able to confirm or deny this assumption. The Bioscience Working Group agrees in general with the proposed scheme of the Geochemistry Working Group for the study and division of the lunar sample. The two main parts of this procedure are:

1. Utilization of primary sample data (e.g., organic compound screening, outgassing, radioactivity, etc.) obtained in the LSRL as an aid in determining future interest in the sample by various groups of investigators.

2. Use of an advisory committee for recommending the allocation of lunar sample material.

The amount of sample that will be required for quarantine purposes should not exceed 5 percent of the total returned sample. Obviously, the amount of sample utilized for pathogen and toxin detection would vary in relation to the variety of sample types collected. In general we envision a need for quarantine samples from each site visited, with preference being to subsurface or protected samples with the consistency of dust or sand. The minimum amount of lunar material needed for each quarantine test is 5-10 grams.

The working group has given some thought to the matter of sequential sharing of lunar samples by different workers. It has been appropriately suggested that when nondestructive tests are performed by one investigator it may be possible for him to pass a sample on to another investigator. The Bioscience Working Group agrees in principle to this but would like to caution that the term "nondestructive tests" means different things to different people. For example, inadvertent biological or chemical contamination of a lunar sample might destroy its usefulness for bioscience research but not for some other type of research. Therefore, it becomes evident that plans for the sharing or sequential use of samples would have to be worked out in great detail by the advisory committee.

The following general breakdown for sample allocation is recommended:

Permanent storage in the LSRL (museum samples)	- 10%
Storage in the LSRL for second generation tests	- approx. 40%
Quarantine testing	- approx. 5%
For distribution to the scientific community	- approx. 45%

SAMPLE PACKAGING

The outer rigid sample containers may be made of stainless steel or of Inconel. These seem to be the most practical construction materials. Teflon may be used as a gasketing material for the containers. If a back-up closure device is required, a metal knife edge seal penetrating into a soft metal such as gold might be considered. Teflon is the only plastic known to be acceptable to the organic chemists. The rigid containers are to be closed in the lunar vacuum for the return. It is most important that this vacuum be reliably maintained during the return trip. If maintenance of the vacuum during the trip cannot be achieved we recommend pressurization with sterile nitrogen.

The inner containers should be made of a teflon-metal laminate. These bags must be flexible, sterile, and able to achieve a vacuum seal. It may be desirable for them to be remotely filled, closed and labeled, using a special aseptic sample tool. This is discussed elsewhere.

MOON-LOCATED SAMPLE

Consideration should be given to the possibility of enclosing a lunar sample in an aseptic manner for permanent storage on the lunar surface. This would assure, as the lunar exploration proceeds, the existence of at least a small portion of the lunar crust in as noncontaminated a condition as possible. It is suggested that the type of container required for this purpose might be a thin metal box that exists as a covering around the sample container during the journey to the Moon. A flexible bag of teflon would not be able to withstand the rigors of the lunar environment for a prolonged period.

CONSIDERATIONS FOR AES

The deliberations of the Bioscience Working Group, in relation to the AES program, were in general rather than specific terms. This was not only because of a limitation in meeting time but also because the present membership of the committee obviously does not cover all disciplines in the bioscience area.

It was apparent to the committee, however, that the bioscience disciplines should have a continued and increased interest in Moon exploration during AES. The capability of putting larger payloads on the Moon, of longer stay-times, of bringing back larger payloads, and of using orbital lunar landers greatly expands the quantity and quality of bioscience lunar research that will be possible. Longer traverses to a greater variety of lunar sites will be possible. Also sampling at greater depths will be done. These improvements obviously allow protobiology and organic chemistry experimentation to be done with a greater degree of sophistication. We envision, for example, that the biologists and the microbiologists will want to undertake projects of the general nature of (1) the survivability of terrestrial organisms and micro-organisms under lunar conditions, (2) the reaction of lunar materials with Earth organisms, (3) the study of many biological phenomena under lunar conditions.

The use of orbital lunar landers will permit the landing of automatically operating bioscience packages on the lunar surface. In this way contamination from the LEM or from the astronauts can be avoided and studies can be made at remote locations not otherwise easily accessible.

We envision also that a sophistication of the sample collection techniques will be possible for AES. Three examples would be:

1. Better selection of types of materials to be returned to Earth.

2. More careful selection of sites which would yield or promise to yield biologically or chemically interesting material.

3. Preliminary in situ screening of material before return to Earth. For example, modern techniques should allow the examination of lunar material at a high resolution and a great depth of focus.

RECOMMENDATIONS

1. It is recommended that an immediate study be started to determine the amount of microbial and organic contamination escaping from the astronauts' suits due to out-gassing on the Moon's surface. The study should also define the extent of the area around the astronauts that would be contaminated by out-gassing. This study should consist of more than theoretical calculations and should be a practical experiment performed using suited individuals in a man-rated vacuum chamber. The information to be derived from this study is needed for final definition of astronaut's sampling technique and affects the requirements for the design of the astronaut's sampling tool described below.

The working group was informed that the current model of the space suit leaks about 150 cc of air per minute and that it is hoped that subsequent improvements will reduce this leakage to approximately 50 cc per minute. The atmosphere within the suits will, of course, contain micro-organisms and chemical aerosol contaminants. Obviously, the amount of microbial or chemical contamination that will escape will depend on many factors but among them will be the pore size of the holes in the suit in relation to the average diameter of the microbial and chemical contaminants available to escape. It could be that a negligible amount of contamination escapes from the suit or that sample methods can be found to prevent such contamination from entering the samples being collected. For example, if the protective aluminized fabric overgarment worn over the space suit is kept clean and sterile this may considerably simplify the sample collection contamination problem. All such illusions, however, will have to await the outcome of the biological leakage tests with the space suits.

2. The Bioscience Working Group recommends that a feasibility and design study be initiated immediately that will lead to the development of a manually actuated lunar sample collection tool for acquiring organically and biologically clean surface and near-surface samples.

The device should be capable of collecting lunar material of a wide range of consistencies, but not necessarily of unbroken rock. All samples will be packaged in suitable sterile and degassed (at 10^{-12} torr) bags or containers. The sampling operation should be automatic in the sense that samples will be acquired from a point as far as necessary from the suited astronaut's body.[1] The sample collection tool will not require direct participation on the part of the astronaut in placing individual samples in the sterile storage bags or in sealing the bags. It is desired that the sample collection tool be capable of obtaining sterile samples up to 1 kg in mass and have a capability of acquiring several such samples and a larger number of smaller samples. If possible, the weight of

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[1]The exact distance and other details should result from the study recommended on following pages.

this tool should not exceed 5 kg. Included with the sampler will be a sterilized bag or container in which the sampling tool will be transported until immediately before usage on the lunar surface.

The sampling device, as described above, can be included as a part of a general purpose field tool or other device if the capability of obtaining a few samples in the cleanest possible biological and organic condition is not compromised.

The Bioscience Working Group further recommends that scientifically competent persons from the various disciplines concerned actively follow the development of the lunar sampling devices. The person in charge of the Lunar Sample Receiving Laboratory should also be directly involved in the development and testing of the lunar sample collection tool.

3. The working group recommends that all astronauts be given training in aseptic and chemically clean sample collection techniques. Such training should consist of (1) 5 hours of classroom instruction, (2) 5 hours of classroom laboratory demonstration, and (3) integration of aseptic and chemically clean sampling techniques into simulation training programs. The general outline suggested for this training is as follows:

a. Classroom Training

(1) Size and types of contaminants of concern

(a) Size, shape and chemical composition of microorganisms

(b) Types of chemical contaminants, especially those organic in nature

(2) Possible methods of transfer of contaminants

(a) Foamite transfer

(b) Aerogenic transfer

(c) Laboratory demonstrations

(3) Methods of aseptic transfer and chemically clean handling

(a) Barrier principles

(b) Hospital and laboratory-type transfer methods

(c) Laboratory demonstrations

b. Training with the developed lunar sample collection device, sample boxes, teflon-metal containers, etc.

4. The working group recommends that a study be made of the problem of organic contamination of the lunar surface resulting from the burning of the LEM's rocket fuel. We understand that on its lunar landing the LEM's controls will burn about 4000 lb of N_2O_4-dimethylhydrazine mixture. We strongly recommend that a study be made of the trace organic impurities in the fuel and of the combustion products formed when the N_2O_4-dimethylhydrazine mixture is burned in vacuum. The organic chemists need to know more than the obvious volatile combustion products. They need to know what higher molecular weight organic compounds are present or are formed, including those present in minute amount (down to at least 0.01 percent). Since gas chromatography and mass spectrometry will be one of the organic chemist's chief tools in searching for lunar organic compounds, these techniques should be used in the search for organic products resulting from the combustion of the retrorocket fuel.

5. Before teflon is finally accepted as a suitable material for gaskets and for sample collection bags, the working group recommends that its behavior under near lunar pressures (10^{-12} torr), under various types of radiation exposure (ultraviolet, infrared, etc.), and under temperatures up to 400° K be investigated.

6. The Bioscience Working Group recommends review of the problem of radiation sources on the Apollo spacecraft. We specifically want to assure that no radiation degradation of the returned sample is possible. A member of our group (Dr. Tousimis) has been assigned to the Radiation Ad Hoc Committee that intends to look into this problem.

7. The Bioscience Working Group is in essential agreement with a joint report relating to Apollo weight priorities. In particular, we emphasize the need for allocation of about 5 kg in the LSEP weight breakdown for an aseptic biological sample collection tool. Also, if a satisfactory container is developed in which to store materials on the lunar surface, we suggest an allocation of 2.5 kg for this container.

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REPORT OF
GEOCHEMISTRY-PETROLOGY WORKING GROUP

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INTRODUCTION

BASIC GOALS IN THE GEOCHEMICAL, MINERALOGICAL, AND PETROLOGICAL STUDY OF THE MOON

Exploration of the Moon is one of the grandest adventures ever undertaken by man. In part it is an adventure in science. Major contributions to many scientific disciplines are certain to emerge from the lunar exploration program. The difficulties and complexities of lunar missions are enormous and place severe constraints on the scope of purely scientific exploration which can be achieved within the program. It is the responsibility of the scientific community to attain the maximum scientific benefit compatible with these constraints.

One of the major unsolved problems with respect to the Earth-Moon system is the origin of the Moon. It has been variously proposed (1) that the Moon originated completely separate from the Earth and was later captured by the Earth, (2) that the Moon and the Earth essentially originated at the same time as twin planets, and (3) that the Moon originated from the Earth and was torn from it at an early stage in Earth history. In attempting to resolve the problem it is of great importance to compare the composition of the Earth and the Moon in terms of bulk chemistry and specific diagnostic element and isotope ratios.

Further it is essential to compare the time scale of lunar events with that established for Earth history. As we decipher the history of the Moon this information can throw light on early Earth history provided an absolute time scale can be established for lunar events. Determination of absolute ages on lunar samples and detailed stratigraphic measurements of carefully chosen sections will help answer questions on the origin of the Moon and establish what possible correlations can be made between major terrestrial and lunar events.

Even the first Apollo samples will probably allow us to establish whether the Moon has persisted as a cold accumulation of undifferentiated "primitive" material or whether there is evidence of chemical differentiation. Selective concentration of certain elements toward the lunar surface would have great bearing on the existence of a lunar core and on the heat budget of the Moon as it is controlled by the distribution of radioactive elements.

The solutions of many major problems related to the Moon depend on the establishment of the gross composition of the lunar surface. This type of information can be estimated from analyses of returned lunar samples combined with orbital remote sensing calibrated on known samples.

It is of importance to establish the relative roles played by internal processes (such as volcanism, degassing) and external processes (such as hypervelocity impact) in shaping the present lunar surface topography. This can be established both by on-the-spot geological observation and by examination of the returned samples. The possibility of erosion, transportation and sedimentation processes active on the lunar surface should be tested. If present, they must be understood.

In recent years the meteorites have yielded valuable information on the extraterrestrial environment because they contain a memory of their lifetime in this environment. Obviously no sample control can be exercised in this area. Ablation in the Earth's atmosphere poses another problem. The Moon is a much better space probe in that correlation with the geologic history of the Moon may allow us to monitor the cosmic ray and solar wind flux over times comparable to the age of the Earth. High priority should be given to discovering areas of the Moon where the oldest rocks are near the surface.

A major area of interest is in establishing the capability for more exhaustive surveys of the Moon. Search for life support materials (especially water) is obviously of great practical importance.

THE ROLES OF APOLLO, AES, AND POST-AES IN THE PROGRAM

An orderly progression of information in solving the problems mentioned above is expected to result from the several stages of lunar exploration. With more time and payload becoming available as the lunar program evolves, more carefully selected field observations and samples will become available. This progression is spelled out in more detail in following sections.

APOLLO

GENERAL PHILOSOPHY

At an earlier meeting of the Apollo planning teams (reference, Apollo Lunar Science Program, Report of Planning Teams, Parts I and II, NASA, December 1964), groups interested in geochemistry and petrology-mineralogy met separately. The present geochemistry-petrology working group reaffirms the conclusions reached at this earlier meeting.

The single most important scientific objective of the Apollo missions is the return of lunar surface samples. The operational constraints under which the Apollo astronauts must work greatly limit their effectiveness as scientific investigators on the lunar surface. The scientific yield from the observations of the astronauts on early Apollo missions, important as they are, will be less than that from the investigations of scientists on Earth upon the returned samples. The severest limitations on what we learn about the Moon from the Apollo flights will be set by the amount of sample available for study after completion of the mission.

Major advances in our knowledge of the Moon and its relationship to the Earth can be made through studies of returned lunar material. A wealth of scientific information can be obtained from samples whose relationship to associated rock types, stratigraphy, structure, and morphology of the adjacent surface, in detail and on a regional scale, is accurately recorded. Nevertheless so much information can be obtained from even random samples that sample procurement is given precedence over all other scientific objectives.

It will be desirable of course to obtain all possible information on the environment, including the context of the selected samples. But if only one scientific task can be accomplished, in the case of a partial failure, it should be return of lunar material in any possible form.

PREPARATION FOR THE SCIENTIFIC PROGRAM

This and the following section are summarized as follows:

PROPOSED SCHEME FOR STUDY OF RETURNED LUNAR SAMPLES

Proposals received

↓

Evaluation (by NASA and NASA consultants)

↓

Funding of selected proposals

Dry run experiments
Handled by USGS

Open also to groups
not funded by NASA

↓

Upgrading of laboratories
Interlaboratory correlation of data

↓

Evaluation of results
Possible funding of other investigators
Selection of principal investigators

↓

Preliminary examination of returned lunar samples

↓

Decisions by advisory committee on allocation of lunar samples

Evaluation of Proposals

Opportunities to participate in the study of returned lunar samples have been presented to the scientific community at large and a large number of proposals have been received by NASA. The proposed exploration of the Moon has generated immense interest in the scientific community. The number of important experiments to be performed on the lunar samples is large and the number of potential experimenters is even larger. In contrast the amount of material available for study is small because the total returned Apollo payload is small and because there are sound reasons for not making the entire sample payload available for experimental work soon after return. The risk involved in this undertaking and the immense cost and complexity of lunar missions place a very high value on lunar samples on both Apollo and post-Apollo missions. Thus it is essential to extract the maximum possible scientific benefit from a relatively small amount of material. This requires collaboration between investigators on a grand scale. No single institution can supply the nation's best scientific talent in all or even most of the important investigations. Many laboratories throughout the country must participate in these studies. Very close cooperation is required to avoid sample waste and needless duplication. However, in many areas of study duplication of experiments is extremely useful. Collaboration between separate laboratories is necessary. The technical and organizational problems are not small in scale, even by the standards of the Apollo program itself.

NASA is faced with the immediate and continuing problem of evaluating proposals for the preparation phase of this work, and studies on the returned material. It is the opinion of the geochemistry-petrology working group that the choice of investigators for work on lunar materials should emphasize projects which are problem-oriented. Proposals which are concerned primarily with obtaining analytical data not directly relevant to solving a particular problem should rate below equivalent proposals which are concerned with obtaining data in order to provide answers to particular questions of scientific importance.

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It is also considered essential that proposals should name the scientist(s) who will actually perform the experiments, and be judged in part on that basis.

The geochemistry-petrology working group has also attempted to compile a list of the more important experiments to be performed on lunar samples. (See section entitled "Staffing of LSRL".) This list is certainly not all-inclusive and will undoubtedly be modified in the future. However, it may be useful in delineating some of the more important areas of geochemical and petrological investigation. Some of these may not be covered adequately in existing proposals, and scientists should be encouraged to participate in investigations in these areas.

Development and Testing of Scientific Capabilities

The group considered the question of how best to utilize the time before the Apollo missions in order to achieve the goal of extracting the maximum scientific information from the returned lunar samples. During this period it is also necessary to reach agreement on which scientists will be responsible for the various areas of research.

To these ends it is proposed to conduct a series of investigations on selected materials with opportunities for potential investigators of the lunar samples to participate. In these "dry-run" investigations there will purposely be much duplication of experiments among different laboratories. Individual scientists may perform on these samples the experiments which they propose to perform on the returned lunar samples. Scientists funded by NASA as part of the lunar sample study program will take part in these experiments, as may any other interested groups. Participation will be especially encouraged from investigators whose field of study is in an area which would not otherwise be covered.

One purpose of these "dry-run" investigations is to allow interlaboratory correlation and comparison of data. Such correlation can allow comparison of different experimental approaches and techniques and may help delimit areas where present techniques and facilities could be improved. Upgrading of the scientific capability of laboratories is an anticipated end product of this program. The results of these experiments may also be used as a basis for funding other investigators of demonstrated competence.

One by-product of such a program is the definition of a group of well analyzed rocks, samples which can be used as standards by geochemists. It should be pointed out that the scope of this program is such that the selected samples will be studied more thoroughly than any rock samples have been in the past. As many of the geochemical studies proposed for the returned lunar samples as is feasible will be included. The program is potentially of great value to terrestrial geologists and geochemists whether or not they are involved in the scientific investigation of the Moon. Samples to be investigated shall be very carefully chosen (1) to be of maximum value in evaluation of data, (2) to be of maximum scientific interest, and (3) to simulate lunar samples.

The USGS presently has available large homogeneous samples of two very common types of volcanic rock, basalt and rhyolite. These may be similar to lunar surface materials and, because of their homogeneity, will allow comparison among laboratories of data measured on essentially duplicate samples.

Meteorites are our only proven examples of extraterrestrial material. Meteorites also pose special analytical and interpretive problems similar to those which lunar materials may provide and it is recommended that a large, fairly homogeneous sample of chondritic material be obtained for this purpose. If the lunar surface topography is the end product of repeated impact cratering then the closest analogy we have on earth, in terms of texture and heterogeneity, is a meteorite impact breccia. A fourth possible sample for these investigations is an impact breccia such as suevite from the Ries structure in Germany. The extreme heterogeneity of such samples will provide a challenge to the techniques of measurement and interpretation which many investigators wish to apply to the returned lunar samples.

We suggest that the USGS is best equipped to handle the preparation and distribution of the samples used in these investigations.

SAMPLING ON THE MOON

Sample Requirements

It is the frequently stated conclusion of the geochemistry-petrology working group that the major requirement for lunar sampling is that as much total sample weight as is possible be brought back. It was recommended last year that if possible two large coherent samples of representative material from the area around the landing site be returned. Large samples permit examination of textural and structural relationships (provided these can be preserved) and also provide material for duplicate measurements at separate laboratories. In addition many small samples should be collected of materials which appear different to the astronaut. If possible the available space in the sample containers should be filled with small fragments and dust up to the available weight capacity so that sample weight returned is not limited by the geometry of the samples and sample containers.

Sampling Methods

Methods used in selecting samples on the Apollo missions should be straightforward and simple. Sampling may present difficulties both in the techniques of breaking off material from the lunar surface and in distinguishing different materials whose surface appearance may be similar because of prolonged exposure on the lunar surface. The astronauts should be well trained in handling the various geological tools with which they will be equipped. Equally important, they should be trained in methods of selecting samples in different geological terrains. No rigid statistical sampling pattern should be insisted upon. Rather it is recommended that the astronauts be given experience in sampling problems and be allowed to use their own discretion in collecting lunar samples. Close contact between the astronauts and several principal investigators prior to Apollo is desirable from this point of view among others.

Sample Containers

A variety of possible materials were considered for the sample return boxes. As sample contamination is a major factor the containers should be fabricated from materials which (a) will not injure any of the experiments planned for the returned samples, and (b) are easily recognizable, and if possible, separable, as contaminants. The ideal material would be a pure single-isotope element of high strength, and high abundance in possible lunar samples. This seems unattainable. The selected material should be of known and simple chemistry and extreme care must be exercised that traces of other substances are not introduced at any stage in the manufacture of the containers. Of the materials considered, stainless steel and Inconel, while not geochemically ideal, seem the most practical.

Agreement was reached with the biology working group that the sample containers to be stored within the metal sample boxes may be flexible bags of laminated metal and teflon. Also within the metal sample boxes there should be a number of smaller metal containers suitable for high vacuum. It is hoped that a relatively small sample can be returned under conditions approximating the lunar environment. A few small sample containers capable of holding a vacuum of 10^{-12} torr should be included within the larger containers.

As gasketing material the group recommends inner teflon seals combined with outer elastomer seals. The teflon seals should be developed to the highest possible degree of reliability; elastomers presently available emit undesirable organic vapors.

CONTAMINATION FROM LEM ROCKET EXHAUST

The LEM descent stage rockets are expected to deposit several tons of exhaust gases and unburned fuel and oxidizer in the vicinity of the landing site. These materials are potential interferences in several experiments, especially the biological and atmospheric measurements. In order that corrections may be made, we consider it mandatory that detailed analyses be made of the fuel and oxidizer, including in time the actual lot of fuel used in the LEM for each mission; the study should include possible decomposition products. Much information may be lost if this is not done.

LUNAR SAMPLE RECEIVING LABORATORY (LSRL)

Design of LSRL

The LSRL will be designed to allow four basic types of experimentation: (1) biological testing (quarantine), (2) sample unpacking, preliminary mineralogical and chemical examination and cataloguing (3) low level counting and (4) gas analysis. The major portion of the geochemical and petrological investigation will not be made in the LSRL but at many laboratories throughout the country.

Before dispersal of samples from the receiving laboratory biological tests, particularly those concerned with possible harmful effects which extraterrestrial material may have on terrestrial organisms, will be performed during a quarantine period. During this period a preliminary examination of the samples can be made and they can be described, catalogued and if necessary subdivided. We agree with the biology working group that this quarantine period should not exceed 30 days, under normal conditions. A delay of this order, however, can greatly diminish the yield of certain geochemical experiments. For this reason facilities will be incorporated in the LSRL to allow both gas analyses and low level counting experiments to proceed during the quarantine period.

Following recovery of the spacecraft from the ocean and its storage aboard ship the sample containing boxes will be separated from the spacecraft and after decontamination of the outside walls will be sent to the sample receiving laboratory. The boxes will enter through locks to a vacuum chamber at 10^{-6} torr where one box will be opened. Occluded gas will be pumped from the box and analyzed. Sample unpacking will be done under vacuum, and behind biological barriers. The smaller high vacuum containers (10^{-12} torr) within the larger box will be moved to a separate vacuum chamber (10^{-12} torr). Specimens especially collected for gas analyses will be separated and stored. One or more sample bags will be opened. The samples to be opened first should be selected on a basis of the astronaut's description. Preferably it should be a sample which is representative and of which duplicate samples have been collected.

The presence of noble gases in the unpacking or adjacent chambers could seriously interfere with rare gas determinations on the lunar samples, and we recommend that noble gases not be used. The most acceptable inert gas is nitrogen.

The selected sample (or samples) will be observed carefully to see whether it degrades in the moderate vacuum chamber. If the integrity of the sample is preserved then other samples can be unpacked, described and weighted remotely. Representative material will be exposed successively to dry sterile N_2, dry sterile air and moist sterile air while being continuously observed. Preliminary mineralogical and petrological examination can hopefully be performed under normal atmospheric conditions. Samples will be selected under vacuum for low level counting experiments and transferred to that facility. Sample subdivision and repackaging, optical examination, microchemical tests and optical emission spectrography can be done behind biological barriers. By the end of the quarantine period enough data on the nature of the samples will have accumulated to allow informed decisions to be made on the distribution of samples to principal investigators.

Sample Storage

Because of the number of important experiments which can be performed on the samples returned in Project Apollo and the number of experimenters interested in participating in the program, the demand will greatly exceed the amount of lunar material available. As science progresses, however, techniques become more sophisticated and the amount of sample required to perform a particular experiment tends to decrease. More important, the relative values of different experiments change as we gain new insight. Experiments performed on lunar samples will undoubtedly include several which we cannot presently envisage. The experiments which are performed will probably appear rather crude and unsophisticated to future generations of scientists. We must also consider that the Apollo samples will come from a small area on the Moon's surface which quite probably will not be revisited by man in the foreseeable future. The samples may be our only record of this particular site. It is recommended, for the above reasons, that a fraction of the samples from each Apollo mission be stored indefinitely at the LSRL.

For quarantine tests not more than 5 weight percent of the sample should be used. The bulk of the sample should be allocated as follows.

A small amount should be used for the preliminary survey examination. This examination will provide the advisory committee with information on which to base their recommendations on sample allotment. Somewhat more than half of the remainder should be held in reserve at the LSRL at least until the first series of experiments are mostly complete. The portion remaining will be distributed among the principal investigators following the recommendations of the advisory committee. Principal investigators will, where possible, use samples cooperatively, using the experience gained in the preflight period.

SCIENTIFIC PROGRAM

Introductory Statement

Chemical, mineralogic and isotopic studies on lunar material will yield information on (1) nuclear processes in the early solar system, (2) the origin of planetary bodies and (3) the geologic evolution of the Moon. Ideally, the total array of measurements on lunar material should include the determination of the abundances of all the elements, their isotopes and their distribution in the coexisting phases of lunar materials.

This goal may indeed be achieved in large part. It is doubtful, however, that it should be pursued without some ideas about priorities. In the presently known chemical context of the Moon, i.e., the chemistry of meteorites, the Earth and the Sun, some groups of elements and isotopes are of more interest than others. Examples of these are given in the brief outline that follows. Similarly, some mineralogic studies are more informative than others. Several illustrations relating chemical and mineralogic parameters on lunar materials to fundamental questions about the solar system and the Moon, are given below:

1. The conditions under which the Moon and other planets were formed in the early solar system can be inferred from the geochemistry of certain groups of elements. In particular, the abundance of relatively volatile elements such as Hg, In, Tl, Zn, Cd, Bi and Pb may indicate something about the temperatures during accretion of the Moon. The fractionation of Rb and Sr in the early solar system may also be related to high temperature fractionation processes in the early solar system.

2. The abundance of certain elements such as Li, Be, B, are sensitive to nuclear processes in the early solar system. Similarly it is important to know whether or not the H/D of K^{40}/K^{41} ratios are the same in all parts of the solar system.

3. The abundance of Xe^{129} in Xe from the lunar materials may indicate whether or not the Moon was formed before or after chondritic meteorites.

4. The history of the Moon will be documented by absolute ages based on potassium-argon dating.

5. The distribution of rubidium, strontium, uranium, thorium and lead, combined with isotopic data on strontium and lead will provide information on the nature and sequence of events on the Moon's surface.

6. The concentrations of U, Th and K will be required to make models of the thermal regime of the Moon.

7. The petrographic examination of lunar samples by X-ray diffraction, microscope, and electron probe will reveal whether or not the lunar samples can be compared to known meteoritic or terrestrial materials.

8. The search for high pressure phases and phase assemblages will assist in the study of impacts, while igneous textures will give information on volcanic or intrusive activity, if present.

9. Differentiation histories may be unravelled by determining the rare-earth distribution patterns as compared to terrestrial and meteoritic analyses.

Neither the items listed in the table which follows, nor the associated descriptive comments are to be taken as the only types of observations which will give information on the history of the Moon and its place in the solar system. As more definite criteria are established they will be used to construct the priority list of things to be done in lunar materials.

Suggested Geochemical and Petrological Measurements on Returned Lunar Samples

Essential Measurements

Bulk analysis and elemental abundances

Some examples of the relationships between selected element abundances and problems of lunar geochemistry and petrology are given below:

1. Is the Moon differentiated — major elements

2. Energy sources and heat production on the Moon — K, U, Th

3. Differentiation and fractionation in lunar rocks — rare earths

4. Nucleosynthetic processes — Li, Be, B

5. Condensation conditions in solar nebulae — volatiles: Hg, In, Zn, Tl, Bi, Pb

6. Evidence of lunar degassing — halogens, S, C, N, H_2O, CO_2

7. Chondritic or achondritic models — alkali metals

8. Separation of metallic phases — Pt metals

Isotopes

1. Nucleogenesis; solar wind history; nuclear bombardment history — isotopic composition of rare gases (Ne, Ar, Kr, Xe); other radioactive and stable nuclides (e.g., Be^{10}, Cl^{36}, Ni^{59}, V^{50})

2. Radioactive ages; magmatic differentiation — isotopes due to radioactive decay (e.g., Sr, Pb)

3. Stable isotope differences resulting from chemical fractionation (e.g., H, D, O)

Phase Identification and Analysis

1. Optical properties (thin section, oil immersion, polished section)

2. X-ray analysis (powder and single crystal)

3. Textural analysis (including particle size distribution)

4. Assemblage evaluation, in terms of crystallization history and the pressure-temperature conditions of formation

5. Electron microscope analysis (powder and single crystal)

6. Electron microprobe analysis

7. Radiation and shock-damage studies

Desirable but not Essential

Isotopes

1. Uranium decay series disequilibrium (e.g., Pb^{210}/U^{238})

2. Stable isotope variations resulting from chemical fractionation (e.g., C, S, N)

Physical measurements

1. U.V. fluorescence

2. Thermal luminescence

3. Density of bulk sample and individual phases

Stability characterization

1. Thermal behavior of bulk sample and individual phases under simulated lunar conditions

2. P-T ranges of new phases

3. Vapor pressure determination

Essential if Sample Suitable

Bulk sample

1. Infrared and ultraviolet emissive/reflective properties

2. Modal analysis

3. Thermal gravimetric study

Separated phases

1. Major and trace element partition

2. Total oxygen in each phase

3. Fluid inclusion study

4. Nuclear track studies

Thermochemistry

1. Low-temperature specific heats

2. Heat of solution

3. Heat capacity

Valuable if Technologically Feasible

Stability characterization

1. Cryogenic response

2. Fast neutron bombardment

Physical measurements

1. Soft X-ray analysis of sample surface

2. Reflectivity

3. Low temperature X-ray analysis

4. Porosity and permeability

Chemical measurements

1. Mossbauer test of Fe and Ti

2. Gas chromatography

APOLLO EXTENSION SYSTEM (AES)

GENERAL PHILOSOPHY

Lunar surface materials returned in the early Apollo program will answer many general questions about the Moon and its surface, and will give a quantum jump in our knowledge of the Earth-Moon system. Some of the first-order problems that will probably be solved at least in part by the first samples are (1) whether the Moon is differentiated, (2) whether volcanism is common, and (3) whether the Moon is of chondritic composition. It is doubtful, however, whether a great amount of detailed knowledge of the history of the lunar surface can be inferred from samples collected at two or three sites. Extensive and careful correlation of samples with geologic structures will become possible only with the extended stay times and increased scientific payload of AES missions compared with early Apollo. The longer missions will also be required for a serious study of the lunar surface crust, and subcrustal structure and the history of the Moon.

The longer stay time will probably be sufficient for collection of more material than can be returned to Earth. This makes some means of field characterization necessary in order to collect the most useful samples. A beginning can also be made in gathering data of geochemical interest on the Moon itself. Some substances, and some properties of many substances, may be drastically altered by the process of sample collection and return. As more time becomes available these can be studied _in situ_. Instrumental traverses may also yield data of interest, especially in the area of gas escape from the lunar interior.

SITE SELECTION

Several types of landing sites for AES exploration of considerable geochemical and petrological interest are listed below. This list overlaps considerably with that of the geology working group.

1. Mare-highland contacts

2. Primordial surface, if identifiable

3. Volcanic features

4. Perpetually shadowed areas (near the poles)

5. Young maria

6. Small ray craters — "hot spots" (regions which remain warmer than their surroundings during eclipses, indicating higher thermal conductivity)

SAMPLE RETURN FROM POST-APOLLO LUNAR MISSIONS

General

Perhaps the most significant scientific achievement of a successful Apollo mission is the return to Earth of materials from the lunar surface. It is doubtful that the importance of this aspect of lunar exploration will decrease in more advanced missions. These missions will furnish samples whose geologic context will be established much more precisely.

High priority should be given to mapping in as great detail as feasible, and samples must be taken and described in the context of these field observations. To make mapping most efficient in astronaut time, his position with respect to the LEM should be continuously recorded by an automatic or semi-automatic device. Indeed, all possible care must be devoted to automating all such "housekeeping" duties. In a two-week stay, as in the shorter Apollo periods, time will probably be the bottleneck in achieving the scientific objectives of the program.

Even in missions with extended stay times and heavier payloads, most of the measurements on lunar materials must be made on Earth. The primary objective of analytical devices used on the lunar surface should be to extend the power of the observer on the lunar surface to differentiate materials which are visually similar.

We have considered two fields in which chemical and petrological problems will place constraints on the design of advanced missions. They are (a) special chemical problems that may guide sampling in a local area or serve as guides in selecting one area over another, and (b) requirements on the quantity of returned materials.

Special Sampling Needs

Some of these which can now be anticipated include:

1. Samples should be collected from regions with different temperature histories, for instance a crevasse or crack vs. the surface, and permanently shaded areas vs. illuminated areas on the surface.

2. Early solar system history may be inferred from very old (primordial) areas. If these are recognized they should be sampled extensively.

3. Co-genetic samples are required with different chemical compositions, particularly U/Pb and Rb/Sr ratios. These will be very important in unambiguously establishing the age of igneous units.

4. Samples which establish the relative abundance of foreign (meteoritic) and indigenous lunar material on the present surface need to be defined and returned.

5. Samples should be obtained by coring devices or other capabilities to sample at depth. These will be necessary in chemical and petrological studies of sedimentation and microstratigraphic problems and to determine cosmic ray and solar wind history. The length of core required depends on the thickness of the disturbed surface layer.

Amount of Returned Materials

We have tried to estimate from present knowledge the amount of material that will have to be returned from a typical two week mission in the AES program, in order to adequately represent the area visited in this time. Criteria which were used in making this estimate were:

1. All members of mappable geologic units should be represented by at least two 200-300 g samples if sample heterogeneity is not a problem; if it is a problem, more will be required for adequate sampling.

2. All drill core obtained in a drilling program should be returned. A single 100 foot core, 1-1/2 inches in diameter, will weigh 70-100 kg for densities of 2-3. Whatever the drill capability finally developed, this is a modest figure for the total mass of core.

3. Impact materials in crater edges may be heterogeneous on a scale of inches and thus require large samples to be representative (20 kg). Several of these will be required.

4. Samples for cosmic ray studies will require 1.5 kg for a complete analysis.

5. Unusual materials (e.g., carbonaceous chondrites) may require one or two large samples (10 kg).

6. Some thermostated or refrigerated materials may need to be returned (5 kg).

7. Samples returned in high vacuum will be required (2 kg).

The masses allotted to items 2 and 3 may at first appear high. However, in the case of cores, we have experience with the pelagic cores, up to 50 feet in length, obtained by oceanographers. Many of these have been largely used up by scientific studies. As for the impact materials, the figures given are based on experience at terrestrial meteorite craters. Also, it is from this category that the main reserve of material will be drawn.

In our judgment these criteria indicate that an optimum sample return capability would be between 200 and 250 kg (450-600 lb) per mission. This would require a volume of about 12 cubic feet.

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ON-SITE GEOCHEMICAL AND PETROLOGICAL MEASUREMENTS

This subject is treated in considerable detail in this report not because it is more important than others, but because if the instruments described are to be used in AES missions, development must be encouraged very soon.

Diagnostic Devices for Lunar Exploration and Sampling

Diagnostic Equipment for Sample Selection

Certain diagnostic equipment appears to be promising for assisting in sample selection on the lunar surface. We do not recommend any intensive analysis during the mission; what is required is sophisticated equipment for doing simple or approximate analysis. The equipment listed is recommended for development and evaluation in simulated lunar missions.

The instruments fall into three categories: (1) those useful on the open surface as well as in the LEM, (2) those useful only in the LEM or a vehicle and (3) those more complicated, difficult or less general pieces of equipment or those intended for later missions. In addition we append a list of those suggested devices that we feel are impractical or undesirable.

1. The portable equipment considered useful on the open surface for sample differentiation:

a. Combined X-ray fluorescence spectrometer and scattering density indicator.

b. Rock splitter.

c. Thermometer.

2. The equipment for use in the LEM:

a. Binocular microscope with arrangements for opaque samples and separated grains.

b. Multichannel analyzer and pattern analysis computer (to be used with 1(a), 2(b), 3(a, c, e), and with the infrared single-crystal probe unit).

3. Bulkier, heavier or less convenient equipment for use in the LEM and/or on the surface:

a. Combined gamma spectrometer-neutron analysis equipment. (This is our only hydrogen detector having reasonable depth penetration and not requiring sample preparation.)

b. Gas sample compressor for collecting atmospheric samples (for use with 3(c) to detect and locate gas emission even beyond the horizon).

c. Moderate to low resolution mass spectrometer (for selecting organic-containing samples and for use with 3(b) to locate gas emission at a distance).

d. Water and organic material detector (a simple detector requiring little sample preparation, usable on the surface if possible. A likely candidate is the ATR (attenuated total reflectance) single crystal infrared probe as a water detector. If the sample is not powdered, sample preparation before analysis might be necessary.

e. X-ray diffractometer.

f. Alpha or proton backscattering spectrometer.

Some description of each of the proposed instruments is given below to indicate the kind of instrument and to give some idea of its expected use.

1. Combined X-ray fluorescence spectrometer and gamma backscattering density indicator. A gas proportional counter is combined with several isotopic X-ray or low energy gamma ray sources to be used alternatively. A sample to be examined by fluorescence is prepared by breaking a rock, exposing the fresh

surface to the source, and counting the fluorescent X-rays. The counter impulses are telemetered to the LEM, sorted in the multi-channel pulse height analyzer for 20-50 seconds and the resulting spectrum compared with library spectra in the pattern analysis computer. The result, either the identity of pattern or a report of failure to recognize, is telemetered back to the astronaut. The recognition interval is expected to be approximately 1 minute. Elemental analysis for the low Z elements from about sodium through iron can be accomplished, the sensitivity for potassium, for example, reaching the concentration in peridotites.

The gamma-scattering density indication is obtained with the same equipment by shifting a low energy (0.1-1.5 MeV) gamma ray source into position and recording the total number of scattered gamma counts. The results are almost instantaneously telemetered back to the instrument in the form of a density number.

Sensor size for the combined instrument is about 0.1-0.2 cu ft.

2. Rock splitter. To obtain exposed faces of rock-like samples, a modification of the familiar sample splitter is proposed. Two chisel jaws are closed upon the sample by a hand-operated hydraulic or screw mechanism. Such a device will be especially useful if the local surface material is relatively poorly consolidated so that no firm surface can be found handy to permit the use of a hammer for fracturing samples. The terrestrial habit of holding a sample while striking it is obviously not satisfactory in a space suit.

3. Thermometer. Some indication of the temperature of a sample at the time of collection would be valuable since diurnal temperature variations are expected to be large and may have bearing on later analysis of the sample. A low-mass quick responding unit would be needed and might have other uses as well.

4. Binocular microscope. A polarizing microscope, lightened to omit useless weight and prepared for clamp mounting, should be provided for viewing opaque samples and for looking at separated grains. A few immersion liquids chosen especially to prevent

contamination of the LEM atmosphere should be provided to give gross refractive index separation.

5. Pattern analysis computer. This may be a version of some of the service digital computers used for modest matrix inversion, similar to that contemplated by Adler and Trombka at Goddard. The choice of this as against a more general-purpose computer or a link to a terrestrial computer is an engineering one.

6. Gamma ray spectrometer and neutron surface analyzer. This equipment provides "natural" gamma ray spectra of sample regions approximately one foot deep by several feet in diameter. Some data on elemental composition can be obtained, especially if K, U, Th are abundant. A pulsed neutron source permits measurement of inelastic scattering gamma-ray spectra, short- and moderate-lived activation gamma-ray spectra, capture gamma-ray spectra and the time signature of neutron thermalization and capture. These methods allow partial elemental analysis of a bulk sample in situ and provide, by measuring the captured gamma rays at 2.23 MeV, direct evidence of the presence of hydrogen without considerable sample preparation. This instrumentation is now under development by NASA.

7. Gas sample compressor. A diffusion pump using mercury or perhaps one of the silicone oils can collect gas molecules arriving at its entrance port with an efficiency of 20-30 percent and deliver them to a sample container at its output. Thus a sample of any lunar atmosphere could be collected over a period of hours, or days if necessary, and returned in a sample bottle. At a lunar atmosphere level of 10^5 molecules/cm^3 a 6 inch pump will produce approximately 10^{-7} mm Hg pressure increase per second in a 10 cm^3 sample container.

8. A moderate-resolution mass spectrometer. Some estimation of organic content should be obtained to permit return of the best samples for protogeological study. The spectrometer can also be connected to the gas sample compressor and will then yield a system able to locate gas emission at a distance since it will indicate changes in the lunar atmosphere, if its density is near the estimated 10^5 molecules/cm^3, with a time constant of

approximately 1 second. Provision of a movable collimator on the input of the gas compressor could localize the direction of arrival of the gas molecules.

9. Water and organic material detector. Some unspecified detector able to distinguish moderate (0.1 percent) water concentrations in samples without requiring long sample preparation or other slow processing. For example, a small sample might be heated using a small solar mirror and the effluent gases condensed and tested by the single crystal infrared probe. Indication of water content and the infrared spectrum of organic compounds would be given. A possible instrument might be developed from the infrared single-crystal ATR probe (attenuated total reflectance: Ge or Si crystal) presently under study by J. Harrick (Phillips Laboratory, New York). This small probe instrument yields an infrared spectrum of any powdered material into which it is inserted. While still in the stage of feasibility study, the precise, specific and semiquantitative nature of this technique for analysis of OH^- H_2O, in solid, powdery samples appear to make it most attractive.

10. X-ray diffractometer. A unit similar to the Surveyor diffractometer is intended. Except for visual examination, this is almost our only sample selection method which allows distinction of different phases.

The working group concludes that an X-ray diffractometer is of indeterminate value as a tool to be included in the LEM. However, inasmuch as an X-ray diffractometer package is already available, it seems worthwhile to have this evaluated as an AES tool. If evaluation on simulated missions is favorable the package might be considered for inclusion in the LEM package. We do not, however, recommend any expenditure of funds for further development of this unit or for development of any other diffractometer unit, unless or until a favorable mission evaluation makes such further development appear worthwhile.

11. Alpha or proton backscattering spectrometer. Some version of this instrument similar to that prepared for Surveyor might be made available. The X-ray fluorescence spectrometer covers this same ground but is perhaps of better resolution.

Some types of equipment have been considered and tentatively rejected for AES. These are:

1. Thin section maker. Too time consuming and probably hazardous.

2. Quick sample saw. We doubt the value of a quick dry-sawed surface as compared to a fractured surface, and there is some doubt that the saw will operate without coolant in vacuum.

3. Alpha-backscatter atmospheric studies. Unlikely to be of value at expected lunar atmospheric pressures.

Equipment for Exploration Geochemistry

Certain analytical tools lend themselves to the mission of exploration geochemistry; that is, directed search for specific materials.

Some specific objects of exploration are:

1. Water-containing minerals
2. Materials bearing organic compounds
3. Sources of gas emission
4. Areas of thermal activity
5. Areas of radioactivity

We assume that lunar orbiters have determined the major topographic and thermal features of the moon, and that landing sites are chosen using this information.

Terrestrial experience has shown that detailed ground exploration (with instruments) is essential in order to locate precisely the targets located by remote sensors.

Although no (internal) thermal sources have been observed from the Earth, such areas would be prime sites for the location of gas collecting equipment. It is possible that with much better temperature and spatial resolution, some thermal sources may be located.

Chemical encrustations may be the location of fossil thermal sources and would be attractive sites for study.

Instruments for use on the lunar surface suitable for defining the distribution of these various materials are listed below, in order of decreasing range of operation. Most of them have been described briefly in the previous section.

Instrument	Detected Parameters	Significance
A. WIDE RANGE		
1. Atomic absorption	He^4, Hg, Na	Detection of active outgassing areas.
2. Gas compressor & mass spectrometer	All gaseous emission	Detection of active outgassing areas.
3. Hand-held infrared radiometer	Heat or radiance differences	Detections of positive thermal areas.
4. Hand-held survey scintillometer	Gamma rays	Detection of areas of radioactivity.
B. CLOSE RANGE		
5. Neutron surface analysis unit	H, O, Si, Mg, Al, Fe, K, O, Th, etc.	Water, organic matter, general characterization of surface.
C. NEAR CONTACT		
6. Atomic absorption spectrometer with flash excitation of the metal	NaCl, KCl, HgCl	Detection of encrustation from fossil outgassing.

D. OPTICAL CONTACT
(Negligible Range) - Powder or liquids

7. Single crystal IR probe - ATR (Attenuated total reflectance)	H_2O, OH^- (Specific)	(a) Water for life support. (b) Lunar surface hydration patterns.
	$CO_3^=$	Possibility of K, Na, Ca "carbonatite" as a magmatic phase.
	C-C bond	Organic compound detection.
8. X-ray fluorescence	elements Na through Fe	Elements analysis.

The instruments not described in the above discussions are the infrared radiometer, the atomic absorption spectrometer and the survey scintillometer:

(1). Infrared radiometer

The infrared unit is a simple, wide bandpass (5-20 microns) radiometer, with an equivalent blackbody temperature sensitivity of about 0.5^o at 350^o K. The angular acceptance (field of view) is about 3^o, the time constant below 1 second. For lunar use this would be a completely self-contained, hand-held unit, with direct-dial readout.

(2). Atomic absorption spectrometer

This spectrometer is an exceedingly specific detector of great sensitivity. The technique relies upon the difference in resonance radiation in a pair of cells containing different isotopes of the material being observed. When sunlight passes through the lunar atmosphere, self-absorption occurs for the normal isotope, which produces an unbalance of resonant radiation in the cells. Photoelectric detectors view each cell and establish the presence and level of the element.

(3). Survey scintillometer

This device could be similar to the type used in uranium prospecting and in health physics consisting of a scintillation crystal, photomultiplier and associated circuitry. The detector and preamplifier could be a plug-in unit to be attached to the survey meter carried for health-physics purposes, or a scintillation device could be used instead of a Geiger tube and thus serve both functions.

Geochemical Observations Requiring the Lunar Environment

Not all important geochemical data about the Moon are derivable from returned lunar materials. The nature of the atmosphere and transient phenomena in the atmosphere must be investigated in the lunar atmosphere. Very finely divided condensates from impact-generated volatiles or from degassing of the interior may be very difficult to return to Earth intact; i.e., exposure to even small amounts of H_2O, O_2, or CO_2 may result in chemical reactions. The detection and characterizations of these compounds may best be done on the lunar surface. Measurements of other quantities, e.g., IR reflectance surface density and texture observations, may also be meaningful only when made *in situ*.

Atmospheric measurements. These measurements are necessary to evaluate the relative importance of internal degassing, degassing by volatilization due to impact processes and accretion of gases from the solar wind. The pressure inferred for the lunar atmosphere is less than 10^{-6} mm, perhaps as low as 10^{-12} mm. Very sensitive devices are required to investigate gases at such low pressures. Meaningful measurements of the atmosphere's composition and pressure will thus require both the development of instruments and adaptation of these instruments for flight hardware. Two concepts have been proposed to date:

1. An ultrasensitive mass spectrometer based on a coincidence concept.

2. Gas compression devices (e.g., Hg diffusion pumps) which will feed a conventional mass spectrometer (see above), and will concentrate gases into very clean containers.

Other measurements on the surface:

1. *In situ* infrared reflectance measurements will be needed to interpret data from orbital missions.

2. Devices which determine the presence of and identify chemical phases whose stability depends on the lunar environment need to be investigated. One method proposed to detect such phases is a sensitive X-ray diffractometer.

3. Mapping of variations in surface density by a device using backscattered gamma rays may be very useful in explanation of surface features.

LUNAR ORBITER MISSIONS

Lunar orbiter experiments have special advantages for geochemistry. First, mapping of the lunar surface can be wide, and even approach completeness. Because of the absence of an atmosphere, all regions of the electromagnetic spectrum are accessible. Some of these, especially the gamma-ray, infrared, and X-ray regions, can give direct information on chemical composition. This may well be an important consideration in the choice of later landing sites, both for scientific interest and also quite possibly for logistic reasons (e.g., availability of H_2O).

Polar orbital missions have a special interest because one may find quite new phenomena. In particular, the regions of permanent shadow may have layers of volatiles (in particular H_2O) at the surface.

Furthermore, data from a large, representative area of the Moon, combined with lunar control analyses and measurements from the AES landing sites, may provide very useful average values, which may establish the concentration of certain elements and minerals in the uppermost layer of the Moon. Such geochemical averages are most important in our thinking about the Earth. Here, they have been obtained by averaging a large number of individual rock analyses (or analyses of composite samples), with the attendant statistical difficulties.

The monitoring of temporary emission of volatiles from the lunar interior is an interesting possibility, and some of the highly specific spectroscopic tools naturally lend themselves to synoptic studies from orbiters. The emanations thus far observed or inferred have involved at most a very small mass of gas by terrestrial standards, and the intensities may not be favorable. However, the importance of such gases justifies a serious effort in developing the instrumentation.

Table I summarizes some facts about possible techniques for observing the lunar composition, and gives tentative ratings for them.

Ratings are given corresponding to their value to geochemistry, mineralogy or petrology. It is desirable, in our opinion, that all experiments rated A through C actually be flown in lunar orbit following Earth orbit checkout, where applicable. An asterisk (*) refers to an experiment whose potential may change radically as a function of further development in the coming years.

One of us (J.R.A.) feels impelled to declare that he had no part in rating the gamma-ray experiment.

A feasible vacuum UV experiment should be considered for lunar orbit following Earth orbit checkout, if proposed. Major, intense chemical absorption edges occur in this region and a change occurs in the nature of the exciting source (the solar spectrum). In passing to the far UV the familiar pattern of continuum with absorption lines changes to one of bright lines and weak continuum. This may make the geochemical information more readily apparent.

TABLE I

LUNAR ORBITAL GEOCHEMISTRY, MINERALOGY & PETROLOGY

Technique already proposed	Spectral range	Use	Rating
Gamma-ray sensing	100 keV-10 MeV	radioactive isotopes	A
Infrared spectral emittance measurement	8-20 microns	mineralogy petrology (phase analysis)	B1*
X-ray sensing	1-50 Å	elemental composition	B2*
Atomic absorption spectrometry	UV, visible, IR	near surface trace elements	B3*
UV passive sensing (spectral reflectance of solar energy)	1800-3000 Å	petrology mineralogy	C1*
UV active sensing (source in orbiter)	2000-3900 Å	petrology mineralogy	C2*
Alpha emission measurement	10 MeV	elemental composition	D
Other experiments suggested:			
Vacuum UV sensing	50-2300 Å	chemical absorption edges	*
Neutron albedo measurement		possible experiment	--
Beta-ray sensing		unlikely to be of value	--

The committee endorses the rest of the lunar geoscience remote sensing program as presently proposed (i.e., multispectral photography, microwave and radar), and foresees this as necessary to provide a context for the geochemical and petrological studies. Earth-based testing of all types of the remote sensors is mandatory where possible.

ATMOSPHERIC STUDIES

The composition and density of the lunar atmosphere are of fundamental importance in evaluating the nature of lunar degassing processes.

The relative merit of measurements made from a lunar orbiter or the CSM versus those made on the surface should be evaluated. The scale height of the lunar atmosphere must be large, on the order of tens of kilometers or more. Locating atmospheric probes in the CSM will have the advantage of both wide coverage and early arrival in the lunar atmosphere.

POST-AES GEOCHEMICAL AND PETROLOGICAL INVESTIGATIONS

GENERAL DISCUSSION

Early Apollo landings will provide a first look at the lunar surface and first samples of known lunar materials. AES landings and missions will permit limited examination of selected features and areas of the lunar surface, and reconnaissance mapping and sampling of these areas. During AES missions, major problems to be examined can be sharply defined, methods of investigation tested and appraised, and the foundation laid for thorough study of the fundamental geological and geochemical questions presented by the Moon. Both early Apollo and AES will thus serve important functions, but they must be regarded as only preliminary steps in an adequate investigation of lunar problems. The main stage, during which maximum scientific returns from lunar exploration can be expected, will require longer stay times, larger numbers of personnel, greater mobility, and more elaborate equipment than provided by the earlier missions. To provide these, a program of post-AES exploration is needed.

The scientific program for these missions must be formulated as soon as practicable, since a definition of the missions themselves, and the engineering planning for them, must follow and not precede this. For this reason, in our opinion, an endorsement of the LESA system is premature at this time.

A few of the scientific considerations involved in advanced mission planning are presented in the remainder of this section.

SCIENTIFIC OBJECTIVES OF POST-AES MISSIONS

We strongly urge that in post-AES missions effort be focused on major scientific problems presented by the Moon, in contrast to an attempt at total mapping of the Moon, or mapping of major portions of it, by surface methods. In our judgment, this approach will yield far greater scientific returns per unit of cost and per unit of manpower in a much shorter time. Subject to their confirmation by earlier missions, attack on the following problems should be the main purpose of post-AES missions:

1. Igneous processes operative on the Moon and their relation to tectonics

2. Other processes of chemical fractionation, such as selective volatilization

3. Surficial processes on the Moon, such as impact phenomena

4. Internal processes induced by major impacts

5. Bulk composition of the Moon

6. Processes of mineral alteration

7. Lunar outgassing

8. Phase assemblages peculiar to the lunar environment

9. Lunar chronology

10. Origin of the Moon

11. The relation of lunar geochemistry and petrology to that of the Earth and their bearing on Earth and planetary problems

The solution of these problems rests heavily on the acquisition of geochemical and petrological information closely correlated with geological and geophysical data. This information can be most efficiently obtained by extended and detailed investigation of areas that illustrate critical features and relationships of lunar geology. Volcanism, for example, should be studied at one or more specific sites where AES and other mission data indicate that a range of volcanic phenomena is displayed. Geochronology requires investigation of boundaries between different units (e.g., highland-mare boundaries). Sampling of units inferred from geologic mapping to be especially ancient, hence possible primordial material, will be of great interest as bearing on the conditions, processes, and time of development of planetary bodies in the solar system.

PLANNING OF POST-AES MISSIONS

Generations of experience both in scientific research and in practical exploration indicate clearly that any complex exploration program must be kept as flexible as possible, so that experience in early stages can be used to guide the later stages. Engineering support following the same principle of flexibility is highly desirable and will have a direct bearing on the success of exploratory missions.

SUPPORTING RESEARCH

Ground-based support activities include (1) mission-oriented research as an integral part of manned space programs and (2) supporting research, less closely connected with particular flights. Both categories are expected to provide continuity and integration in the lunar science program.

This group recommends that experiments performed on returned lunar samples be considered as mission-oriented, in the sense that they are an indivisible part of the overall lunar program. Development of instruments, of course, is mission oriented, and we recommend that investigation of new possibilities in instrumentation be vigorously promoted. A good example of a need for this approach is the development of a convenient sniffer for detecting lunar water.

Field testing of instruments should include application to lunar-analog terrestrial sites, as an important part of ground calibration. Field testing, from the surface or from aircraft, must be done wherever possible, perhaps by the USGS.

Supporting research is essential for meaningful and useful interpretation of information obtained from lunar landings. In the broad sense the supporting aspect of the lunar program must include continuing research on terrestrial analogs of possible lunar structures, materials and processes. Without this the mission-oriented work as such will soon suffer.

For the most efficient use of the returned lunar material a large body of information must be at hand, both for intelligent distribution of samples at the LSRL and for optimum use of the samples in individual laboratories. Continuing research, as planned for the first Apollo samples is required. The system of dry runs and interlaboratory calibrations will give increasingly refined data on such questions as the relative nondestructiveness of the many measurements to be performed, and hence their interference with each other when performed on the same sample.

In addition to this we recommend that SRT support be increased to insure independent development of ideas which have application to lunar studies. Necessity for this support is obvious if, as is widely believed, lunar surface material is similar to such presently known materials as terrestrial rocks, meteoritic material and cosmic dust. A narrow interpretation of NASA's role here might be based on the supposition that these areas of work, which often are related to other fields, will be adequately supported elsewhere. However, considering the scale of the lunar program, this outside support alone may prove quite inadequate.

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We must note here the consequences of the possible finding that the lunar materials are seriously degraded in low vacuum or inert atmosphere. In that event it will be necessary to provide high vacuum facilities in many laboratories.

DATA PROCESSING AND ANALYSIS

The geochemistry-petrology working group expresses serious concern about the readiness and availability of scientific manpower and physical facilities needed to devote to the analysis, evaluation and interpretation of lunar exploration data. Problems are expected to arise in the compilation and analysis of topographic and geologic data, and surface and orbital geochemical and geophysical data.

The manpower shortage may not be severe during the early Apollo phase. It may well be severe when AES data are returned. We recommend that an estimate of the amount of the expected data and data reduction from early Apollo and AES explorations, and an estimate of current scientific manpower be made at once. If the shortage is shown to be severe, support for training scientists and construction of laboratory and analytical facilities should be increased. We emphasize strongly the long lead time required by such programs.

GENERAL MISSION REQUIREMENTS

PLANNING MISSION PROFILES

This group has examined the geochemistry and petrology parts of several reports prepared by industrial corporations, and has found them in many cases overgeneralized and unrealistic. Although such studies have in the past been considered necessary for long-range planning and procurement, it is hoped that instead of delegating the definition of the lunar science program to industrial concerns and their consultants, this function will remain the responsibility of OSSA and its present working groups. In this way, NASA is more likely to obtain a meaningful and realistic program, and to provide opportunities for participation to the scientific community.

ENGINEERING ASPECTS

The inclusion of several intense sources of radiation on the Apollo spacecraft is of extreme concern to the members of this working group. Radioactive contamination of the lunar surface and radiation effects on instruments and film could seriously compromise scientific information to be gained in the lunar science program.

The joint committee chairmen's report treats this subject in greater detail. The radiation problem is one of the most serious to date in the more general area of interface between engineering and scientific requirements, and points out a need for closer communication among the groups concerned.

ASTRONAUT TRAINING

This subject is covered in the working group chairmen's report. We wish to emphasize the need for recruiting of more people trained in the geological sciences into the scientist/astronaut program, in order that mapping and sampling on the lunar surface may be done in the context of considerable experience on Earth.

SUMMARY OF RECOMMENDATIONS

APOLLO

1. Sample return should be given top scientific priority on the Apollo missions.

2. Astronauts should be knowledgeable in returned sample requirements and techniques of sampling.

SAMPLE RETURN

3. Sample containers should be fabricated from materials of known and simple chemistry. Stainless steel and Inconel are considered feasible for sample boxes. Teflon is recommended for sample bags and as a gasket material.

4. The sample receiving laboratory should be designed to handle sample unpacking, preliminary examination and cataloging, quarantine and biological studies, gas analysis, and low-level counting experiments.

5. A small amount of sample should be used for a preliminary survey examination. Up to 5 percent should be allotted for quarantine testing. A large amount of the remainder should be distributed for first-generation experiments, with a somewhat larger fraction held in reserve for later work. A smaller part should be held in reserve indefinitely.

6. Returned samples should be made available for scientific study within the shortest possible time. It is recommended that the quarantine period be not more than 30 days.

7. Geochemical, petrological and mineralogical examination should be performed on returned lunar samples soon after sample return so that these data can be of value on succeeding missions.

8. A series of 'dry-run' investigations shall be conducted prior to return of the first lunar samples. Samples to be investigated shall be very carefully chosen (1) to be of maximum value in evaluation of data, (2) to be of maximum scientific interest, and (3) to simulate lunar samples. Experiments on these samples are to be used for interlaboratory correlation and calibration, for upgrading in techniques and facilities, and ultimately as a factor in the selection of principal investigators.

9. Orientation toward a specific problem or problems should be a criterion for the selection of investigators who wish to participate in dry-run investigations and in studies of the returned lunar samples.

AES SURFACE MISSIONS

10. The major geochemical goal of AES is the return of intelligently selected samples from known geological contexts.

11. In order to allow adequate geochemical, petrological, mineralogical and biological investigations of returned lunar samples the sample return capability of each mission should be approximately 250 kilograms (550 pounds).

12. At least one of the astronauts on each AES mission should be a trained, experienced geologist. An attempt should be made to increase the number of such persons in the astronaut program.

13. The astronaut's position on the lunar surface should be monitored automatically during mapping and sample collection. Every effort should be made to minimize the proportion of the astronaut's time spent in mechanical duties.

14. Communication between AES astronauts and Earth-based scientists, on day-to-day mission planning and on problems that arise, is to be desired. Such communication should be restricted to brief discussions at prearranged times and when requested by the astronaut.

15. Certain diagnostic tools which can aid the astronaut in mapping and selection of samples should be developed and evaluated.

16. For maximum flexibility in allowing changes of instrumentation between missions, instrument packages should be designed in a modular configuration in AES and subsequent missions.

LUNAR ORBITERS

17. Remote sensing instrumentation should be developed further and evaluated in the hope that the most valuable sensors may be flown in lunar orbit following Earth orbit checkout. Other types of instrumentation, for parts of the electromagnetic spectrum not presently covered, should be explored.

SUPPORTING RESEARCH

18. Experiments performed on returned lunar samples should be classified as mission-oriented in that they form an indivisible part of the overall lunar exploration program. Supporting research which is not mission-oriented should be expanded and upgraded because of its importance in interpreting and utilizing the wealth of new data that will accumulate as a consequence of both Apollo and later missions.

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REPORT OF
PARTICLES AND FIELDS WORKING GROUP

MEMBERS OF WORKING GROUP

CHAIRMAN: W.N. Hess, Goddard Space Flight Center, NASA

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W. Webber, University of Minnesota

J. Trombka, NASA Headquarters

INTRODUCTION

For the purpose of this meeting the particles and fields area was divided into the following subjects:

The Lunar Magnetic Field (Dessler and Sonett)

Particle Measurements on and Near the Moon (O'Brien)

The Lunar Electric Field (Petschek)

Galactic Cosmic Rays (Shapiro)

Solar Energetic Particles (Webber)

Neutrons (Hess)

Charged Albedo (Trombka)

Other topics also covered were:

Radio-Astronomy and Radio Propagation

Lunar Atmosphere and Ionosphere

The scientists assigned to the topics in the list above were responsible for contacting authorities in the field and preparing position papers on the separate subjects. These subjects were then discussed at length by the working group and recommendations were drafted.

SUMMARY

A summary of the findings of the working group is, for early LSEP's: (1) a magnetometer and particle detector should be included to measure the gross electrical conductivity of the Moon, the thermalized solar wind that constitutes part of the lunar atmosphere, and also to investigate the complex interactions of the solar wind and lunar surface, (2) a lunar atmosphere and ionosphere experiment should be included. The lunar atmosphere and ionosphere should be measured early because of both intrinsic interest and the increasing contamination produced by successive missions, (3) it is desirable also to measure the electric field near the surface of the Moon measured on one of the LSEP's.

A separate report has been prepared to cover the interests in this area through the use of lunar orbiters. This seemed appropriate because planning for lunar orbiter science is well along on some subjects but the Particles and Fields discipline had not been discussed before this meeting.

On lunar orbiter, the group recommends: (4) that a similar package to the LSEP package be flown in a magnetically-clean and radiation-clean spacecraft. These orbital experiments should be carried out simultaneously with and for the same durations as the LSEP experiments. We recommend flight in two types of orbits, (a) in the planned altitude range of about 50 to 100 km so as to study day-night changes in the particles and fields environment with a 2-hour period and, (b) in the altitude range of 100 to 2000 km in an elliptical orbit so as to penetrate any shock front. (5) In the AES programs the group recommends, in each of the subject areas discussed, a phased series of experiments as discussed below. A more complete statement of the group's findings treated by subject is presented here.

RECOMMENDATIONS

THE LUNAR MAGNETIC FIELD AND THE INTERACTION OF THE SOLAR WIND WITH THE MOON

These two subjects are linked together here because in the view of the committee they are very closely related and probably are different parts of the same problem. If the lunar field is produced by accretion of solar field due to the solar wind striking the Moon (as seems likely) then the two subjects are inseparable.

1. It is recommended that a three-axis magnetometer be included in the LSEP's. The magnetometer should be capable of operating continuously during both lunar day and night, sampling the vector magnetic field at least once per second. The sensor should be placed at a location where the magnetic field due to the LSEP is less than 0.25 gamma. The magnetometer should be capable of measuring transient fields in the range 1-200 gammas with a resolution of at least ±0.5 gamma throughout this range. The resultant telemetry requirements are at least 60 bits/second. It is expected that the instrument should weigh less than 10 lb, excluding cabling and orientation jigs, etc.

2. A particle-detector package should be included in the early Apollo LSEP together with a magnetometer. This package should measure the flux directionality and energy distribution of electrons and protons with energies between about 10 eV and 100 KeV, during both lunar day and night. A reasonable particle-detector package would weigh 5 lb and take 30 bits per second.

3. It is recommended that a three-axis magnetometer be flown on Apollo Lunar Orbiter missions coordinated with the observations from a ground based magnetometer as given in (1) above. It will be necessary for the environment of the orbiting instrument to be magnetically clean to ±0.05 gamma (both permanent and transient). The system used should permit operating the magnetometer for the life of the LSEP. This probably requires a subsatellite. The magnetometer should be comparable to the LSEP instrument in characteristics.

4. A surface-based particle package as in recommendation (1) should be used in coordination with a similar package flown at the same time in a lunar orbiter, not necessarily manned. The system should later be extended to a network that will include at least two surface packages, located on opposite sides of the Moon.

5. It is recommended that magnetometers be developed for implacement on the lunar surface as a first step in what ultimately would result (in the AES program) in a network of magnetometer stations. A fundamental configuration of particular interest would be two (2) magnetometer stations 180° apart (i.e., on opposite sides of the Moon) near the equatorial plane. Specifications on sensitivity and frequency response should be determined from the results of the survey experiment (recommendation (1)). Otherwise the specifications should be that of recommendation (1).

THE LUNAR ELECTRIC FIELD

The Moon very likely has an electric field for the first 10-100 m altitude but the magnitude of this field is difficult to estimate. The electric field is also clearly related to the interaction of the solar wind with the lunar surface.

6. We recommend that a measurement of the vertical component of the electric field on the lunar surface be attempted in the Apollo program as early as possible. The expected range of interesting fields are of the order of 0.1 to 100 volts/meter for the first 10-100 meters.

7. In the AES program, we recommend coordinated measurements of particle characteristics and magnetic and electric fields made in three domains:

(a) On the lunar surface,

(b) On an insulated flagpole some 10 meters above package (a),

(c) On a lunar orbiter at an altitude of order 100 kilometers.

The particle detector package here would weigh 10 lb and use 100 bits per second.

GALACTIC COSMIC RAYS

8. Certain cosmic-ray studies could profit from the "enroute" capabilities of the Apollo vehicle, which would permit measurements outside of the Earth's magnetosphere and its radiation belts. Since these need not interfere with lunar-landing or lunar-orbiting activities, we recommend that they be scheduled for early lunar missions, as well as later ones. Examples of such studies are: (a) investigations of very heavy primary nuclei, (b) studies of low-energy cosmic-ray nuclei, and (c) studies of cosmic gamma rays. Items (a) and (b) could be carried out with nuclear emulsion stacks, as well as with other techniques. The development and utilization of subsatellite techniques for the favorable deployment of the apparatus (e.g., from the service module) at distances about 10 meters from the spacecraft should be encouraged, as recommended elsewhere in this report. Also, the provision of an air lock in the command module would obviate the requirement of an extra-vehicular activity (EVA) for recovery of equipment when this is essential. In the earliest manned lunar landings, it would be difficult to justify the emplacement of apparatus for observation of galactic cosmic rays from the lunar surface. To do so would detract from the prime purpose of these missions–the exploration of the Moon per se.

9. Some of the rock samples collected in the earliest lunar landings should be exploited for the study of galactic cosmic-ray history by analysis of appropriate radiogenic and stable nuclides.

10. Experiments for the exploration of the Moon's cosmic-ray albedo would be useful for assessing the albedo background that subsequent experiments in the lunar vicinity would suffer. Such experiments are recommended for the lunar orbiting phase of early lunar missions, to be carried out on a noninterfering basis, e.g., from the service module.

11. In subsequent lunar missions, in the AES program and beyond, we recommend that an increasing share of the scientific

capability on and near the Moon be devoted to those galactic cosmic-ray observations that could benefit significantly from the special properties of the lunar environment, e.g.:

(a) Cosmic gamma-rays. The same apparatus could be adapted for study of primary electrons and positrons. The difficulties of lunar background (albedo) are recognized, but it is assumed that suitable countermeasures would be employed. Lunar experiments on cosmic gamma rays—a subject still in its infancy— should be preceded by a vigorous program of experimentation near the top of the Earth's atmosphere using balloons. We recommend strong support for such a program, which should include the development of reliable balloons capable of lifting a ton of equipment to 125 000 ft and about 500 lb of payload to about 150 000 ft, with flight durations of about 24 hours.

(b) Monitoring of low-energy (< 1 BeV) galactic cosmic-rays. The same apparatus could be used for monitoring solar energetic particles.

(c) Ultra-high energy cosmic rays ($>10^{12}$ eV).

(d) Monitoring of (a) and (c) as well as particles in the range 10^{9} - 10^{12} eV.

(e) Cosmic neutrinos.

We recommend that (a) and (b) be included on early AES missions, and (c) and (d) on later ones. Item (e) presents difficulties greater by several orders of magnitude, and would be impractical until a substantial lunar base will have been established.

SOLAR ENERGETIC PARTICLES

The occasional violent outbursts of protons from the sun related to solar flares can be studied from the Moon in ways not possible from the Earth.

12. We recommend that the radiation monitoring nuclear particle detection system on the service module on Apollo be reviewed by the panel appointed by the working group with a view to extracting its full scientific potential without interfering with its operational use.

13. We recommend that a particle telescope be flown on an early lunar orbiter to study the anisotropy of different charged components of solar and the lower energy galactic cosmic rays less than 1 BeV. Such a single instrument can give extremely valuable information that cannot be obtained near the Earth.

14. We recommend that a multiple-station particle telescope system be developed for a more complete study of anisotropy of different charged components of solar and the lower energy galactic cosmic rays as part of the AES program. The system should have at least two ground stations on opposite sides of the Moon for detailed and continuous study of solar cosmic ray events. The addition of an orbiting particle telescope would greatly enhance the usefulness and reliability of the system.

NEUTRONS

A study of neutrons looking out of the surface of the Moon can yield information of the chemistry of the Moon.

15. We recommend that a neutron experiment be flown on early lunar orbiter flights to survey for the hydrogenous content of the lunar surface. It would be very useful but not necessary to have this instrument flown in connection with a gamma-ray instrument that would measure the concentration of Fe and Si and K. The instrument must be located so that the neutron background from the spacecraft is not a problem. This probably means using a boom or trailing cable.

CHARGED ALBEDO

There seems to be no useful basic physics to be obtained by studying the high energy charged secondary particles coming out from the Moon. It is useful to understand the fluxes of these particles in that they constitute a background for cosmic ray measurements. Recommendation (1) covers this point. One of the areas of possible interest comes from the suggestion that if a neutron generator experiment is considered for flight, a proton detector should be considered for use with the X-ray spectrometer. Most other experiments considered in the section are considered as useful for geochemical analysis, and were considered by the Geochemical Working Group. Besides these subjects which are within the particles and fields discipline there were several related subjects which came up for discussion.

RADIO ASTRONOMY AND RADIO PROPAGATION

This subject is really outside the area of Particles and Fields but certain aspects of space plasmas can be measured by radio detection, especially at low frequencies, so we decided to treat the subject briefly here.

The recommendations in the present category refer to the AES program only.

16. We recommend that a sensitive receiving system be installed upon the lunar surface for the detection of electromagnetic radiations from galactic, extragalactic and solar system sources in the low frequency region, 0.001 - 5 Mc/sec^{-1} approximately. The earlier phase experiments would require simple and small-size antennas and would have crude (2 pi) directivity only. Later phase experiments should include improved directivity requiring more complex antennas (interferometer arrays) of considerable size and extent emplaced by the astronaut(s).

We also recommend the following radio propagation experiments:

17. Measurements by Earth-lunar transponder(s) of integrated electron densities in the cislunar space, and of the effects of the interposition of the Earth or Sun-Earth magnetosphere between the Earth and the Moon.

18. Measurements with antenna(s) deployed upon the lunar

surface of impedances. The use of single wires strung out upon and/or above the surface, energized with frequency sweep from about 0.001 - 30 Mc/sec^{-1}, would yield valuable information about the lunar surface material.

19. Evaluation of ground wave propagation and radio propagation in general upon the lunar surface with a receiver deployed some 1-10 kilometers on the surface from the transmitter of (2) just above.

LUNAR ATMOSPHERE AND IONOSPHERE

Professor F. C. Michel of Rice University, who has been a member of the lunar atmosphere measurement team, met with the particles and fields working group at Woods Hole. We include in this report a discussion of the lunar atmosphere and ionosphere.

20. We recommend that a spectrometer (preferably a neutral mass spectrometer, but at least an ion mass spectrometer if development is not completed on the former) be flown on the first LSEP. It is expected that each experiment if individually packaged would weigh 5 - 10 lb and consume 5 - 10 watts. This experiment must be performed early in the lunar exploration program to avoid contamination by the landing vehicles. The telemetry is expected to be nominal (say 10 bits/sec) since relatively long times are required to gather good statistics at low pressures. For the spectrometers a mass resolution of 1-2 percent would appear adequate to distinguish among the likely atmospheric particles. All instruments should be capable of performing adequately in the pressure range 10^{-7} - 10^{-13} atm. The precision of each determination by single measurement devices (ion density, directed flow, or total pressure) should not be significantly poorer than 1 percent while the absolute accuracy should not be poorer than 10 percent. Time resolution of 0.1 second seems desirable for pinpointing of outgassing sources, although the above constraints together with a very thin lunar atmospheric pressure might not permit this value.

21. We recommend that the LSEP design be modular such that other atmospheric experiments could be used after the first successful Apollo mission. Following the first successful mission we

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recommend a three instrument package containing a neutral mass spectrometer, a total pressure gauge and an ion densitometer. Assuming substantial success of at least one of the neutral particle spectrometers on the earlier missions, it is proposed that more emphasis be placed on ionospheric measurements, for example an ion mass spectrometer, an ion densitometer, and a directed flux measurement. If atmospheric variations are discovered in the previous missions, however, a total pressure gauge should be flown additionally or in place of one of the above ionospheric measurements.

22. It is recommended that both ion and neutral mass spectrometers be included onboard a lunar orbiter for determination of a (partial) atmospheric composition profile. Due to the weaker lunar gravitation, the scale height will be much greater than for the Earth, and furthermore the ram effect will increase the effective pressure at the instruments, hence useful information can be gathered at altitudes of the order of 100 km. Depending on the results of Apollo measurements, concepts such as an ionospheric topsounder may deserve serious consideration. It seems likely at this time that such instruments would operate in the frequency range 1 - 30 kc/sec.

23. It is recommended, in view of the relatively large payload capabilities in the AES phase, that an Atmospheric Variability Survey (neutral mass spectrum, and total pressure) together with an Ionospheric Variability Survey (ion mass spectrum, density and flow) be undertaken to form the basis for a network (one survey station of each type per lunar surface mission): It should be anticipated that the precision and time resolution specifications may have to be tightened on the advanced missions in order to obtain useful information, e.g. a precision of 0.1 percent with a time resolution of 0.01 sec. With such high time resolutions, two instruments on a single vehicle can be used to advantage. Again, electromagnetic measurements (e.g. the ionosonde) may be practical.

GENERAL

In the general discussion at this meeting several ideas were brought forward that do not deal with a specific scientific subject.

24. In view of the interference to scientific experiments posed by radiation sources and stray magnetic fields in the Apollo spacecraft, we recommend that considerable attention be given to a subsatellite which is designed to be a purely scientific package with 100 to 200 lb capability.

25. In order to recover materials from outside the spacecraft and bring such materials into the command module for return to Earth without requiring excess EVA by the astronaut it is recommended that airlocks be included in the design of the Apollo spacecraft.

MAGNETIC FIELDS ON AND NEAR THE MOON

A. J. Dessler and C. Sonett

INTRODUCTION

The magnetometer on Lunik II set an upper limit of about 100γ (10^{-3} gauss) on the magnitude of the lunar magnetic field at the impact point (Dolginov et al., 1962). For this reason, as well as others having to do with lunar magnetic decay, it is believed that the Moon has a negligible intrinsic magnetic field. Accordingly it appears likely that the dominant contribution to the lunar magnetic field may come from the interplanetary magnetic field diffusing into the lunar interior. There is consequently two-fold interest in measurements of magnetic fields on and near the lunar surface, viz

1. such measurements will determine the magnetic field of the Moon and provide information on the bulk electrical conductivity, and

2. measurement of these magnetic fields will permit study of interplanetary magnetic fields and compressed fields associated with possible lunar shock fronts.

It should be possible, with a single magnetometer package on the lunar surface, to determine the gross internal electrical conductivity of the Moon. Such a measurement could be helpful in placing constraints on such internal lunar properties as composition and temperature. The experiment would also yield useful data related to the flow of solar wind past the Moon, e.g., to the question of the formation of a standing shock.

The nature of a standing shock front created by the Moon in the supersonic solar wind has been treated theoretically. However relatively little experimental information is available. The lack of an intrinsic magnetic field would be associated with the absence of a liquid core (this conclusion is drawn on the basis of its low density and small size). Consequently the intrinsic lunar magnetic field would not present an obstacle to the supersonic solar wind so as to cause a shock, whereas for the earth it is the magnetic field that causes such a shock.

However, Dessler, Kleinmann, and Cloutier have considered a mechanism that might cause a lunar shock. It is simply that the electric field of the moving solar wind plasma causes body currents in the Moon, thereby generating a magnetic field which must obstruct and interact with the solar wind to cause a shock. This mechanism does depend on the (unknown) electrical conductivity of the Moon, and it will occur if the conductivity is between 1 mhos/meter, and 10^{-7} mhos/meter within which range it seems likely to be.

Since the obstructing magnetic field is produced by currents within the Moon, one may reasonably expect a shock standoff distance of about 500 km at the subsolar point. But the shock thickness should be about 100 to 1000 km (up to the ion cyclotron radius for a proton velocity of 500 km/sec in solar wind magnetic field of 5 gamma), so the Moon may be partially immersed in the shock transition.

One therefore may expect that thermalized solar wind will strike the lunar surface, and some may be neutralized and absorbed. One also expects very great differences in the lunar magnetic and particle environment at different local times around the lunar surface.

DETERMINATION OF GROSS LUNAR CONDUCTIVITY

The decay time for a magnetic field in a body of conductivity σ and permeability μ is given by $\tau \approx \sigma\mu L^2$ where L is the effective scale of the body (here, say, the radius of the Moon). For the case of very dry rock, $\sigma \cong 10^{-7}$ mhos/m, the diffusion time for the Moon becomes ~1 sec. For earthlike materials the conductivity varies over a range of 10^5 and depends strongly upon the water content. Also, temperature is an important factor.

From equation (1) it is seen that the effects of conductivity and permeability are both linear in the decay time. For the case of the solar wind the relevant characteristic time is short since the wind is transported one lunar diameter in about 4 sec. Very dry rock has a skin depth of approaching 10^8 cm at a frequency of 1 cps. Therefore the body of the Moon (radius ~2×10^8cm), even if the conductivity is as low as very dry rock at room temperature, lies in a transitional regime where the interplanetary field partially passes through the core and is partially deviated as in the case of the magnetosphere. Ignoring for the moment the question of shock waves, from this more simple viewpoint it is expected that interplanetary field will accumulate against the subsolar side of the Moon and that this will result in some field compression. This compressed field would diffuse into the Moon.

The field which is swept up into the interior of the Moon will be especially interesting for times when the configuration of the interplanetary field is changing. Especially important will be the changes in direction of the field that occur during storms as well as every 5 to 10 days. These changes will result in gross changes in direction of the internal field. Thus magnetic layers of varying polarity should be found.

Solar wind pressure can compress the interplanetary field to about 50γ on the sunlit hemisphere. On the dark hemisphere, the ~50γ field that had diffused into the Moon will begin to diffuse out to approach the interplanetary value (~5γ). Simply by studying the decay of the field a reliable estimate of the gross integrated conductivity can be obtained.

A magnetometer experiment would operate approximately as follows:

> For the 2 weeks while the magnetometer station was on the sunlit hemisphere, a record would be compiled of the magnetic fields that were diffusing into the Moon. When the Moon turns on its axis so the magnetometer station is facing away from the Sun, a 2-week record of magnetic decay would be obtained. With this method it should be possible to determine the gross lunar conductivity if it lies in the range 10^{-7} mho/m to 1 mho/m. (These two limits are determined by the extreme time periods of (a) time for solar wind to flow 1 lunar diameter and (b) time for Moon to turn 360° on its axis).

MAGNETOMETER CONSIDERATIONS

The types of magnetometers which have been used extensively are nuclear resonance (He and Rb) and flux gates. For fast, (i.e., ~1 sec) measurement both He and flux gates are satisfactory, although some question may be present regarding the line width of the resonance for He. Either magnetometer requires remoteness from the central data processing, telemetry, etc., so that the background field will not be more than about 0.25 gamma. In general this will require a cable separating the magnetometer from the rest of the equipment of a length determined by the magnetic cleanliness of the system.

Either magnetometer will require thermal control. This is possibly more critical for the He magnetometer. The instrument will have to have a known orientation to at least a few degrees. The reference system is arbitrary as data reduction can include appropriate coordinate systems.

Telemetry should provide for buffering of data so that the three axes are sampled simultaneously. This is important for transient effects. Provision should be made for calibration of the magnetometer response and the zero offset. In the event that sufficient telemetry bandwidth is available, extension to frequencies above 1 cps should be made. The data system might include narrow band filters so that the returned data consists of a crude power spectrum. This does not provide phase information and a detailed trace of the signal from each sensor is preferable. Depending upon further evaluation, it might be meaningful to have time-shared data for the extended frequency range.

The requirement for 1 cps and a range of ±200 gamma with digitization to ±0.5 gamma means about 60 bits/sec of data. A small additional increment is required for engineering data such as temperature to provide instrument status. Some command capability is required for calibration purposes.

The astronaut requirements are relatively simple. They consist of unloading, implacement, and actuation and checkout.

APPLICATIONS OF GEOPHYSICAL PROSPECTING

From a more generalized standpoint we consider the use of Earth techniques for the exploration of the lunar subsurface. These techniques are both active and passive. The latter depend upon the character, i.e., frequency response of the returned signal when the material is driven by natural signals. The process requires that the results be fitted to a layered model and intrinsically dependent upon the skin depth at different distances under the surface. Also it is required that the character of the input signals be understood. The active methods operate both upon ac and dc principles. For these methods it is essential that sufficient current flow into the material so that the signal level can be interpreted. This is difficult on Earth and must be carefully considered for the Moon where the surface conductivity is likely to be low.

CONDUCTIVE PROSPECTING

For geophysical prospecting, one important approach to the determination of the layered conductivity involves the application of current probes directly into the Earth. The advantage of this system is that of the three electrical parameters which characterize a medium, μ, σ and $\mathbb{E}$, only the conductivity, σ, is important. It is valid to model the Earth as a planar medium of layered conductivity. The variables in the problem are the spacing of the electrodes and the frequencies which are used. The depth of the effective penetration increases as the frequency is lowered and as the spacing is increased. The latter introduces problems of background noise and the effective S/N ratio.

On Earth, to eliminate radiation field effects, 10 cps is the upper frequency limit for the applied field although 2 cps is more realistic. In order to probe to the mantle it is necessary to resort to periods which are of the order of 24 hours.

For the Moon the application of the technique described would probably be limited because of the expected low surface conductivity which would limit the current introduced into the lunar material. The conductivity in the vicinity of the probes is especially important. Customary potentials are of order 1 kilovolt. As an example the experiment of Cantwell, et al., involves sending 200 amperes into the ground. The length of the transmitter dipole (ds) is 50 to 100 miles and power substations must be employed. The separation of the transmitter and receiver is 100 miles. The depths of penetration are 30 to 40 miles. Earth conductivities range from 10^4 to 10^{-6} mks and probably are greater than for the Moon. As stated above a principal issue would be the coupling of the transmitter to the surface material. Little is known of this problem for the Moon. However, the expectation of an unconsolidated surface would increase the likelihood that electrical coupling from the electrodes to the surface would be difficult. It is especially important to have sufficient coupling in the immediate vicinity of the electrodes. The reason is that the main part of the potential drop occurs near the electrode and thus the near conductivity dominates the total current flow into the ground. It is suspected that grave difficulties would surround the application of the conductivity technique to surface layers of the Moon. However, the method should not be abandoned completely from consideration until the actual conductivity can be determined by direct experiment. The advantage that still accrues is that the method is dependent only on the conductivity.

INDUCTIVE PROSPECTING

In this method a signal is applied inductively to the surface material so that the electrical conductivity is no longer an independent parameter. The controlling factor becomes the skin depth, which is determined both by the frequency and the product of the permeability and conductivity. The experiment can be carried out in several different ways, using horizontal or vertical electric or magnetic dipole radiators. The particular configuration depends upon the details of the experiment. It has been suggested that the frequency range of 300 cps to 10^2 Mc/sec be considered for the lunar case.

MAGNETOTELLURICS

The subsurface electrical characteristics of the Earth are explored by several different techniques. The magnetotelluric approach is inductive and determines the response of the structure to the application of magnetic variations. Either natural or artificial signals are used, the former being the natural micropulsation spectrum of the Earth. Clearly, for the case of the Moon, something should be known about the natural environment before detailed statements can be made concerning the application of the technique using the natural radiation. In the magnetotelluric approach both the conductivity, σ, and the permeability, μ, enter into the computation; the effective impedance depends upon their product. The effective depth of penetration of the wave is given by the skin depth for the frequency in question. Assuming the Moon to have a conductivity equal to that of the driest rock on Earth, at frequencies $\sim$0.01 cps the skin depth is of the order of 10^4 km. Thus low frequency magnetoselenic waves should effectively penetrate the Moon. Because of this it should be possible to probe the total lunar sphere with natural signals. (It is assumed that the natural spectrum includes frequencies near one cps, a likely assumption based upon Earth measurements near the geomagnetic termination.) However, geometry of the problem becomes more complex than is usually assumed for magnetotelluric prospecting, since now the spherical body of the Moon must be considered. The problem is essentially the boundary value problem where a spherical body is excited by a source composed of nonplanar waves.

For the detection of ferrous material under the surface or from meteoritic infall, magnetometer traversal over the surface is required and should form a part of the general geological survey to be conducted with roving vehicles. This might mean a trailer analogous to the towed glider used for aerial survey over the Earth. The development of magnetoselenic gear for the subsurface response requires that consideration be given to a net though certain information can be obtained from a single site.

It is assumed that the development of a site instrumentation package for electrodynamic studies will serve to provide the prototype for other sites so that a certain uniformity in design can be achieved.

SUMMARY

A single lunar magnetometer station can obtain data that will be extremely useful in unraveling a physical picture of the internal constitution of the Moon. The specific data can be obtained by studying magnetic diffusion as a number representing the gross average electrical conductivity of the body of the Moon. This information could be combined with other findings, e.g., based on seismic data, to give limits or establish hypotheses concerning the lunar interior.

In addition, the information so obtained will yield useful data related to plasma interactions of the solar wind with the Moon.

PARTICLE MEASUREMENTS ON AND NEAR THE MOON

B. J. O'Brien

INTRODUCTION

In this section we consider the charged particles (mainly electrons and protons) with energies above thermal energies, that may be encountered on or near the Moon. For convenience, we discuss particles with energies between about 10 eV and 100 keV, and thereby encompass the following categories of phenomena (Fig. 1):

1. solar wind

2. thermalized solar wind

3. bow–shock radiation

4. magnetospheric radiation

5. auroral radiation

6. the low-energy range of solar energetic particle radiation

All of these phenomena can be expected to be encountered by lunar orbiters and on the lunar surface. It is important to note that an adequate experimental package should be able to measure particle intensities and energy spectra that may be expected in each and every one of these phenomena.

The importance of such measurements to lunar science and lunar-based science is threefold:

First, adequate measurements and analysis are necessary for understanding of the history and properties of the lunar surface and interior. (For example, particle bombardment of the surface may produce luminescence, radiochemical effects, etc., and thermalized solar wind may be the dominant constituent of the lunar atmosphere. Further, particle measurements are essential to permit unambiguous interpretation of magnetometer measurements from which the lunar electrical conductivity can be evaluated.)

Second, there are unique physical phenomena associated with the Moon in interplanetary space. (For example, the small or negligible lunar magnetic field, the absence of a lunar atmosphere and the presence of the Moon in the supersonic solar wind, all lead to a situation where a lunar-based particle detector may measure solar wind, an interplanetary shock front, thermalized solar wind and so on, with detailed interactions and phenomena not available for study elsewhere in the solar system, and on a scale impossible to simulate in the laboratory.)

Third, the Moon provides a peculiarly useful platform from which to measure and study various interplanetary phenomena. (For example, for a few days around times of full Moon, the Moon is expected to be in the magnetospheric tail of the Earth. It will thus be bombarded by electrons, and protons with energies of order 10 keV, in a class of radiation generally categorized as being auroral and/or magnetospheric radiation.)

In general then, in this report we have separated lunar particle measurements into three segments, with decreasing scheduling priorities as follows:

Class (i) those measurements from which one can evaluate properties of the lunar surface and/or interior

Class (ii) those measurements of unique phenomena produced by the peculiar properties of the moon in interplanetary space, and

Class (iii) those measurements which use the Moon or a lunar orbiter as a platform from which other nonlunar phenomena can be seen or measured.

We have used the above order of priorities to develop recommended experiments for early through advanced phases of lunar scientific studies. However, the Moon happens to have such properties that a well-conceived particle measurement for Class (i) can also serve useful functions in the other two classes.

SOLAR WIND

Measurement of ionic composition, velocity, density and anisotropy of the unperturbed solar wind should be made from a lunar orbiter and also – but at a lower priority – from a lunar-based package. Decision on the lunar-based package requires a knowledge of how often the pure solar wind can impinge on the lunar surface, and this should be resolved by anchored-IMP-like studies.

Peculiar advantages of lunar-anchored solar-wind packages briefly are concerned with the < 15-minute flight time difference for solar-wind arrival at the vicinity of the Earth and Moon. At quarter Moons, for example, one can probe the transverse scale of solar-wind inhomogenities. At new Moon, one has a 15-minute alert before a disturbance reaches the vicinity of the Earth, so that special telemetry sampling capabilities can be implemented for Earthbound packages, and vice versa near full Moon.

It is believed that the pure solar wind is generally modified at a subsolar standoff distance of 500 to 1000 kilometers from the lunar surface. However, even with a shock front, the solar wind may frequently impinge on the lunar surface itself. Any lunar-based particle package should therefore include instruments to measure pure solar wind.

THERMALIZED SOLAR WIND

It is believed that the lunar surface is wrapped in a flowing mantle of thermalized solar wind. The thermalization process is believed to generally occur at a shock-front transition region at a subsolar standoff distance of some 500 to 1000 kilometers. Part of the thermalized solar wind will be neutralized and will then simply bombard the lunar surface and be absorbed in it. The charged component will flow around the Moon to form a lunar wake.

The Moon has unique properties that will cause the detailed characteristics of this thermalized solar wind to be of considerable interest. For example, the small or negligible lunar magnetic field will lead to the dominance of the interplanetary (i.e., solar) magnetic field in any magnetic effects. Indeed (see Magnetic Fields by Dessler and Sonett) perhaps any lunar magnetic field is actually induced by the interplanetary magnetic field and by the fields set up in the shock front and thermalization processes. The small or negligible lunar magnetic field and atmosphere may lead to the situation where one has essentially a solid body with finite conductivity opposing the solar wind. The lunar dimensions are of the same order as the ion cyclotron radius in the solar wind. Measurement of particle densities, temperatures or energies, and anisotropies can thus be made on and near the Moon in a unique and simple environment. Associated measurements of the pure solar wind should be made, perhaps with a lunar orbiter.

Since the thermalized solar wind may impinge upon the lunar surface, it may be a dominant part of the lunar atmosphere and ionosphere. This aspect is treated elsewhere, but it is important to note here because it illustrates another way in which measurements of Fields and Particles can contribute to understanding of lunar properties.

Associated with measurements of particle characteristics in the vicinity or surface of the Moon should be adequate magnetic-field measurements.

BOW-SHOCK RADIATION

It is not generally agreed yet whether there is a standoff bow shock or an attached shock where the Moon is enveloped by the supersonic solar wind. Indeed, it may well be that variations in the solar-wind pressure are sufficiently large that both types of shock occur. The relevance here to particle measurements is that lunar measurement of electrons and protons over the energy range about 10 eV to about 100 keV will permit distinction between solar wind, thermalized solar wind and bow-shock radiation inasmuch as the last two classes are distinct.

"Bow-shock" energized electrons with energies of 50 to 100 keV were observed by Fan et al and by Anderson on the IMP satellites in the Earth's vicinity. There has been considerable theoretical speculation as to the source of these particles and whether indeed they are actually distinct from the high-energy portion of the thermalized solar wind produced at the shock front.

The Moon, with its small or negligible magnetic field, and with its small or negligible atmosphere, provides a unique opportunity to study the plasma phenomena involved when the solar wind infringes on the Moon at supersonic velocities. It may thus provide the opportunity for clarification of the complex interactions that occur in such large-scale processes.

AURORAL OR MAGNETOSPHERIC RADIATION

Several theories imply that, at times around full Moon, the

Moon should lie within the magnetospheric tail of the Earth which should be some 50 to 100 R_e wide at the lunar orbit. In the past few years several satellites have measured the charged particles found in the magnetospheric tail at distances from the Earth of up to half the Earth-Moon separation. These particles are often thought to be the source of radiation that causes terrestrial auroras, and – although this is still a subject of some theoretical controversy – these particles are therefore often referred to as auroral and/or magnetospheric radiation.

Consequently, these particles may be expected to bombard the Earth-side of the lunar surface for some 4 or 5 days around the time of the full Moon.

LOW-ENERGY REALM OF SOLAR ENERGETIC PARTICLE RADIATION

Elsewhere a separate treatment is made of solar energetic particle radiation, such as is produced sporadically in solar disturbances. Here such radiation with energy less than about 100 keV is included because occasionally such low-energy particles occur in solar outbursts (e.g., in rocket studies by Davis and others of the November 1960 outbursts) and because the same instrumentation can measure these particles and the other categories discussed above.

Large fluxes of protons (and perhaps electrons) are emitted in solar outbursts, and those with energies below about 100 keV are apparently contained within the plasma cloud that approaches cislunar space with velocities near solar-wind velocities, i.e., at about 1000 km/sec. But the exact relation of these particles to the relativistic solar flare radiation on the one hand and to the quiescent solar wind on the other hand is unknown. It is impossible to investigate this relation in regions dominated by the geomagnetic field.

However, at times other than full Moon, the lunar surface or a lunar orbiter provides a useful platform for further study of this relation. It is useful to do such studies near the Moon because the Moon is about 10 to 15 minutes flight time distant from the Earth for such particles. So one can conceivably and usefully correlate terrestrial and lunar experiments. For example, at new Moon, the lunar package might provide an alert for terrestrial rocket-borne studies. And at full Moon, terrestrial alert might be used to switch a lunar package into a high-resolution telemetry mode.

Scientific interest in such measurements is great because they may solve a number of problems. For example, Kopal and others attribute lunar luminescence effects to bombardment of the lunar surface by such sporadic radiation. Again, the processes that cause solar emissions of relativistic particles are unknown, and measurements of the particle spectra down to near-solar-wind energies will provide clues to these mechanisms. For example, it is not known at present whether there is a monotonic energy spectrum in this radiation, or whether there is a dearth of lower-energy particles from which one might surmise about a minimum-energy-of-escape criterion. Indeed, at present there is very little information about the flux of 50 to 100 keV solar protons, and whether they are present continuously — like the solar wind — or only sporadically — like the solar energetic particles. This question should be resolved by unmanned space probes within the next few years.

GENERAL CONCLUSIONS

There are measurements of low and medium-energy particle fluxes on the lunar surface and in the lunar vicinity that should be made because:

1. They are vital for understanding of certain characteristics of the Moon itself

2. They can investigate phenomena that occur in the vicinity of the Moon but in no other presently-accessible region

3. They can make use of the peculiar advantages of a lunar platform

Acknowledge with thanks valuable discussions with J. A. Van Allen, J. A. Simpson, and Leo Davis.

SURFACE ELECTRIC FIELD MEASUREMENTS

H. Petschek

The interaction of the solar wind with the lunar surface can produce a contact potential of the order of the electron mean energy (~100 eV) over a distance of roughly a Debye length (~50 meters). This electric field depends upon plasma conditions just above the lunar surface and upon the presence or absence of solar radiation. It has been suggested that dust may migrate over the lunar surface if it is appropriately charged and if a sufficiently large electric field exists to allow the individual particles to hop. If significant dust layers exist this migration could be important for determining the erosion over the lunar surface.

It seems likely that the interaction of the solar wind with the Moon can lead to a large variety of conditions depending upon both position of the moon relative to the solar direction and whether the solar wind strength is increasing or decreasing. Following an in-increase in wind strength the plasma may flow directly into the Moon in which case conditions 100 meters above the surface would correspond to conditions in the ambient wind. On the other hand a decrease in wind strength might allow the magnetic field to expand outward from the Moon and push the plasma flow completely away from the surface as is the case for the Earth's magnetosphere. Such an event would give rise to a small change in magnetic field but a virtual disappearance of the electric field. During steady wind conditions one would anticipate a somewhat thermalized plasma corresponding to higher temperatures and densities than exist in the solar wind. Since at least in the absence of direct sunlight the surface electric field should be proportional to the square root of the product of density and electron mean energy some quantitative information on this product might be obtained from such a measurement.

Particle detectors provide more detailed information on the distribution in energy of particle fluxes reaching the lunar surface. These fluxes may, however, be significantly affected by the surface potential. Surface electric field measurements would therefore aid

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in the interpretation of thermal energy particle detectors. This ambiguity in the response of particle detectors also exists to an unresolved extent in satellite experiments. It is, however, probably more serious on the Moon since the high resistivity and large size allow variations in surface potential between shaded and sunlit portions of the surface. Sunlight may also be less important on the lunar surface due to a lower photoelectric efficiency.

In the absence of direct solar photon fluxes the potential across the surface sheath is obtained by balancing the electron and ion fluxes. For a thermalized plasma

$$\frac{n_i \tau_i}{4} = \frac{n_e \tau_e}{4} \exp. -\left(\frac{e\Phi}{kT_e}\right)$$

therefore

$$e\Phi \approx kT_e \, L_n \sqrt{\frac{m_i \tau_i}{m_e \tau_e}} \sim 4 \, k \, T_e$$

The extent of this field is of the order of the Debye length $\sqrt{\frac{kT_e}{4\pi n e^2}}$ The resulting electric field is, therefore,

$$E = 4\sqrt{4\pi NKT_e} \text{ e.s.u.}$$

Taking $N = 10/\text{cm}^3$ and $kT_e = 200$ eV this gives 20 volts/meter. This should probably be regarded as being within a factor of 3 of the upper limit to the surface electric field. Lower fields would be expected in lower density or temperature regions or as a result of photoionization.

In the presence of sunlight this result is probably changed significantly by photoelectric emission. Quantitative estimates depend upon the effective photoelectric cross section of the surface. If significant photoelectron fluxes are obtained the electric field will try to return the photoelectrons to the surface. In this case potentials of several volts should be sufficient to reflect almost all photoelectrons back to the Moon. This would reduce the magnitude of the surface field to the neighborhood of 1 V/m and of the opposite sign to that considered earlier.

These electric fields are large compared to those occurring in the undisturbed solar wind (10^{-3} V/m) and should therefore be easier to measure.

GALACTIC COSMIC RAYS

M.M. Shapiro

INTRODUCTION

Half a century after their discovery, the cosmic rays remain one of the most challenging phenomena of nature. Their sites of origin, the mechanisms by which they acquire their fantastic concentrations of energy, their modes of propagation through space, their multifarious interactions with the media they traverse—all these tantalizing problems demand solution.

Clarification of these questions is vital to our understanding of many cosmic processes, and it bears profoundly on some of the most spectacular phenomena in astrophysics—the strong radio sources, particularly the quasi-stellar sources; exploding galaxies and supernovae. Answers to the intriguing puzzles of the cosmic radiation will illuminate the fields of stellar and galactic evolution, as well as the newly emerging discipline of relativistic astrophysics.

The usage "galactic cosmic rays" in this report is not intended to exclude radiation of extragalactic origin, but to differentiate the truly "cosmic" particles originating outside of the solar system from energetic particles of "local", i.e., solar origin. The latter form the subject of a separate report from this working group. The range of particle energies with which we are here concerned is that above 10^8 eV. A remark is in order about the new and fruitful field of X-ray astronomy which is occasionally mentioned in this report. Notwithstanding its close relationship to cosmic-ray astrophysics, it encompasses a domain of photon energies well below that normally associated with the cosmic radiation. It is being separately considered by a subcommittee on astronomy.

SOME GAPS IN OUR KNOWLEDGE

Though much is known about the properties of the cosmic radiation, vast areas of this discipline remain to be explored, e.g.: the detailed chemical and isotopic composition of the principal primary component—the nuclei; the low-intensity electromagnetic components—electrons, positrons and gamma rays, and their energy distribution; location of gamma-ray point sources, and elucidation of the diffuse cosmic gamma radiation; detection of the elusive cosmic neutrinos; the composition and energy spectra of the ultra-high-energy particles (those $\gtrsim 10^{12}$ eV), and their distribution in directions of arrival, with special reference to anisotropies; the detailed effects of solar emissions on the galactic radiation; and the history of cosmic rays on a galactic time scale. The foregoing list is far from exhaustive.

Our knowledge of the heavier primary nuclei ($Z > 10$) is limited. Our knowledge of the primary cosmic rays other than nuclei is rudimentary. In the case of γ-rays, electrons and positrons, this is due largely to the low flux of these components, and the corresponding difficulty of overcoming spurious background. If observations could be carried out in a lower-background environment with large detecting areas, long exposure times, fairly elaborate arrays of detectors for discrimination against background, then progress could be expected. In the case of cosmic neutrinos, the main difficulty is the exceedingly small cross section for interaction with matter; this necessitates enormously massive detectors. An equal difficulty, in Earth-based observations of cosmic neutrinos, is the copious production of neutrinos by cosmic rays in the Earth's atmosphere.

BALLOONS AND SPACE PLATFORMS

Most of our knowledge of the primary cosmic radiation has been gathered from balloon platforms floating near the top of the atmosphere. Even the few residual grams per cm^2 of air above the balloons constitute an absorbing and multiplying layer that interferes with certain observations on the primaries. The background problem, notably that caused by secondary radiation from the atmosphere below the balloon, severely limits many areas of inquiry. (Nevertheless, it must be emphasized that large balloons for cosmic-ray research are very far from being obsolete.)

The advent of satellites has made it possible to study the primary radiation well above the Earth's atmosphere for extended periods of time, long compared to the duration of balloon flights. However, the radiation belts of the magnetosphere—though of great intrinsic interest—constitute a source of intense charged-particle background that limits certain observations on the primary cosmic radiation. Space probes that go beyond the magnetosphere offer the opportunity of sampling the cosmic-ray flux in interplanetary space away from the interfering radiation belts.

EXPERIMENTS IN MANNED LUNAR MISSIONS

In view of the national commitment to a program of manned lunar exploration, further opportunities are in prospect for extending our investigations of the cosmic radiation into the cislunar region. Observations will be possible (a) en route to and from the Moon, (b) from lunar orbiting vehicles, and (c) from the surface of the Moon itself. The wise and discriminating exploitation of these opportunities will bring rich rewards.

Since any experiments in the lunar vicinity will be difficult and expensive, it is pertinent to inquire: What types of observations on the galactic cosmic rays is it important to carry out on manned lunar missions? What are the merits and disadvantages of making these observations on or near the Moon rather than in regions of space closer to Earth? Would the expected scientific gains warrant the considerable cost and research effort?

THE MOON AS A PLATFORM

Salient lunar characteristics important for cosmic ray experiments including the following:

1. Absence of an atmosphere that absorbs the primaries and generates a host of confusing secondaries.

2. Absence of a magnetic field having an intensity comparable to that of the Earth; absence of radiation belts such as those in the Earth's magnetosphere.

3. Slow rotation of the Moon, which makes it a relatively stable platform, with slowly changing orientation in space. This platform can support apparatus requiring extensive area, and large yet constant spatial separation.

4. The presence of surface features (e.g., mountains, rims of craters) which permit occultation observations, and hence precision in locating sources.

5. Availability of unlimited quantities of solid materials for shielding, for the controlled generation of secondary particles, etc.

In addition to the foregoing features intrinsic to the lunar environment, the availability of man in lunar missions will contribute significantly to the success, and even the feasibility, of certain experiments.

Among the disadvantages of doing experiments on or near the Moon are the following:

1. Harsh environmental conditions, such as great extremes of temperature.

2. For cosmic ray observations, as for certain other radiation experiments, the albedo of secondary radiations generated in the lunar surface by cosmic rays and energetic solar particles will constitute a troublesome background.

3. The long lead time—years—required for preparation of experiments, especially in manned missions.

4. The high cost.

Appropriate measures can be taken to mitigate the environmental difficulties, and the albedo background (e.g., for some types of albedo, by means of Cerenkov counters). Not much can be done about the long lead times or the high cost. However, the latter factor is relevant to any research in the vicinity of the Moon. The justification of any single type of experiment in the lunar environment is a formidable task except in the context of the national commitment to a program of lunar exploration. We assume that there will be a series of lunar missions culminating in the establishment of one or more observatory bases on the Moon. The incremental cost of carrying out scientific experiments that can better succeed in the lunar environment is then justifiable provided that the research is important and the experiments well designed.

COSMIC-RAY EXPERIMENTS "EN ROUTE"

It is recognized that the main objectives of the early lunar missions are to achieve a manned landing and to explore the Moon itself. Experiments that would not contribute to these objectives should be scheduled on later missions, if they possess sufficient scientific merit. This would apply to the emplacement of equipment on the Moon's surface for observation of galactic cosmic rays. Nevertheless, even in early lunar missions, the impressive capabilities of the Apollo vehicle could be exploited for observations in regions of space outside of the Earth's radiation belts. These regions, free from the intense particle background in the vicinity of the Earth, are not ordinarily accessible to satellites.

The service module of the Apollo spacecraft provides opportunities for equipment requiring substantial weight, volume and power. In its round trip to the lunar vicinity, a time of the order of several days is available for measurements on the galactic cosmic rays outside of the Earth's magnetosphere. The equipment could be designed to make only modest demands on the astronauts' time en route, and to require none of their time during critical periods, e.g., from time of arrival in the lunar vicinity to departure therefrom. Thus, the experiment would not interfere with lunar exploration per se.

Among the investigations that it would be worthwhile to carry out en route are studies of low-energy cosmic ray nuclei in interplanetary space, away from the geomagnetic field and its background of trapped radiation. The chemical and isotopic composition at the lowest energies could be studied with nuclear emulsions or other detectors. The vehicles hitherto available for investigation in this low-energy domain suffer from inherent limitations. In balloon experiments, there is an air cutoff. In satellite exposures, there is interfering background from the radiation belts, especially over the South Atlantic anomaly.

The very heavy primary nuclei are a potential source of critical information about processes of nucleogenesis and acceleration in cosmic ray sources. Owing to their short ranges, these nuclei ($Z \geqslant 20$) also suffer from air cutoff. Their flux is so low that it would be valuable to expose continuously sensitive detectors of large area—e.g., nuclear emulsions in suitable configurations—for the collection of statistically significant samples of these particles.

The new technique of charged particle tracks consisting of damage trails in certain solids, may also become a useful tool for the study of heavy primary nuclei. The tracks are revealed by preferential chemical etching. For particles with a high rate of ionization loss, this method shows promise of complementing the photographic emulsion technique. The latter is likely, however, to remain unsurpassed in the wealth of detailed information obtainable from individual tracks.

The new field of γ-ray astronomy is one of the most exciting and one of the most difficult of space disciplines. It is exciting mainly because gamma rays, undeflected by the magnetic fields that pervade the galaxy, preserve their original direction, and thus can point to the location of cosmic-ray sources. Cosmic γ-rays are difficult to investigate because of their very low intensity, and because of the great variety of events that can generate a spurious γ-ray "signature" even in a carefully designed detector. Apparatus for detecting and measuring cosmic γ-rays $> 10^8$ eV must be sizable and fairly complex.

In addition to the search for point sources mentioned above, a less glamorous but fundamental area of inquiry is the diffuse gamma radiation, which can be produced in virtually all regions of space. Cosmic γ-rays can be born in many ways, among them the collision of protons or other cosmic-ray nuclei with the nuclei of interstellar matter, via the production and decay of neutral pions; the collision of electrons (or protons) with photons—the inverse Compton effect; and bremsstrahlung. Determination of the energy spectra and spatial distribution of the cosmic gamma radiation should clarify the relative importance of these and other processes, as well as other astrophysical questions.

A telescope for investigation of cosmic γ-rays would consist of an array of detectors such as large area scintillation counters, spark chambers, Cerenkov counters, and one or more "production layers" for the conversion of gamma rays into electron pairs. It would require auxiliary apparatus, such as photomultipliers, logic circuits, pointing devices for orientation of the telescope, etc. Such an array could, in principle, be adapted to studies of primary electrons and positrons as well. An effective telescope would weigh several hundred pounds, and, in its extended configuration would be ≥ 3 meters long. It would require several watts of power.

Since much of the troublesome background simulating cosmic γ-rays would originate in the space vehicle itself, the experiments would be far more effective if carried out from a subsatellite devoted to this experiment alone. This subsatellite would be deployed from the Apollo vehicle (say, to a distance of $\sim$30 meters) by the astronaut and subsequently controlled by him. It could be tethered, with power supplied from the service module, or independent.

The subsatellite technique would also be exceedingly valuable for other types of experiment, e.g., magnetometers, or exposures of nuclear emulsion stacks. In the former, this would provide a means of getting away from stray magnetic fields associated with the spacecraft. In the latter, it would remove the sensitive emulsion from the albedo background generated in the vehicle, and also from the radioactive sources in the spacecraft.

For materials that require recovery, such as nuclear emulsions, an air lock should be included in the design of the Apollo command module. This would make it possible—without EVA by the astronaut—to retrieve such materials from outside the spacecraft into the command module for return to Earth.

TIME HISTORY OF COSMIC RAYS

The surface of the Moon, unprotected by an atmosphere, has long been under steady bombardment of galactic cosmic rays and solar energetic particles (as well as solar wind and meteorites). Nuclear interactions engendered by these particles in lunar rocks have left tell-tale residual nuclei—both radioactive and stable. Geochemists, applying the techniques of nuclear chemistry, have hitherto depended heavily upon meteorites found on the Earth for clues to the chronology of the galactic cosmic radiation. They have tried to learn, for example, whether the cosmic radiation in interplanetary space has been essentially constant in geologic time, apart from solar modulation. There is good reason to believe that the materials at the lunar surface contain valuable information on both galactic and solar energetic particles. The problems of separating and assessing the respective effects of these two streams of radiation are not trivial. In principle, however, their very different energy spectra, and perhaps the differences in compositions, could help in this task. Certainly, some of the rock samples to be collected in the earliest lunar missions should be made available for these studies. A significant scientific bonus will thus accrue from the precious lunar materials that will be returned to Earth.

LUNAR ALBEDO OF ENERGETIC PARTICLES

The same bombardment of high-energy particles that leaves a nuclear signature in the lunar rocks also produces an albedo of secondary particles that splashes from the Moon's surface, and creates a background of baryons, mesons, and leptons in the lunar vicinity. While this albedo is not of great fundamental interest, it does constitute an interfering background that will probably limit the usefulness of a Moon-based—or even of a lunar-orbiting—cosmic ray observatory. The problem may turn out to be serious notwithstanding the techniques available for coping with it in special circumstances, e.g., by means of anticoincidence counters, or with Cerenkov counters that distinguish the sense of motion (forward versus backward) of a relativistic particle. Theoretical estimates of the albedo—its composition, intensities, and energy spectra, would provide an uncertain guide to prospective experimenters. In order to permit the realistic design of lunar-based experiments on cosmic rays and solar energetic particles, preliminary determination of the nature and magnitude of the energetic "elementary particle" albedo of the Moon would be highly desirable. This could be done from a lunar orbiting spacecraft, by means of automatic apparatus deployed from the service module. It might be accomplished in one of the Apollo missions, assuming that this would not interfere with lunar landing, exploration, or lift-off.

COSMIC-RAY EXPERIMENTS IN THE LUNAR VICINITY (Later Missions, AES)

In early Apollo missions, other priorities would probably preclude observations of cosmic rays from the Moon's surface. For subsequent lunar missions—the AES program and beyond—serious consideration should be given to those galactic cosmic-ray observations that could benefit significantly from the special properties of the lunar environment. It is assumed that the help of astronauts would further enhance the prospects of success. Their assistance would be valuable in the emplacement and repair of equipment. Also, they could adjust certain parameters in detection equipment so as to increase sensitivity, or to improve resolution, or to effect other "trade-offs."

Some important areas of cosmic-ray research that could profit from lunar-based observations will now be discussed.

The field of γ-ray astronomy has been briefly described above. In the search for discrete γ-ray sources, the promising candidates include the strong radio sources, the newly-discovered X-ray sources, and certain optical ones, e.g., the exploding galaxy M-82. The identification of a γ-ray source with a discrete celestial object might be achieved by techniques of occultation, as has been done with X-rays from the Crab Nebula. With the Moon's negligible atmosphere, one could exploit the ridges of mountains, the rims of craters, and similar features of lunar topography to measure precise directions by means of such eclipses.

Theoretical estimates of the γ-ray flux to be expected from point sources suggest values as low as 10^{-7} or 10^{-8} photon/cm^2 sec. For such intensities, an apparatus with a detection area of 1 m^2 would have to be in operation for several months to obtain meaningful data. The stability and the slow rotation of the Moon would make it useful as a base for γ-ray telescopes. Ultimately, detection areas of several square meters, and equipment having a mass of several tons might be required. Some of the materials contributing to this mass might be local lunar materials. For study of the diffuse gamma radiation, a few hundred pounds of apparatus with a detection area of $\sim$0.1 m^2 may suffice to yield significant results. The flux of this radiation is believed to be less than 10^{-3} that of the nucleonic component.

The discipline of gamma-ray astronomy is still so young that lunar experiments should be preceded by a vigorous program of experimentation near the top of the Earth's atmosphere using balloons. It is necessary to develop reliable balloons capable of lifting a ton of equipment to 125 000 ft, and several hundred pounds of payload to $\sim$150 000 ft. The longer the flight times that can be attained, the better. Testing and calibration of cosmic γ-ray detectors in suitable beams of high-energy accelerators should also be encouraged. By these means it should be possible to achieve the high capability of discrimination against background that is required. In addition, if point sources of γ-rays exist which send fluxes of $\sim 10^{-5}$ or 10^{-6} photon/cm^2/sec to the Earth, it may be possible to detect these from balloons.

Some preliminary γ-ray research has already been done in Earth-orbiting spacecraft, as well as from balloons. Further work of this type will yield significant information as well as helping in the design of subsequent lunar experiments. However, balloons and satellites have certain limitations. Thus, balloon experiments are probably incapable of measuring the diffuse cosmic gamma rays, owing to the formidable background from the Earth's atmosphere. Moreover, although discrete γ-ray sources may be detected from balloons, the short duration of balloon flights makes these platforms marginal in the long run. In order to collect sufficient data, periods of the order of months will probably be required. Furthermore, observations in regions of space away from the radiation belts would eliminate another source of background.

It is worth reiterating that the same apparatus used for gamma ray detection can also be utilized to collect valuable data on primary electrons and positrons.

The cosmic ray energy spectrum is known to extend up to particle energies of $\sim 10^{20}$ eV. However, for the wide portion of the spectrum above $\sim 10^{12}$ eV, terrestrial observations have encountered great difficulties in unraveling the composition of the primaries, their directional distribution, and even the exact shape of their energy spectra.

The exceedingly low intensities of these ultra-high-energy particles necessitate very long collection times, which are impractical of attainment with balloons near the top of the atmosphere. Attempts have been made with giant stacks of nuclear emulsions suspended from balloons (e.g., as in the International Collaborative Emulsion Flights) to collect at least modest numbers of "jets" produced by particles in the domain of 10^{12} to 10^{14} eV. Even with a rather staggering amount of work, only a few hundred such particles have been collected. In each case, of course, the nucleonic cascade and the electromagnetic showers produced by the primary particle must be studied microscopically in great detail. Because of the limited statistics on the high-energy primaries, these exposures have yielded rather more information about nuclear interactions at high energies than about the ultra-energetic cosmic rays per se. The main advantage of the solid photographic detector is that it gives a "handle" on the nature of the primary particle, i.e., whether it is charged, and if so, the magnitude of its charge. Knowledge of the relative numbers of protons and various heavier nuclei at these high energies is of great interest. Another advantage of the emulsion stacks is that one can follow visually the successive development of the nuclear and electromagnetic cascades.

At energies $\geq 10^{14}$ eV, the particles become so scarce that only a handful have been recorded in the several large stacks flown from balloons. Since particles of these energies produce extensive air showers at mountain altitudes and even at sea level, our knowledge of them comes from measurements made upon their remote progeny deep in the Earth's atmosphere. Estimates of the energy are often uncertain by an order of magnitude, and the charge of the incoming particle is unknown. Attempts to infer the nature of these primary particles from certain characteristics of the developed shower (e.g., its muon richness or depletion) have not given clear-cut answers. Nor do we have enough information about possible anisotropies, especially at the higher energies, say about 10^{15} eV. Yet the nature and the detailed distribution in arrival directions of these particles hold the most vital clues as to cosmic-ray origin and acceleration. In particular, such information could enable us to distinguish between galactic and extragalactic origin of cosmic rays.

A lunar-based apparatus for the detection of ultra-high-energy cosmic ray particles would give us direct access to the primaries. With sufficiently long collection times on a stable platform free of an atmospheric blanket, it would be possible to accumulate statistically significant data on the high energy primaries. Sizable collection areas (some square meters) would be required, but the equipment could be relatively compact in depth because the showers would be developing in solid materials rather than in air. Estimates of the energy would still be dependent upon studies of the cascades.

An array including a variety of detectors could be employed in order to provide sufficient selectivity, and to enhance the reliability of energy estimation. Scintillation counters, spark chambers, Cerenkov detectors, and nuclear emulsions could be components of this array. A significant portion of the array could be devoted to the "calorimetry" of the developed shower. The charge of the incoming particle could be determined from its rate of ionization loss, and one could ascertain whether it is a γ-ray. The slow rotation of the Moon, combined with rotation of the telescope about a horizontal axis would suffice to sweep out most of the celestial sphere for studies of anisotropy.

Since considerable quantities of dense materials are required in studies of high-energy "jets" for the generation and absorption of secondary particles, it is desirable and it may be possible to use lunar materials at least in part for these purposes. The astronauts would thus be faced with other tasks in addition to those mentioned above.

It must be acknowledged that, at energies well above 10^{16} eV, the sensitive area and total mass of detector would have to be exceedingly large—perhaps prohibitively so, in order to detect an appreciable number of these rare primaries.

The Moon would provide a good platform for the secular monitoring of low-energy cosmic rays, say those less than 1 BeV. Such studies would teach us a great deal about solar modulation of these galactic particles, about interplanetary magnetic fields, and about the details of cosmic-ray propagation through the interplanetary medium.[1] The emplacement of two detectors, 180^{o} apart on opposite sides of the Moon, would provide a particularly useful system for these purposes. The addition of an instrument in lunar orbit would make it possible to intercalibrate the two lunar-based instruments.

The same apparatus could be designed to record solar energetic particles as well. It is not suggested that this monitoring task must be done on the Moon, but rather that it could be done from lunar-based instruments in a more sustained and effective manner over the long periods of time required. Additional considerations that favor a lunar environment for these observations, and description of appropriate experimental arrangements, will be found in the report dealing with "solar energetic particle studies."

Though neutrinos are notoriously difficult to detect, they carry astrophysical information of a special kind, and sometimes come from regions otherwise inaccessible to "observation." Competent physicists bold enough to pursue cosmic neutrinos deserve encouragement. High energy neutrinos are detected

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[1]In certain directional measurements, the 2π shielding geometry of the Moon would be useful.

through the charged secondary leptons (mainly muons) that they generate. The first serious attempts to detect these particles, now under way, face a major hurdle: the background of neutrinos produced by charged cosmic rays in the Earth's atmosphere is so great that the prospect of distinguishing true cosmic (i.e., primary) neutrinos from these is not very bright in terrestrial experiments. From this point of view, the Moon's negligible atmosphere makes it a suitable site for cosmic neutrino detection. However, the enormous masses of material, running to hundreds of tons or more, required in a neutrino experiment pose obvious problems. To be sure, most of the mass is needed for absorption and conversion, and lunar material could be used for these purposes. It would still be necessary, however, to move huge quantities of lunar material. Moreover, large quantities of special detector materials would still have to be transported to the Moon. Hence, despite the importance of the experiment, cosmic neutrino detection at the Moon will probably become feasible only when a substantial lunar base will have come into being.

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SOLAR ENERGETIC PARTICLE STUDIES ON OR NEAR THE MOON

W. Webber

In this report, we shall take as a working definition of solar energetic particles that intermittent solar emission of particles (mainly nuclei) above ≈ 1 MeV in energy. This effectively separates the energetic particle regime from solar thermal plasma studies as well as "auroral" type phenomena such as those associated with the Earth's magnetosphere. It does cover, however, the recently discovered solar M regions or beams of low energy solar particles (1-10 MeV) existing in interplanetary space for perhaps many weeks. In addition no consideration is given here to solar X- and gamma ray emission, although clearly these phenomena are closely related to the energetic particle emission.

We consider that the field of solar energetic particle studies is very closely related to many aspects in the study of galactic cosmic rays. This is particularly true experimentally where it is considered likely that an experimental arrangement designed to study solar cosmic rays would also be used for the study of low energy galactic cosmic rays.

We shall first consider the general objectives of solar energetic particle studies, deferring until later a discussion of the merits of lunar based solar particle studies vis-a-vis similiar studies on satellites near the Earth. Finally we shall consider a possible experimental configuration as well as a number of specific techniques that might be used in a lunar based study. First let us briefly summarize our conclusions. They are: (1) While the Moon presents some limited advantages in certain aspects of solar cosmic ray study we do not believe that these advantages are great enough to demand a strong recommendation for such studies at least in the early phases of the lunar program. (2) A solar cosmic ray program recommended for later missions is a combination monitor and study program. This would essentially measure the anisotropy, intensity, charge and energy spectrum of solar cosmic rays and low energy galactic particles from a number of sites on or near the Moon.

GENERAL COMMENTS ON SOLAR ENERGETIC PARTICLE STUDIES

Two basic objectives are of dominant importance in directing the course of study of solar energetic particles. These objectives are (1) To understand the mechanism whereby these particles attain their high energies in a relatively short time in fairly localized regions associated with solar flares (2) The processes governing the propagation of these particles outward in the interplanetary

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medium: This includes the characteristics of the diffusion process itself as well as possible changes in energy of particles travelling in this moving, expanding medium of plasma and magnetic fields.

A study of the spectrum, charge and isotopic composition, time behavior (including onset and decay characteristics as a function of energy and direction) and directional characteristics of solar cosmic rays over as wide an energy range as possible and with as detailed time and directional resolution as is possible is a most important input for understanding the relationships between the initial acceleration of these particles on the Sun and the ensuing propagation of the particles in the interplanetary medium. The relative abundance of particles of different charge and isotope, as well as the comparative spectra of these different components will give us all important clues as to the regions in which acceleration takes place and the mechanism and time scale of the acceleration process itself. A study of the time behavior of particles of different charge to mass ratio (including electrons) as well as the detailed directional characteristics of these particles as a function of time will greatly improve present crude understanding of the general features of the interplanetary magnetic fields and electromagnetic conditions and the processes which control particle intensity as a function of distance from the Sun. Also our understanding of the very important physical picture of the motion of energetic particles through a moving thermal plasma containing magnetic fields will be greatly enhanced.

ENERGETIC SOLAR PARTICLE STUDIES IN THE LUNAR ENVIRONMENT

The ability to make solar cosmic ray studies from locations on or near the Moon (possibly under manned supervision, as well) presents a number of opportunities to significantly increase our understanding of problems related to solar, interplanetary, and terrestrial physics. In a few cases the lunar environment provides a unique location to carry out these studies while in others, it is, in a sense, in direct competition with Earth-satellite based measurements. One of the advantages of the lunar environment is the low radiation background, as compared with measurements in the Earth's magnetosphere. This fact, which is a result of the lack of a significant lunar magnetic field makes solar cosmic ray studies near the Moon quite feasible and in fact comparable with corresponding studies made from Earth satellites when they are outside the magnetosphere.

This results immediately in two distinct advantages for the lunar environment.

1. The measurements can be made continuously at a location moving very slowly with respect to the Earth-Sun coordinate system. This permits a simpler and more direct (as well as more complete) interpretation of the various spatial, directional, and temporal characteristics of the energetic particles than can be obtained in an Earth satellite which may be moving rapidly through the Earth-Sun system as well as in and out of the magnetosphere. It also permits a more direct comparison of near Earth conditions with measurements remote from the Earth (e.g., >0.1 AU as obtained on space probes). These advantages may be used uniquely if in some instances two or more stations are set up at different locations on the Moon and one or more lunar satellites are available in low altitude lunar orbits.

2. This is the only known instance (or at least the earliest) in which man might be available for a set of programmed experiments of a scale impossible to be performed in unmanned vehicles outside of the Earth's magnetosphere. This is especially important during active periods after the start of a solar cosmic ray event.

For example, experiments designed for an unmanned satellite usually must cover predetermined limits of counting rate and charge range and as a result cannot look at charge components with widely different intensities or follow time variations throughout the enormous intensity changes occurring during an event. In addition, it is hard to visualize in advance a programmed series of directional measurements to suit each event. These objectives could certainly be much better achieved at a manned location, or in a manned vehicle where the actual experimental configuration could be changed with time to obtain specialized data from particular events. Considerations of the safety of the observer would, of course, set limits to the intensity of events that might be studied.

Finally we should note another distinct characteristic of the lunar environment. The Moon is an effective stable platform with any number of reference landmarks (lunar surface features such as mountains, limb) available. This may be used to obtain a very accurate and well-known pointing accuracy. In addition, physically the Moon is a large mass of absorber which acts in a directional sense to collimate the incident radiation. (This includes both the 2π characteristics as well as specific directional features that would arise as a result of occultation by lunar features.) Additional directional characteristics could be obtained by constructing more than one lunar observatory—or by providing a lunar base with a lightweight "tower" that could be used for a variety of directional studies.

At the same time this mass of material may create background problems which actually make it less desirable than a satellite location. This might particularly complicate the study of low energy electrons for example.

Mention should also be made of the temperature on the lunar surface, which clearly requires some heating to be supplied to the experiments to enable them to operate through the lunar night as seems to be desirable.

THE GENERAL EXPERIMENTAL CONFIGURATION FOR MAKING SOLAR ENERGETIC PARTICLE STUDIES IN THE LUNAR ENVIRONMENT

A possible configuration for the monitoring and observing of energetic solar particles over long periods of time in the lunar environment might eventually include:

1. At least two bases upon which the main detecting systems are located. The geometrical configuration of these bases (e.g., relative to the Earth-Sun line) is not immediately clear but one base probably should be on the Earth-facing side—another somewhere on the opposite side of the Moon.

2. A lightweight tower arrangement (up to ~100 meters) at one site. Some detectors or parts of detectors might be located

on the tower to provide comparison with ground based measurements, give time of flight studies, and provide various types of directional measurements and occultation studies.

3. Possibly two small lunar satellites, instrumented to some extent. One of these should be in a low orbit, 20-100 km altitude, that takes it over both stations. It can be used for comparison studies and directional measurements. The other satellite (which might well be identical in instrumentation) should be in a much higher orbit, (~1000 km) still within range of both ground stations. It can also be used for comparison studies and directional measurements.

This system just described provides a unique (to the Moon) geometrical relationship between detectors which can provide essentially unique measurements, particularly on the directional (anisotropic) and temporal characteristics of both solar and galactic cosmic rays.

DETAILED EXPERIMENTAL COMPLEMENT FOR SOLAR ENERGETIC PARTICLE STUDIES IN THE LUNAR ENVIRONMENT

At the present time it is very difficult to visualize in detail the individual experiments that might be carried out. Many of the experiments could be used jointly with other disciplines (e.g., galactic cosmic rays). Rather than consider each possible experiment at this time, let us consider some general guide lines.

Possibly 20 to 40 lb of solar energetic particle experiments might eventually be utilized at the main stations with 10 to 20 lb accommodated on the small satellites and on the tower. A number of separate detecting systems should be used—overlapping in both energy range and counting rate dynamic range, and capable of determining the charge composition of the radiation at least through a charge ~20. They should be directional detectors; those at the (manned) stations being mounted in such a way that the direction of viewing and the opening angle could be changed continuously and rapidly. Under normal operation some of these detector systems could monitor the galactic cosmic rays but during periods of solar activity they could be programmed to obtain a maximum of data on selected aspects of the incident solar cosmic rays.

Let us specifically consider a detector system that could monitor the solar cosmic rays and study the features of these particles in sufficient detail so that definitive answers might be obtained on the acceleration process and on interplanetary propagation physics.

This detector is a multi-element scintillation Cerenkov telescope of viewing angle $\pm 20^{\circ}$ and solid angle area ≈ 50 ster cm^2—covering the range 10 MeV to 1 BeV. Such a telescope would give very high resolution separation of charges as well as energy spectra of the individual charges. The estimated weight is ≈ 15 lb and power ≈ 2 watts. Under normal operation these telescopes (installed at each of the above stations) could monitor galactic cosmic rays—studying their anisotropies and charge and energy spectrum and its change with time. During periods of solar activity they could be programmed to obtain a maximum of data on each aspect of the incident solar cosmic rays.

In addition to this monitoring program a number of other studies in this field come to mind where the lunar environment would provide a distinct advantage over Earth satellite based studies. These include:

1. Possible occulation measurements for measurement of finer directional features of solar particles (using the tower arrangement).

2. Time of flight studies for high resolution energy measurements at low and intermediate energies (using the tower arrangement).

3. Study of radioactive lunar materials and relationship of this induced radioactivity to the time history of solar cosmic ray particles.

4. Possible long exposures of special materials on the Moon to measure trace constituents of solar (e.g., radioactivity) cosmic rays.

NEUTRONS

W.N. Hess

Neutrons will be generated in the top layers of the Moon as a result of the nuclear interactions of cosmic rays. Estimates show the neutron flux should be about 5 times larger than the terrestrial flux and the lunar leakage fraction is about twice the terrestrial average value. This means the leakage flux should be about 5 neutrons/cm^2-sec with an energy spectrum not unlike that in the Earth's atmosphere. The magnitude of the leakage flux is large enough to be measured easily. The shape of the neutron energy spectrum contains information about the composition of the medium in which the neutrons were produced. Most of the neutrons are produced by nuclear evaporation with energies of 1 MeV. They are then gradually slowed down by collisions with the atoms in the environment and eventually either leak out of the lunar surface or are absorbed. Most of the neutrons are generated and live in the top 100 to 200 gm/cm^2 of material. The equilibrium energy spectrum of the leakage neutrons depends on the relative rates of thermalization of the neutrons by collisions and loss of neutrons by absorption. Calculations of the shape of the energy spectrum for various lunar surface materials are made in the paper by Lingenfelter, Canfield, and Hess (ref. 1).

There are two important parameters of the surface material that determine the spectral shape: the total thermal absorption cross-section and the hydrogen content. The hydrogen is important in that it is a very good thermalizing agent because the proton mass is the same as the neutron mass. Calculations made for several different assumed chemical compositions show that by using two detectors one can get a reasonable value of the H/Si atom content. Using a 1/v type detector such as a BF_3 counter and a moderated BF_3 counter with a flat efficiency-energy curve, the ratio of the count rates of the two detectors contains useful information. Figure 1 (in ref. 1) shows how this count rate ratio varies as a function of the H/Si atom ratio assuming a chondritic composition. If the thermal cross section is known to ±50 percent from reasonable assumptions about the surface composition and maybe from other experimental data, then the H/Si ratio can probably be determined to a factor of three or four if it is larger than 0.05. If Σ can be determined accurately then the H/Si ratio can be determined accurately.

From tables 1 and 2 in reference 1 we can see that the value of Σ is probably dominated by the concentrations of Fe, Si, and K. These elements and several others which seem less important can be studied by the γ-rays they produce as a result of neutron capture. Such measurements should give a quite good determination of Σ.

One should be able to prospect for hydrogen by a neutron measurement. The experiment that should be attempted would be to fly the two neutron detectors needed to measure R on a lunar orbiter vehicle that also carried a γ-ray experiment to measure the concentrations of the elements important in determining Σ. In this way values of the ratio H/Si could be determined for various positions on the lunar surface. Variations of the ratio could be determined more accurately than the absolute value of R. It would be interesting to try to relate such variation to lunar topography. Some rocks such as serpentine are very rich in water, while others as tektites are low in water content. If different lunar features were of these two rocks we should be able to observe a measurable variation in R. If there are exposed ice fields in shadowed polar craters as has been suggested, they should be easily detectable if they are of comparable size to the altitude of the orbiter.

For the neutron experiment to be successful the detectors must be mounted on a boom long enough to eliminate the vehicle-produced neutron background as a problem. The vehicle should have considerably less than 1 ster solid angle as seen by the detector. The instruments should have a high enough efficiency to give a meaningful value of R in about 1 minute in order to get $\sim$100 km spatial resolution.

It may also be appropriate to try to develop a hand instrument for an astronaut to use to aid in sample selection which would directly read R, the ratio of the two detector count rates. Such an instrument used in conjunction with other proposed hand instruments might give useful estimates of the H/Si ratio.

Prof. Robert Haymes of Rice University and Richard Lingenfelter of UCLA have helped in preparing this report and agree with its main points.

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METHODS OF OBTAINING LUNAR SURFACE ANALYSIS BY ACTIVATION AND ALBEDO COUNTING

J. Trombka

The possibility that some information concerning lunar surface composition can be determined by studying either the particulate or electromagnetic radiation emitted from the lunar surface, has been considered by a number of investigators. This activity may be attributed to natural radioactive materials in the lunar surface, activity inducted by the incident cosmic radiation, or particle albedo. The possibility of including particle generators and detectors to study induced activity and particle albedo produced in a controlled manner and well defined geometry has also been proposed. Many of these techniques show great promise and have seriously been considered by both the Geochemistry and Particles and Fields subcommittees. The usefulness of neutron albedo for the determination of the hydrogenous content of the lunar surface is described elsewhere in the Particles and Fields working group report. The Geochemical Working Group has considered in detail the possibility of using the gamma ray spectrographic techniques to determine lunar surface compositions on both orbiting vehicles and during lunar landing missions. A detailed consideration has also been given by the Geochemistry group to the use of neutron techniques (with a neutron generator brought to the lunar surface as source) for the determination of lunar surface composition.

Two other techniques have also been considered, measurement of gamma ray spectra from a lunar orbiter after solar flare bombardment and measurements of charged-particle albedo. These techniques are marginal in their usefulness but should be considered for completeness.

SOLAR-FLARE BOMBARDMENT (Lunar Orbiter)

For the low-energy protons which predominate in a solar-flare spectrum, a not insignificant component of secondary radiation is due to inelastic scattering gamma rays which are characteristic of the struck nucleus. Thus, a γ-ray spectrometer looking at proton-irradiated material may be expected to see a line spectrum of γ-rays which is characteristic of the elements being irradiated superimposed on a continuum. In particular, for a time-integrated solar flare with 6.6×10^8 protons/cm^2-steradian for $E > 5$ MeV, 1×10^8 protons/cm^2-steradian for $E > 30$ MeV, and 4×10^4 protons/cm^2-steradian for $E > 500$ MeV, the total number of γ-rays of energy 0.842 MeV (the first line in aluminum) will be about 2.5×10^6/cm^2. Unfortunately, the strongest line in the spectrum from ^{56}Fe would likely be 0.845 MeV.

It should not be difficult to measure a spectrum with useful detail with such a source. The difficulty, of course, will rest in preventing the solar flare itself from causing counts in the spectrometer-sensing element directly. The simplest proposal for this is to shield the sensing element from the solar flare. If the spectrometer is mounted on an orbiting lunar satellite and kept directed toward the Moon, then the shield need only cover the 2π + solid angle of the upward hemisphere. The difficulties with this simple arrangement are that the shield would have to be much too thick if it were to exclude the very high-energy particles which would be present in a solar flare, and Y-secondaries from the shield would compete with those from the Moon.

Another proposal is that an anticoincidence counter, combined with a rather thin shield, could be relied upon to shield the γ-ray spectrometer from cosmic rays striking it from the direction opposite to the Moon. A relatively light 10-g/cm^2 shield would reduce the peak counting rate in a 1000-cm^2 plastic anticoincidence counter to about 10^6 counts/sec from a model flare, so even during the early parts of a flare sophisticated scintillation spectroscopy equipment might be able to reject all flare charged particles and allow pulse-height analysis about 10 percent of the time. Unfortunately, even this thin shield would have to be carefully designed to minimize γ-ray production since this production in the shield and the remainder of the spacecraft might give rise to as many counts as the lunar surface. Slightly higher resolution, and lower package weights could be attained if refrigeration problems could be solved to allow use of germanium semiconductor γ-ray spectrometers only a few times larger than currently available.

The flight package required might weigh from 100 to 500 lb, depending on the type of spectrometer. The spectrometer would have to be oriented toward the Moon with accuracy when turned on.

It is concluded that this technique is only marginal in usefulness.

MEASUREMENTS ON CHARGED-PARTICLE ALBEDO

Cosmic-Ray Bombardment of Solar Flares

The charged-particle albedo from cosmic-ray or solar-flare bombardment of the Moon might be measured. In either case it will be necessary to shield the counter from the incident particles. This problem will be somewhat easier than when trying to measure the γ-rays from flares described above but not trivial.

Extracting composition information from such measurements is very problematic. Only the top surface of the Moon is of importance, no direct element identification is possible, and trace elements will not be picked up. At best an average Z or A could be determined.

Up through the iron group the fractional proton albedo should be essentially constant as based on 90° scattering by 160-MeV incident protons (Bertini-Dresner Calculations, see Phys. Rev. 131, 1801 (1963)).

There is some hope of obtaining information if charged-particle ratios can be measured. C and O give 60 to 80 percent as many alphas as protons, Al 25 percent, and Co 8 percent. However, these ratios, even if accurately predicted by the Bertini-Dresner calculation, would be affected by charged-particle stopping, and thus a rather extensive pre-analysis would be required if this method is seriously to be considered. Even more serious, α particles in the incident flare would be scattered to confuse the data.

The average emitted proton and α particle energy might be used to obtain some information since this quantity does to some extent depend on A. However, this would again be smeared by the incident spectrum and energy loss so a very crude average A is the most one could hope to obtain.

We conclude this is not a hopeful analysis technique.

Proton Albedo from 14 MeV Neutrons

If a 14-MeV neutron generator is to be placed adjacent to the Moon's surface, a charged-particle spectrometer might be used to observe (n,p) reactions characteristic of the materials in the uppermost few mg/cm^2 of the crust. The spectrum from a thin foil would be characteristic of the material, with good resolution, and the effect of the thick scatterers would be to yield a continuum with a sharp high-energy edge. Attainable count rates would likely approach 1/sec. This approach should be analysed carefully as an ancillary experiment if the γ-ray secondaries from these neutrons are to be studied as in the experiment using neutron generators considered by the Geochemistry group.

This technique should be considered in further detail.

This section represents views and papers presented by the Geochemistry group, Particles and Fields committee, and F.C. Maienschein, R.G. Alsmuller, Jr., M. Leimdorfer, and R.W. Peele of the Oak Ridge National Laboratory.

RADIO ASTRONOMY AND RADIO PROPAGATION

I. Axford and A.H. Weber

Radio astronomy employing equipment installed upon the lunar surface is an area of investigation of considerable interest to and with unique possibilities for the Apollo Extension System (AES) program. The absence of Earth-like ionosphere, atmosphere and magnetosphere permits the detection of low frequency electromagnetic radiations (in the range 0.001 megacycles sec^{-1} or lower to about 5 megacycles sec^{-1}) not received upon the Earth. The Moon affords a stable platform with the probability of low ambient noise especially for observations from the far side of the Moon which is screened from Earth-originating noise.

Sources of electromagnetic radiation in the low frequency range are: (1) galactic and extragalactic synchrotron radiation producing a more or less constant background but affording some information about instellar absorption in the frequency range observed; (2) the Sun which would emit radiations modulated throughout the lunar month and emits also bursts in the megacycle sec^{-1} region; (3) Jupiter which would have an emission pattern with monthly modulations of different phase than the Sun; (4) the magnetosphere of the Earth which emits noise due to cyclotron and synchrotron emission by magnetically trapped charged particles and due also to Cerenkov radiation from the top of the ionosphere; (5) other sources.

Solar and Earth magnetosphere low frequency noise may be correlated to some extent with the solar wind and magnetometer measurements which can be made at the same time and place.

The frequency range stated above is determined at the high end by including capability of receiving a frequency or narrow frequency band which is received on Earth through the ionosphere so permitting a checkpoint between lunar and Earth-based radio astronomy receptions.

For the first experiments in the AES program small and/or simple antennas can be set up on the lunar surface and used to monitor galactic, extragalactic and solar system radiation sources in the VLF range. Such measurements would extend the radio astronomy spectrum to lower frequencies not observed on Earth and would permit some identification of discrete sources both outside and within the solar system by the expected modulations produced by such sources taking into account the broad (2π) directivity afforded by the simple antennas on the Moon. Such equipment could be deployed and installed by one or two astronauts working on foot or with a small, powered vehicle.

For the intermediate phase investigations considerably greater directivity should be involved than for the early experiments. Simple interferometers or interferometer arrays should be employed and these would be set up by the astronauts using a powered surface vehicle.

The advanced phase investigations would use large phased-array antennas or large reflectors of the trihedral-corner type, for example, and locations would include the far side of the Moon.

Both the initial and intermediate phases of investigation should include exploratory radio astronomy at low frequencies to determine design date (antenna types, sizes and configurations for example) for an extended lunar-based ratio astronomy program of the advanced phase type and to evaluate specifically the feasibility of an eventual full-scale radio astronomy station or complex upon the Moon.

The Radio Propagation aspects of the present program (detailed to some extent in the corresponding Recommendations) include a series of measurements which are quite standard and routine and so are not discussed further here.

The program of Radio Astronomy, Plasma Studies, and Radio Propagation employing lunar based equipment has been discussed with and suggested by Professors Eshleman, Helliwell and Bracewell at Stanford University, Dr. James Warwick at the National Bureau of Standards in Boulder, Professor George Swenson of the University of Illinois, and others.

IONOSPHERE/ATMOSPHERIC MEASUREMENTS

F.C. Michels

INTRODUCTION

The experimental upper limit on the lunar atmospheric surface pressure is less than or equal to 10^{-6} atm, while the experimental upper limit on the lunar ionospheric density is less than or equal to 10^3 ions per cm^3. These numbers essentially exhaust the data, such as it is, on the lunar atmosphere. The ionospheric density limit has been used to infer an upper limit on the neutral gas pressure of less than or equal to 10^{-13} atm; however, the Earth's ionosphere itself has at most an ion density of about 3×10^6 ions per cm^3. Clearly then important theoretical assumptions about the lunar ionosphere have been made which may not in fact be appropriate. In any event arguments have been made to show that a lunar atmospheric pressure of about 10^{-13} atm would already obtain simply as an equilibrium value for particles captured from and then lost to the plasma streaming away from the Sun (the "Solar Wind"). It should further be noted that volcanism, if occurring on the Moon at the terrestial rate could sustain a lunar atmospheric pressure of about 10^{-7} atm.

At a pressure of 10^{-13} atm, the lowest value quoted above, the total mass of the lunar atmosphere would be about 100 metric tons, as compared to the perhaps 5 tons of rocket exhaust products that would be expended near the lunar surface by a lunar surface mission. Such exhaust products are therefore a potentially serious contaminant of the lunar atmosphere, and such contamination can only be expected to accumulate during the decade of lunar exploration under the AES program, to say nothing of the possible contribution from its Russian counterpart.

It seems likely that the obvious and very appropriate geophysical measurements, for which the necessary equipment has already been developed, will have de facto priority. However, it must be emphasized that certain geochemical, biological, and atmospheric determinations stand an excellent chance of being permanently compromised by the very act of landing. Such unique measurements therefore deserve the highest priority. While some biological and geochemical interests will be partially preserved by sample return, it is impractical to collect and preserve gas samples at pressures as low as 10^{-13} atm; consequently instruments must be set in place to locally monitor the lunar atmosphere. In the next section we discuss these experiments and their relevance to lunar science.

RELEVANCE (Atmospheric)

It is completely possible that the lunar atmosphere is dominated by volcanism or other outgassing processes. Determination of the amount, composition, and variation of the atmosphere would immediately give geochemical and geophysical information not otherwise available. The atmospheric measurements are therefore directly pertinent to the lunar body as a whole.

The lunar surface materials will to some degree, perhaps importantly, influence the atmospheric composition and dynamics of the lunar atmosphere. Effects important to the lunar atmosphere may easily be too subtile for direct laboratory examination.

The interaction of the solar wind with the Moon as a whole as well as its surface, together with as yet unanswered questions concerning the dynamics of such a system, can be studied by the effects on the lunar atmosphere and ionosphere.

Finally, and most importantly, the role of the unexpected should not be underrated. It should not be assumed that the lunar atmosphere is unimportant merely because it is acknowledged to be thin.

RELEVANCE (Ionospheric)

Since the ionosphere is expected to derive primarily from the neutral atmosphere, ionospheric measurements may be used to infer data on the neutral atmosphere. The relevance of the latter data has been discussed above. Ionospheric measurements are therefore an important companion to atmospheric measurements.

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Interaction of ions with the lunar surface (neutralization, retention, etc.) may play an important role in the thin lunar atmosphere, providing information (complementary to the neutral atmosphere data) on the nature of this surface.

The interaction between the solar wind and the Moon, which is expected to lead to magnetic effects (see recommendations of the Particles and Fields Working Group on the Magnetometer Experiment), must also lead to perturbations of the lunar ionosphere. Ionospheric measurements therefore complement the magnetometer experiment.

And again the unknown. Does the lunar ionosphere disappear during the long lunar night? Are the electron and ion temperatures significantly different? Etc.

EXPERIMENTS

We will consider five direct measurements pertaining to a lunar atmosphere, namely:

1. total pressure
2. neutral mass spectrum
3. ion density
4. ion mass spectrum, and
5. directed ion flux

In addition, there are various electromagnetic methods for determining the electron density (e.g., the ionosonde) which may also be included in (3) above, although we actually envision a less ambitious instrument for measuring the local ion density on the early Apollo missions.

Measurements (1) and (2) pertain directly to the neutral atmosphere, and useful information on the neutral particles may be inferred from the ionospheric measurements (3) and (4). The possibility that the solar wind actually reaches the lunar surface requires consideration of (5). Clearly the maximum geochemical information is contained in the measurement of the neutral particle spectrum.

With the exception of the neutral mass spectrometer, instruments to reliably perform the above measurements presently exist. Neutral mass spectrometers asserted capable of operating at the low pressures envisioned are now beginning to appear, and it now seems reasonable to suppose that the necessary modifications of these instruments for spacecraft requirements can be accomplished well in advance of the first Apollo mission.

ORBITER EXPERIMENTS

TO: Peter Badgley, Program Chief,
Advanced Missions,
Manned Space Science Programs,
NASA

From: Fields and Particles Working Group

Subject: Lunar Remote Sensors in the Discipline of Fields and Particles.

Introduction

As your letter of July 6th, 1965 indicated, and as your comments at the Woods Hole meeting reinforced, there is a need for immediate input to you of information for planning purposes of remote sensors in lunar projects. Here we present to you scientifically valuable and practicable experiments in the discipline of Particles and Fields which we recommend should be carried out with remote sensors in lunar orbiters and in cislunar space.

This memo does not treat remote sensors in Earth orbiters. The two pertinent justifications of Earth orbiter flights of remote sensors are (a) flight-testing for potential lunar orbiters and (b) research investigation of the Earth environment. Neither justification is particularly relevant to Fields and Particles, the first being absent because most of the envisaged instrumentation is essentially "state of the art", and the second because similar instruments are currently flown or planned to fly in the unmanned satellite program of OSSA.

Accordingly, we present here several valuable experiments for remote sensors in lunar orbiters and cislunar vehicles. Actual experiments are outlined and justified for their scientific value and for their relevance to lunar and cislunar studies in this and other disciplines.

There are three major points of interest in lunar remote sensors in Fields and Particles:

1. They are needed to give information about basic lunar properties. For example, the lunar magnetic field may be simply that produced by the diffusing interplanetary magnetic field, which changes in magnitude and direction. Again, the lunar atmosphere may be dominated by thermalized solar wind, which also fluctuates in velocity and density. Furthermore, lunar luminescence and induced radioactivity are produced by the variable fluxes of solar energetic particles and cosmic rays. Clearly then, to understand these several lunar properties the impinging fields and particles must be measured, and this is what we recommend below.

2. There are many phenomena that occur in the vicinity of the Moon that are of fundamental scientific interest because they are peculiar to the Moon with its unique properties of negligible magnetic field, small atmosphere and dimensions comparable to the ion cyclotron radius in the solar wind. Consequently, study of any lunar shock front and associated phenomena will be very valuable.

3. There are many measurements of value where the Moon and lunar orbiter and lunar missions can be used as bases for observations of nonlunar phenomena. For example, for 4 or 5 days at times of full Moon the Moon may well be inside the magnetospheric tail of the Earth and so be subjected to bombardment by auroral/magnetospheric particles in the tail.

Experiment #1

Solar-Wind Lunar Interactions

It is believed that the supersonic solar wind impinging on the Moon may form a shock front at which the particles are thermalized and then flow into and around the lunar surface. In fact, this thermalized solar wind may be a dominant part of the lunar atmosphere, and also the associated magnetic field may diffuse into the Moon and dominate the lunar magnetic field. Two very useful lunar remote sensor experiments in lunar orbiters in one of two different orbits would be the following combination:

1. Measure transient magnetic fields up to 200 gamma with a resolution of $\pm 1/2\ \gamma$ in three orthogonal directions with a time resolution of about 1 second.

2. Measure flux and energy spectrum of electrons and of protons over the energy range about 10 eV to about 100 keV in three orthogonal directions.

   Total weight about 20 lb

   Telemetry about 100 bits/sec

This should be coordinated with similar lunar surface-based measurements. It will also provide information on the magnetospheric tail of the Earth. One orbit should be near circular at an altitude of 50 to 100 km to study day-night effects. Another orbit should be eccentric ranging from a few hundred kilometers perigee to a few thousand kilometers apogee so as to penetrate the shock front.

Experiment #2

Energetic Solar Particle Measurements

At intervals of about one month during years of high sunspot activity and less frequently during solar minimum, the Sun emits intense fluxes of energetic nuclei, ranging from energies of order

100 keV to relativistic energies of order 10 BeV. These particles may occasionally pose a radiation hazard to lunar personnel and packages, they may excite fluorescence and induce radioactivity in the lunar surface. They consequently need to be monitored, and lunar-based packages will serve this role. But similar sensors on lunar orbiters would provide measurements of anisotropies produced in the particle radiation by interplanetary magnetic field. Furthermore, coordinated measurements should be made with similar packages on a lunar orbiter and on opposite sides of the lunar surface in the equatorial region.

Experiment #3

Neutron albedo

Bombardment of the lunar surface by galactic cosmic rays and solar energetic particles produces an upwards-moving flux of neutrons ("albedo neutrons") over the energy range of 1 eV to tens of MeV. Analysis of the energy spectrum of the albedo neutrons at three energies can provide information on the hydrogenous content of the lunar surface, e.g., including the existence of significant ice beds. Such an instrument in a lunar orbiter can survey the lunar surface properties.

Experiment #4

Ionosphere and Atmosphere

A neutral-particle mass spectrometer and an ion spectrometer should be included in early lunar orbiters so as to determine a partial profile of the lunar atmosphere.

Experiment #5

Galactic cosmic radiation

Certain cosmic-ray studies can profit greatly by the weight, size and recovery capabilities of lunar orbiters and payloads in cislunar space. For example, a large nuclear emulsion package in an air-lock device would permit (a) studies of the charge spectrum of low energy cosmic rays that cannot be studied easily inside the magnetosphere and (b) studies of high-energy cosmic rays and their interactions that cannot be studied with adequate statistics on balloon flights.

In addition, a very useful remote sensor experiment in a lunar orbiter would be a measure of charged-particle albedo. This knowledge will be valuable in itself and more valuable as a measure of possible contamination of lunar and galactic gamma rays.

Conclusions

The above list of experiments is not intended to be comprehensive, but merely indicates some of the significant experiments in Fields and Particles that can be carried out with remote sensors in lunar orbiters. We consider that, at the present time, there is no necessity for the establishment of a "team" in the Fields and Particles discipline, simply because most of the instrumentation is in the "state of the art". There are significant instrument developments needed, e.g., in gamma-ray and electric-field detection, but these should be treated separately.

N66-14833

REPORT OF
LUNAR ATMOSPHERES WORKING GROUP

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BACKGROUND

Measurements of the lunar atmosphere are of interest from an atmospheric physics viewpoint. Additionally, however, such measurements can be expected to significantly supplement the geologic data gathered on the Moon, since the lunar atmosphere may have evolved from solid lunar material. Geology without lunar atmospheric studies, or vice versa, would unnecessarily increase the number of conjectures that must be made to properly appreciate the lunar evolutional process and its current state of evolvement. Since Apollo missions may contribute significantly to the contamination of the lunar atmosphere, it is important that measurements of the lunar atmosphere be accomplished as near the beginning of the program as possible.

The lunar atmosphere is known from optical measurements to be less dense than about 10^{-6} that of the Earth's atmosphere and the ionized component is less than about 10^3 ions/cm^3, as determined by radio measurements. Beyond these upper limits, all else is inferred.

In a steady-state atmosphere, the concentration of particles of a given kind is determined by the input rate and the loss rate. The measurements mentioned above therefore limit either the input rate to a very low value, or the loss rate to a very high value, or both. The former extreme would be characterized by a residual atmosphere of gravitationally bound heavy gases (i.e., zero input rate), while the latter extreme would be characterized by a rapid escape mechanism (e.g., solar-wind particles striking atmospheric particles and driving them away).

POSSIBLE SOURCES OF LUNAR ATMOSPHERE

The wide variation in theoretical predictions concerning the lunar atmosphere arises mainly from differing concepts concerning the source mechanisms. Rather than discuss the theories, we here simply mention the various possible mechanisms and how they pertain to the measurements. The possible atmospheric control mechanisms are:

(1) An original atmosphere with no further accretion. In this case, the remnant atmosphere would be examined by a surface instrument. An exceedingly slow loss mechanism (e.g., $t_{loss} > 10^8$ years) would be required to leave any trace of the original atmosphere. Since thermal-escape undoubtedly occurs to some extent, it can easily be shown that the only remaining components of an original atmosphere would be heavy gases such as xenon or krypton. A mass spectrometer would therefore detect only heavy gases.

(2) Volcanism or outgassing in general of volatiles from the interior of the Moon. Atmospheric components so generated should be mainly water vapor plus traces of SO_2, NH_3, CO_2, etc. (i.e., typical volcanic efflux). If the loss rate is large compared to the rate for photodissociation in the solar radiation, then these components would be detected as molecules, while for the contrary situation, monatomic oxygen would be the principal constituent detected; this would arise from photodissociation of water vapor, where the hydrogen escapes rapidly due to its small mass.

Gases may also be released from rocks or magmas near the lunar surface. Gases entrapped in and evolved from rocks are, after H_2O, primarily CO_2, HCl, Cl_2, H_2, H_2S, CO, CH_4, N_2, and O_2. Rocks and magmas of different composition evolve varying amounts of these gases, and thus allow an estimate of the composition of the rocks from which the gases are evolved. Gas compositions are also useful in following the process of magmatic differentiation, and would be of significant value if the composition of gases emanating from a volcanic vent on the Moon could be measured for a period of time.

Recent work on gases in terrestrial rocks indicates the following generalizations:

a. Gases other than water range from 0.1 to 6 cm^3/g

b. CO_2 is generally near 50 percent of the total gas other than H_2O in basalts, but it is generally low in rhyolites and intermediate in granites and andesites

c. H_2 is the dominant gas in granites, but it is highly variable in other rocks

d. Sulfur, reported as S_2, is generally 2 to 9 percent of other gases in basalts, is also high in some andesites, but is generally low in obsidians and granites

e. Cl_2 is commonly 10 to 30 percent in rhyolites and some andesites, it is less than 10 percent in basalts, and it was found to be less than 1 percent in two samples of granite

f. F_2 is the dominant gas in most obsidians and in some basalts, and it ranges from 10 to 30 percent in most other rocks

g. CO, N_2, and Ar do not show systematic differences

It has been postulated that strong Earth-induced tidal forces acting upon the Moon cause fault lines in the lunar crust to shift and slip to the extent that there will be brief periods when trapped subsurface gases will be released. Large scarps and fissures on the lunar surface are consistent with this concept. Detection of gases released from such vents would be extremely valuable to the understanding of the Moon's internal structure. Continuous monitoring of regions of sporadic or periodic outgassing would be desirable in order to detect gases with short retention times in the lunar atmosphere.

(3) Meteoric Volatilization. The effect of meteoritic bombardment of the lunar surface causing agitation of the surface material may have significant effects in accelerating the geological evolution of the gaseous atmosphere by releasing the occluded and absorbed

gases in the lunar surface material. This is similar to (2) except that individual inputs could be distinguished by the rapid rise and subsequent decay of fluctuations in the atmosphere due to the sudden release of gas rather than the relatively slow outgassing process. Furthermore, simultaneous seismic measurements of impact could also aid in distinguishing such events. The seismic experiments that have already been proposed should integrate meaningfully with the atmospheric measurements.

(4) Release by Energetic Particles. Impact on the lunar surface by energetic particles, especially protons from the solar wind, will tend to break down compounds and produce free potassium, aluminum, cadmium, etc. The vapor pressure of many of these materials is high enough so that they may contribute significantly to the lunar atmosphere. Since these materials are not present in the terrestrial atmosphere, it may be possible to prepare the lunar instrumentation so that it will not release such materials on outgassing, and it should be possible to detect much lower concentrations of these materials than of water vapor or other terrestrial gases.

(5) Solar Wind Accretion. Gas so accumulated will initially be essentially ionized and monatomic, due to the high temperature of the solar wind ($> 10^5$ $^{\circ}$K) and the even higher temperature of its source, the corona ($> 10^6$ $^{\circ}$K), but it may become neutralized and combined into molecular forms after reaching the Moon. The composition would be similar to the Sun, possibly altered by diffusive separation, and the solar wind would therefore provide an atmosphere composed mainly of oxygen and nitrogen. A large proportion of nitrogen would then serve to distinguish (5) from (2) and (3). Furthermore, a solar wind incident on the lunar surface should be directly detectable.

IMPORTANCE OF MEASUREMENTS

The analysis of gases at the lunar surface will be of value to geologists in determining the kinds of geologic processes, especially those involving magma generation, that were or are present within the Moon. From the composition of the gases evolved during magmatic processes, much can be determined concerning the composition of the rocks and magmas within the Moon, which in turn will aid in determining the history and origin of the body. It is evident that measurement of time variations in the lunar atmosphere is potentially capable of distinguishing among the more plausible accretion and loss mechanisms.

The possible existence of volcanism is exceedingly important since such phenomena may provide volatiles that are useful for life support (both intrinsic and extrinsic). The location of volcanic sites, if they exist, can be facilitated by deploying several atmospheric pressure gages (one per Apollo mission, for example): time variations at different locations could be interpreted to locate the volcanic site, analogous to the location of earthquakes with several seismographs. The feasibility of such a program cannot be judged until at least one pressure gage is in place, and if proven feasible, then two more gages should be desirable at widely spaced locations (i.e., three Apollo missions in all). Therefore the first gage should be landed at the earliest opportunity. In brief, the first datum, no matter how crude the information or how poor the resolution, should be obtained just as soon as possible, hopefully before the exhaust gases from retro-rockets have had a chance to disrupt seriously the lunar atmospheric composition.

CONTAMINATION

The total mass of lunar atmosphere in terms of the particle concentration at the surface is approximately 100 g/(particle/cm^3). Present experimental and theoretical estimates give $\sim 10^6$ particles/cm^3 for the particle concentration, or about 100 metric tons for the total atmospheric mass. The Apollo's LEM will release up to 5 metric tons of exhaust gases. The above estimate involves important uncertainties, and the Apollo reaction products may even dominate the atmosphere. It is unfortunate that the vehicle carrying the atmospheric-measurement experiment may itself seriously contaminate that atmosphere, and the experiment should therefore be capable of operating for an extended period. At the very least, the loss rate for the contaminant gases can thereby be determined. If these loss rates are sufficiently large, then the atmosphere will return to its steady state and be observed by the lunar atmosphere experiment. Loss due to solar wind interaction may give rise to loss time constants of the order of 1 month, or about 1 lunar day. Thus the experiment should last, at the minimum, for several months. It is desirable, in any event, to observe any changes in the atmosphere that may occur between lunar day and lunar night, since this can provide further information on composition (e.g., the freezing out of volatiles during the very cold lunar night).

The contamination problem provides a powerful argument that a first attempt at lunar atmosphere direct measurement should be made from an orbiter. The merit of such an approach, assuming that the altitude of the orbit would be low enough, is that: (a) a reasonable opportunity would be available for making measurements prior to contamination, (b) any burst of volcanic origin such as that recently detected optically might well be detected directly, and (c) outgassing at the dawn meridian might be detected. It is very important to have the opportunity to look for such gases before significant contamination takes place.

An environmental factor that may be altered by rocket gases during the first and succeeding lunar missions is accumulation of condensed rocket gases upon possibly existing primitive deposits of frozen water and carbon dioxide in permanent or semi-permanent shaded regions on the lunar surface. During future lunar surface exploration into these shaded regions, the question may arise as to whether any frozen constituents were primary in origin or products of rocket gases, or possibly both. Knowledge of the diffusion and retention times of rocket exhaust gases around the Moon's surface would aid in determining the answer.

With the advent of more rocket landings and surface exploration activity, considerable amounts of rocket gases will be added to the lunar atmosphere, and these gases will be modified by charged-particle and electromagnetic-radiation energy from the Sun. This action of the solar radiation will result in a continuously changing atmosphere. These changes could affect scientific investigation of the overall lunar surface materials due to absorption and desorption of gases. These gases may react upon mineral deposits exposed on the lunar surface as the gases condense during the long lunar night (14 Earth days).

It is, therefore, imperative that consideration be given to retention times of rocket exhaust gases in the lunar atmosphere and their effect upon future manned lunar surface exploration.

RECOMMENDED MEASUREMENTS

Optimally the lunar atmosphere experiment should measure the following neutral constituents:

1. total pressure
2. mass spectrum

and the following ionic constituents:

3. total concentration
4. mass spectrum
5. directed flux

The most direct approach to lunar atmospheric measurements is the use of some type of mass spectrometer to measure the neutral gas composition and an ion mass spectrometer for ion composition. A total neutral pressure measurement alone should be done only as a last resort if an adequate mass spectrometer cannot be developed. It would appear, at the present state of the art of mass spectrometry, that considerable development work to create a device compatible with the possible ranges of lunar atmospheric pressure must be performed before a practical package can come into existence. With the estimates of lunar atmospheric pressures ranging from 10^{-10} torr down to 10^{-15} torr, a major improvement in sensitivity of a mass spectrometric device will be necessary. In addition, the ion-generating region for a neutral gas spectrometer should employ some technique other than a thermionic emitter in order to avoid outgassing of the system and gettering of the gas molecules, thus presenting a biased composition.

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Relative to the Apollo program, the possibility of leaving behind a mass spectrometer package to telemeter the lunar atmosphere over a period of time seems to be most desirable. It would provide information concerning the rate of cleanup of the atmosphere after departure of the LEM as well as day and night atmospheric composition. Further, some information concerning solar activity and its effect upon the composition of the lunar atmosphere could be obtained.

Charged-particle analyzers should be set up on the lunar surface to examine the energy spectra of both positively and negatively-charged particles and their directions of arrival. If the solar wind impinges without disturbance on the lunar surface, the measurements made with this instrument would be simply those of the undisturbed solar wind. It is more likely that a region of disturbance or shock wave exists for some distance out from the Moon, in which case the measured particle fluxes would not be characteristic of the undisturbed solar wind.

An ion mass spectrometer and ion trap should also be included in the instrumentation; these measurements would be especially useful if the solar-wind particles reaching the Moon are completely thermalized or if there is significant ionization of lunar gases. An ion mass spectrometer can provide information on relative concentrations, but it is not very good for establishing absolute concentrations. An ion trap is particularly effective for determining the absolute concentration but it has poor capability for analyzing the relative abundances of different constituents except in very idealized situations. Thus the two instruments complement one another.

Pressure gages should be used on all missions. It is probable that pressure gages are the only instruments sufficiently developed to be useful in an orbiter, where there could be a real payoff in the sense of detecting discrete sources of morning surface outgassing.

In summary, the maximum direct information on the lunar atmosphere must come from measurements on the neutral components, while the experimental techniques are better developed for measuring the ionized components of the atmosphere. The total neutral particle pressure can be measured with available techniques. The mass spectrum should be measurable, depending on progress in instrument development in this area. We therefore suggest the following priorities among the possible atmospheric measurements for the first three Apollo missions.

First Mission:

1. neutral mass spectrum (if adequately developed)
2. neutral particle pressure
3. total ion concentration
4. directed ion flux
5. ion mass spectrum

Second Mission:

1. neutral particle pressure
2. directed ion flux
3. ion mass spectrum
4. neutral mass spectrum
5. total ion concentration

Third Mission:

1. neutral particle pressure
2. neutral mass spectrum
3. ion mass spectrum
4. directed ion flux
5. total ion concentration

The development of a neutral particle mass spectrometer capable of operating in the expected pressure range (10^{-13} atm.) should be pushed with the nominal intention of sending that instrument on the first mission; the ion equipment also should be included if space is available. In any case, it should be available as a replacement if development difficulties delay the neutral mass spectrometer so long that it cannot fly in early Apollo missions.

AVAILABILITY OF INSTRUMENTATION

Except for neutral mass spectrometers, instrumentation of the type and sensitivity required for the recommended program has been developed and is presently in use in space systems. Ion traps and ion mass spectrometers have been flown in many vehicles, including EGO. The directed ion flux could be measured with a solar wind detector, of which that flown in Mariner is a good example, or with a spectrometer for low-energy particles, such as that in the ISIS program. Pressure gages of the Redhead type have been extensively used and are essentially on-the-shelf items.

Neutral-particle mass spectrometers of the required sensitivity have not yet been operated in the laboratory. What is required, however, is apparently only a marriage of existing techniques. The addition of electron multipliers and counting techniques to an instrument of the quadrupole type can probably supply the required sensitivity, while the introduction of coincidence techniques may provide an even better instrument. Instrument development rather than research appears to be the requirement, and it appears probable that a suitable instrument can be developed in time for the early Apollo missions.

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REPORT OF
ASTRONOMY STUDY GROUP

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SUMMARY

RESOLUTIONS

The Astronomy Study Group was interested in the Apollo Extension System (AES) program for the 1970-1975 time period. As a source for initial discussion, the observatory base capabilities and possible astronomy experiments described in the LESA Report[1] were reviewed.

The following resolutions were made:

The Group considers that the Moon may well offer an attractive and possibly unique base for astronomical observations and recommends that studies begin as soon as possible to explore the lunar capabilities for astronomy. These studies should involve evaluating engineering studies on Earth, environmental studies on the Moon, and testing with small telescopes on the Moon.

It is felt that it is extremely important to start feasibility studies for a dish of the order of 100 feet to be used between millimeter and infrared wavelengths immediately after the 1975 time scale. The dish has to be above the Earth's atmosphere.

The Group considers that the information to be gained from radio astronomy observations at frequencies between 10 Mc/s and 50 kc/s is of considerable importance. To make these observations on a reasonable number of radio sources, and to map the continuum radio emission over the sky a beam area of about 100 square degrees or less at 1 Mc/s is necessary.

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[1]North American Aviation, Inc. Report SID 65-289-4, A Study of Scientific Mission Support Lunar Exploration System for Apollo, June 16, 1965.

The Group recommends that a feasibility study be started as soon as possible to determine whether the antenna should be placed in high Earth orbit or on the lunar surface, and the type of antenna to be used in each case. Information about the lunar environment is essential to decide if the Moon is a suitable place for such an array, and should be obtained as soon as is possible.

NEED FOR ENVIRONMENTAL DATA

It was apparent that adequate environmental data are not available at present. Problems of a lunar base were discussed, but in many instances it was not possible for the Group to specify in any detail the environmental data which would be required.

The importance of studying the lunar environment, at an early date, was emphasized for all branches of astronomy. The studies should provide an answer to how much, and in what detail, environmental data should be acquired before engineering design can be started for astronomical facilities on the Moon. The major environmental areas requiring study were discussed for radio, optical and X- and gamma-ray astronomy.

Radio Astronomy

1. Mechanical properties (bearing strength, stability, etc.)

2. Electrostatic charge (dust and surface rock)

3. Background noise (radio interference from Earth or spacecraft)

4. Impedance and dielectric properties (lunar subsurface)

Optical Astronomy

1. Mechanical properties (bearing strength, stability, etc.)

2. Micrometeoroids (primary and secondary flux, erosion of mirrors, etc.)

3. Light background (luminescence, dust and atmosphere)

4. Thermal environment (above, on, and below the surface both lunar day and night)

5. Surface characteristics (reference points on Moon)

X- and Gamma-Ray Astronomy

1. X-ray background (from solar wind, cosmic ray, bombardment, etc.)

2. Gamma-ray background (radioactivity, etc.)

WEIGHTING OF EXPERIMENTS

Many types of experiments and instruments were discussed and are described in detail in the next section. It was decided to consider the individual experiments in the LESA report and to have a secret ballot vote on each.

A record of the voting results is given in Table I together with a definition of each category of vote. It is important to note that only lunar surface operations were considered in the voting and only in the time period from 1970 to 1975. It was felt that the votes on a number of the experiments would change rather markedly if the time period should be extended.

TABLE I

WEIGHTING OF ASTRONOMY EXPERIMENTS

Title of investigation	Vote category[1]			
	A	B	C	D
Radio astronomy				
Experimental VLF antenna (dipole)	11	2	0	0
Galactic radio background	1	6	4	1
Radio-burst monitoring	1	6	4	0
100 sq degree array	1	3	6	2
Lunar radio transponder	3	4	3	0
100 ft dish (mm-μ)	0	4	3	2
Radio telescope (mm) 20 ft dish	0	4	3	2
Lunar radio observatory (all wave)	1	0	2	6
Optical astronomy				
12 inch wide-angle telescope	3	5	5	1
12 inch high-resolution telescope	7	1	4	2
40 inch telescope	3	3	4	4
Interstellar (Lyman-alpha) survey	0	7	7	1
Einstein shift experiment	0	2	9	3
Corner reflector	3	4	2	0
X and gamma ray astronomy				
X-ray occultation	6	4	1	0

[1]Definitions:

A - Excellent science; needs Moon, should be done on LESA.
B - Good science; Moon suitable or provides needed experience.
C - Good science but does not need Moon; should be done if ample resources are available.
D - Do not do on LESA - 1970-1975.

INTRODUCTION

PURPOSE

The purpose of the meeting was to review the LESA (Lunar Exploration Systems for Apollo) report (see footnote 1) followed by further discussion of the use the Moon has for astronomy, of what was needed to find out how to use the Moon effectively for astronomy, and of what experiments on the Moon make sense for astronomy.

Allenby, Tifft and Beattie first outlined the role of the Study Group and the purpose of the LESA Study in the AES program.

LUNAR AES POTENTIAL

The Lunar AES program has valuable potential. We do have, or will have by 1970 presumably, a capability of manned operations both in orbit and on the Moon, and we will have, presumably by this time period, a capability of taking large payloads both to orbit and the Moon. Therefore, for the first time in the space program we are in a situation where we no longer have to be weight-limited within very large volumes. We are not going to launch a 200-inch or even a 120-inch telescope, but still, by satellite standards, we are not weight-limited. We are probably not power-limited because we probably can use some of the new power supply systems that are being developed. We are not limited to things that can be completely automated because we will have man available to make changes.

Therefore, we can look at it from the standpoint that the capability which we have been slowly building in the unmanned satellite program is in fact about to take an order of magnitude step foward, which is probably as significant potentially as the step between the Vanguard satellites and the observatory-type satellites. Do we want to use this capability for science? If so, what makes a meaningful program towards its utilization, keeping in mind the other parts of technology? For example, how do we build large diffraction-limited telescopes; or how do we erect large radio arrays in space, taking account of the technological limitations there; what is a sound program which will make use of all of the capability we have both manned and unmanned?

Another aspect is that this capability for large payloads for manned operations, in both space and on the Moon, has been procured at significant expense. A large industrial complex has been built up. So, in addition to the question as to what makes the sounder scientific program, the question will probably arise as to how do we make the soundest, most reasonable use of this capability which we have procured. And the answer to these two may not be necessarily the same.

There is a third problem, which unfortunately makes one stage more difficult, and that is the fact that at the same time that we are getting these very strong pressures to utilize large instruments in orbit and on the Moon, we have very severe budgetary limitations. There seems to be very little hope that the NASA astronomy budget is going to expand significantly beyond what it is. And, we have equally severe manpower limitations with apparently little hope of the NASA astronomy manpower expanding beyond what it is. Or, even if the manpower should expand, the scientific competence in the country is not likely to expand at a tremendous rate. This then leads to a paradoxical situation in which we can't necessarily do exactly what we think would be best in answer to any one question, but try to perform the best science overall.

SPECIFIC TOPICS

The following five technical questions were asked of the Group.

1. What preliminary work must be done in the early time frame in order to give us the environmental data and the technological data that we need to make a meaningful decision as to what we want to do in orbit, or particularly in this case, on the Moon.

2. Taking the LESA report as it stands, are the experiments which are proposed good experiments for the time period that we are talking about, viz., 1970-1975?

3. Are there other experiments which we should seriously consider for the Moon in the 1970-1975 time scale that are not included in the LESA document?

4. Among the experiments which might be done on the Moon in this time period, if we can't do all of them, what are the science priorities?

5. Again, if we can't do everything, what are the relative priorities between using this AES capability in orbit and using it on the Moon?

RADIO ASTRONOMY

LONGWAVE RADIO ASTRONOMY

The longwave radio astronomy discussions dealt with that portion of the electromagnetic spectrum which is generally inaccessible from Earth and lies between about 100 Kc/sec and 30 Mc/sec. The Earth's ionosphere cuts off frequencies lower than about 10 megacycles per second, the exact frequency depending on the solar cycle, and causes absorportion to frequencies up to about 30 Mc/sec. The interplanetary medium is expected to absorb frequencies below 100 Kc/sec. If longwave measurements are to be made, and there is good reason to do so, they will have to be made from outside the Earth's ionosphere.

The LESA report does not go far enough in the proposed experiments for longwave radio astronomy. The suggested experiments will probably have been completed by the time LESA is on the Moon since all these experiments have already been proposed for orbital satellites and should be performed within the next few years.

Longwave radio astronomy will need one or two large radio telescopes in high orbit or on the Moon. The limitations on the size of the instruments will be set by the solar plasma environment at perhaps 20 kilometers in aperture. This conclusion is based on the already known fact that irregularities exist in the interplanetary plasma. These irregularities would result in a condition similar to poor seeing in optical telescopes.

The following resolution was passed by the Group:

Considerable information is to be gained from radio astronomy at frequencies between 50 Kc/sec and 10 Mc/sec on radio sources and on mapping the sky. The Group recommended that feasibility studies should be started as soon as possible on a 100 square degree array. The suitability of high and low orbits and the lunar surface should be considered together with the most suitable antenna in each case. Information about the lunar surface is considered very important to the design, and lunar environmental data should be obtained as soon as possible.

The discussions on the individual experiments proposed in the LESA report are summarized below.

Experimental LF Antenna

As an early step in the use of the Moon for radio astronomy purposes a simple dipole can be set up to test the lunar environment. The electrical characteristics and impedance of the antenna would be known from tests on Earth before it was transported to the Moon. If the antenna is used at frequencies of the order of 10 Mc/sec then information on the conductivity and dielectric constant of the lunar soil can be obtained. At lower frequencies the electron density in the lunar environment could be determined after the cosmic noise and impedance properties have been measured. In this way, early in the LESA program, a small radio "telescope" could investigate the parameters of the ionosphere, the ground conditions, and the noise interference environment. This information will be necessary to the design of any larger telescopes. The erection of a small experimental antenna is considered a good way of obtaining environmental data.

One major problem which can be foreseen for low frequency radio astronomy is the Earth-generated radio interference. The Moon may offer a unique solution to this problem in that it should be possible to establish a radio astronomy site on the side opposite the Earth and to use the bulk of the Moon as shielding.

The Group strongly endorsed the suggestion that an experimental site testing antenna be erected on the surface of the Moon during the 1970-1975 time period. The preferred location may be on the far side of the Moon and if possible an environmental testing package should accompany the dipole.

Galactic Radio Background and Burst Detection

The Group supported experiments on galactic radiation but it was pointed out that most of the experiments outlined in the LESA report will have already been done by the Explorer series of satellites by 1970. Regarding burst phenomena, the Sun and Jupiter are of specific interest because of the time varying phenomena which have already been observed right down to the ionospheric cut-off frequency. There is every reason to expect them to go well below this frequency. It is possible that other planets may also produce burst radiation. According to the Russian experiments and to observations made by the Harvard group, the Earth also emits burst radiation.

A number of institutions have already produced instrumentation suitable for making these low frequency measurements from the Moon. These include radiometers, to measure cosmic noise and bursts from various sources, and an impedance probe.

In view of these facts the Group acknowledged that good science could be achieved in examining galactic radio background and radio bursts and that the Moon was a suitable location for these measurements, but it did not indicate that they should have high priority on LESA between 1970 and 1975.

100 Square Degree Array

To examine low-frequency radio sources in any detail, an instrument such as has been suggested in the Woods Hole report is required. This instrument has a resolution of the order of 100 square degrees at a frequency of 1 Mc/sec. If such an instrument could be built on the Moon, it would be competitive with those that have been proposed for orbit in space. For a large array, the lunar stability problem is not of prime concern; since this would be a long wavelength instrument, the angular resolution would be at most minutes of arc. The librations of the Moon should therefore be adequately calculable.

The antenna considered for LESA was primitive in this respect. Some sort of antenna for galactic, solar and planetary nonthermal radiation was suggested. This is barely a start in what could be done in longwave astronomy. A much larger instrument as suggested above would be far more desirable.

One factor that bears on the question of whether such an antenna can be built on the Moon is the suitability of the lunar environment. Such characteristics as the surface and subsurface properties, the height of the ionosphere, the spatial distribution of dust, and any possible electrostatic charge should be studied. Some of these questions may be answered by the Apollo investigations, and others can be answered by using an experimental antenna in the LESA program.

The Group strongly endorsed the suggestion of a 100 square degree array, but considered that it should not have a very high priority in the 1970-1975 time frame.

Lunar Radio Transponder

The suggested experiment involves placing a radio transponder on the surface of the Moon, so that signals can be sent from the Earth and returned via the transponder. The amplification and phase shift introduced by the transponder would, of course, be known. The transmitted signals could be of two types, continuous wave, or pulse. Range could be measured by sending pulses to the Moon and receiving them at the same station. A measurement of Doppler shift would allow the rate to be derived. Possible advantages from such a system would come from measurements of lunar libration, lunar orbit, Earth-Moon separation, lunar size, Earth's radius, and lunar and terrestrial rotation rates. However there is no certainty that any of these measurements can be made with a sufficiently high accuracy at low frequencies.

An important problem in working with radio ranges is the determination of the accuracy with which a pulse can be transmitted and received. Experiments have been performed using two NASA satellites synchronized between the U.S. and Japan. An accuracy in time of 1/10th of a microsecond was achieved. Relating this to an Earth-Moon transmission reveals a distance accuracy of approximately 15 m. If on the other hand light is used instead of low frequency radio transmissions, an accuracy of the order of centimeters could be anticipated.

The Group considered that the primary importance of the radio transponder was in determining the cislunar electron density. There was however some feeling that the transponder was not the best method of achieving this measurement and it was suggested that the subject requires further study. The astronomical and geodetic benefits suggested for the radio transponder were considered inferior to those which could be obtained from optical methods.

An additional suggestion was that EGO or ISIS could be used with a transponder and thereby eliminate the interference caused by the Earth's ionosphere.

SHORTWAVE RADIO ASTRONOMY

The shortwave radio astronomy discussions dealt with that portion of the electromagnetic spectrum which is inaccessible from Earth and lies between wavelengths of about 1 mm and wavelengths of about 10 microns.

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The millimeter and submillimeter range was rather inadequately discussed in the LESA report. Most of the observations suggested for the 20-foot diameter dish proposed for LESA could probably be done from aircraft or balloon-borne instruments. Consequently there seems little reason to carry such an instrument to the Moon.

Two problems which would have to be solved for a lunar telescope operating in the millimeter range are stability and tracking. The mechanical properties of the lunar surface and subsurface will have to be known to determine whether or not a pedestal capable of carrying a few thousand pounds of Earth weight could be stable, day and night, over long periods of time to better than one second of arc. More data are required on the lunar environment to ascertain the need for thermal shielding.

An antenna rigidly attached to the Moon would be useful only for certain problems. Because of libration, it would not remain pointed in a fixed direction. Hence in the millimeter range a steerable antenna would be required to track a celestial object for several hours. The tracking would be more complicated than on Earth since there is lunar motion about two axes instead of only one.

Useful measurements of the structure of the low chromosphere of the Sun, particularly plages, may be obtained. There is some indication that these regions become more active prior to flares, and hence interesting information can be gained several days before flare activity. It should also be possible to study the radio spectra of radio sources, both galactic and extragalactic. The small amount of work that has been done up to the present refers mainly to 3-C-273, a quasi-stellar source. The quasi-stellar sources vary in intensity of radiation. The variation seems to be a function of frequency but becomes more pronounced at higher frequencies. Some radio sources, including quasi-stellar sources, show complex spectra in the sense that they can no longer be described by a simple power law. This immediately implies different regions with different characteristics.

Polarization measurements in the submillimeter wavelengths are also important for the mapping of the magnetic field in radio sources. Here the requirement is to go to the very high frequencies to get away from Faraday rotation in the source, which is an inverse function of the square of the frequency. Only in these very short wavelengths can it be assumed that there is little or no Faraday rotation and at least the integrated magnetic field along the line of sight can be determined as well as the distribution across the source may be found.

In addition there are low temperature objects, of the order of a few hundred ^{o}K which have been discovered and which peak in the 10-20 micron range. There are obvious reasons to study these objects and perhaps others with even lower temperatures which will peak at even longer wavelengths.

Finally there is the old question of spectroscopy of the planetary radiation in this submillimeter region. Band structures are very likely to occur due to atmospheric constituents, although this is a subject which has hardly been touched up to the present.

The Group discussed the 20-foot radio telescope as proposed by LESA and followed this by a discussion of a 100-foot dish which was the subject of a resolution. Finally a lunar radio observatory to operate at all wavelengths was discussed.

20-Foot Radio Telescope (millimeter)

The LESA report has drastically underrated the importance of millimeter and submillimeter wavelength and infrared astronomy. The recent results that Frank Low and others have been obtaining indicated the importance of this really interesting region of the spectrum. The experiments proposed in LESA could probably be accomplished from aircraft or balloon-borne instruments.

To take advantage of this region of the spectrum and of the lunar base, a 20-foot dish appears quite inadequate. The Group did not recommend that this experiment be done on LESA in the 1970-1975 time period.

100-Foot Dish (millimeter to micron)

There is every good scientific reason to go ahead as quickly as possible with a radio telescope of aperture on the order of 100 feet. Such a millimeter wave dish could very well be placed in low orbit since the main requirement is to avoid the Earth's atmosphere. This instrument would require servicing, and hence visits by man for at least short periods of time would be needed.

There is a 36-foot dish, good presumably to a wavelength of one millimeter, which is being built at Kitt Peak. This should receive an adequate amount of radiation through the Earth's atmosphere even though there will obviously be some attenuation. Meaningful measurements should be made in the region of the spectrum longer than 1 millimeter with this dish. It is unlikely that dishes larger than 36 feet in diameter can be built effectively on the Earth because of thermal and gravitational deflections. However for the moment it appears that the spectrum below 1 millimeter in wavelength can be adequately taken care of by instruments built and operated on the Earth.

If studies are to be done at shorter wavelengths than 1 millimeter then either an Earth-orbit or a lunar-based instrument will be required, and if good results in the millimeter range are desired, dishes bigger than 36 feet in diameter will be needed.

A need can be seen for a dish of the order of 100 feet in diameter which is diffraction-limited in the 1-millimeter region and a good collector down to approximately 10 or 20 microns. Stability is a problem at very short wavelengths. Therefore the instrument must be stable for the period of time between visits by man. It is conceivable that the instrument can be recalibrated by remote control, but if visits can be made by man the pointing precision should be recalibrated at each visit. An accuracy of the order of 1 second of arc (or at best 0.1 sec of arc) would appear to be satisfactory. If the instrument can be assumed to be stable, then pointing will not be a severe problem.

It appears that a steerable antenna may be required. One that is fixed rigidly on the Moon would be suitable only for a limited range of problems and because of libration it would not be looking at any fixed direction in space. If a steerable antenna is used then there must be a tracking capability built into the instrument. This will be a little more complicated on the Moon than it is on the Earth where there is only one axis that is essentially fixed.

The following resolution was passed by the Group.

The Group feels that it is extremely important to start feasibility studies for a dish of the order of 100 feet in diameter to be used between millimeter and infrared wavelengths, immediately after the 1975 time scale. The dish has to be above the Earth's atmosphere.

LUNAR RADIO OBSERVATORY (all wave)

A major space installation was implied for the lunar radio observatory experiment. However, there were inadequate reasons given for supporting the idea. Within the Earth window, the Earth should certainly be used as the base. Outside this window specific instruments make much more sense in the 1970-1975 time period.

OPTICAL ASTRONOMY

The Moon may well offer an attractive and possibly a unique base for astronomical observations. It is recommended that studies begin as soon as possible to explore the lunar capabilities for astronomy. These studies should involve evaluating engineering studies on the Earth, environmental studies on the Moon, and testing with small telescopes on the Moon. The lunar environment studies should include but not be limited to the lunar atmosphere, temperature measurement, rock testing, and engineering studies of the bearing strength of the soil.

At an early date, and certainly within the period 1970-1975, there should be a small telescope on the Moon, something in the neighborhood of a 12-inch aperture. This telescope would not be a major research tool; it would be principally an environmental-exploration tool. It could also do certain specialized science for which the Moon seems particularly appropriate, but the principal aim is to explore the lunar environment from the point of view of astronomical instrumentation.

As an intermediate stage, after 1970-1975, consideration should be given to placing on the Moon an intermediate size instrument, on the order of magnitude of a 40-inch telescope. A telescope of this size has tremendous capability and is not limited to specific experiments. Such an instrument is large enough to explore in depth the capabilities of major astronomy from the lunar surface. It is within the capability of AES and it could provide a basis for comparison between orbital AES operations and OAO-type operations. It should provide the baseline information for deciding between lunar and orbital operations in the early 1970's.

The final stage will require a Large Space Telescope with 100- or 120-inch aperture. This is not within AES or LESA capability but should represent a major goal for space astronomy.

A strong AES program would involve a low-orbit (100-300 miles) and a high-orbit (synchronous) operation plus a lunar operation. It would involve projects of various types within this program to provide the baseline for generating the fundamental information upon which the best possible Large Space Telescope can be built.

The Group discussed participation in the AES and LESA programs in terms of astronomical facilities rather than experiments. The major exception being the previously recommended need for study of environmental conditions on the surface of the Moon, a problem area of prime importance.

TWELVE-INCH TELESCOPE

A 12-inch telescope was the basic instrument proposed for the early stages of LESA. Both wide-angle and high-resolution experimental telescopes were considered. The Group concluded that a high resolution telescope would be preferable for the first lunar instrument but that a wide-angle telescope should also be used if ample resources are available.

The purpose of the 12-inch telescope is to confirm the results of preliminary environmental studies, to assess the engineering problems of telescope design and operation on the Moon, and to make preliminary evaluations of the astronomical potential of the Moon.

12-Inch High Resolution Telescope

A high resolution telescope will have application beyond engineering and environmental studies, in detailed observations of the planets of the solar system. It may also produce positive observations of planets, clusters, nebulae and galaxies at various wavelengths. In order for the high resolution telescope to be diffraction-limited with a 12-inch mirror, it will have to operate at about f 50. It should then be able to give a resolution of 1/3 second of arc on a continuous basis. The best Earth-based instruments may achieve this resolution but only from time to time under optimum seeing conditions and using much larger apertures.

In operation, a case can be made for both photoelectric and photographic recording of data. Photometry could be used for the study of stars in various wavelengths, for spectroscopy and for evaluating the performance and degradation of the system. Photometric systems probably can be programmed and fully automated so that they can operate during the periods when man is not present.

Photographic recording of images presents more problems than photometry for very high resolution systems. It is probable that a man will be needed to maintain the focus and process the plates before bringing them back to Earth for further study. Photographic plates can be made to contain an enormous amount of data and there are clearly a myriad of possibilities that can be achieved photographically with an experienced man present.

The basic problems involved with a remote telescope are the pointing accuracy, the stability of the system (including its platform), and deleterious environmental effects. The librations of the Moon are probably well enough known to allow programmed exposures of the order of hours. Changes in the alignment of the axis from either thermal or seismic effects may require an accurate tracking capability but this was not considered a major problem. The seismic and tidal effects cannot be fully assessed until an instrument is operated with high positional accuracy. The major environmental effect on a high resolution system appeared to be meteoritic erosion of the optical surfaces. It was not possible to say if this would be a serious problem. The thermal effects would be a problem during the day to night transition but should not present a major problem during relatively short exposures with a small instrument. Long-term effects through the 14-day, light and dark periods may be significant. The problem of light background would appear to be more significant for a wide field system.

The Group endorsed the suggestion that a high resolution telescope of approximately 12-inch diameter be placed on the Moon during the 1970-1975 time period.

12-Inch Wide Angle Telescope

In addition to obtaining engineering and environmental data, a wide resolution telescope could be used for observing the zodiacal light, the gegenschein, lunar libration clouds of particles, Lyman-alpha radiation, and Earth-oriented phenomena such as the geocorona. It is also possible that lunar luminescence could be studied. The proposed telescope would have to have a field of view of about 5° to study such things as the zodiacal light. It could probably be operated entirely photometrically but would be sensitive to the background illumination on the Moon.

The Group considered a wide angle telescope of about 12-inch diameter to have good potential for a lunar base but did not endorse it as strongly as the high resolution system.

FORTY-INCH TELESCOPE

The Group agreed that if the Moon is found to be a suitable location for astronomy, a 40-inch telescope should definitely be considered for installation on the surface. Preliminary design studies for such an instrument, and its auxiliary instrumentation, should be started as soon as possible. However, a definite program for the future should not be planned until more is known about the physical environment of the Moon, and therefore it should not be included in the LESA program in the 1970-1975 time frame.

A preliminary engineering study by the Grumman Aircraft Company indicates that during the AES missions it will be possible to package, deliver, and deploy a telescope up to a 40-inch size using the LEM adapter. These preliminary results look encouraging.

One of the problems with a diffraction-limited 40-inch telescope is that of pointing because of the very high resolution (0.1 seconds of arc). A computer program will be required to accomplish this. A simple equatorial system cannot be set up on the Moon because the motions of the Moon necessitate constant correction in order to point at a given object in the sky. Extremely long exposures, with practically no sky background, as we consider it from the Earth, may then be considered. This means exposures of the order of 12 hours to several Earth-days. It may be possible to do offset guiding on bright objects by using knife-edge techniques and photoelectric guiding. Elimination of the sky background can probably be adequately accomplished.

The 40-inch telescope may be used for both photography and photometry. Photography will require observers to be almost continuously present. The LESA system currently planned calls for a man being there for about 2 weeks in every 3 months. Unless the system is changed to having men there almost continuously, extensive photographic work with the 40-inch telescope may not be possible. In addition it is doubtful that photographic data could be transmitted to Earth, since photographs could contain at least 100 000 bits per square millimeter of film.

However beyond 1975 it may be possible, although perhaps still difficult, to do photography remotely for reasonable lengths of time. The telescope could be loaded with photographic plates and run for a period of time more or less automatically, as long as the films can be retrieved at some later date. If each exposure is of the order of several days, a visit once a month by an astronaut might well be sufficient to collect the plates that have been taken and set up things again for another month. The telemetry problems might be eliminated by bringing the plates back.

Other possible technical problems in the operation of a 40-inch telescope are guidance, stability, optical alignment and focusing. Guidance would not be a serious problem to automate, but the stability of the lunar surface as a base for orienting a telescope must be considered. If the lunar surface is stable to the accuracy desired, and if the lunar motions are predictable to this same accuracy, then the lunar surface may be a good place to put a 40-inch telescope to solve the guiding problems, because essentially all the motions required can be prestored and computed. If on the other hand there are transient motions that are unpredictable, the process is then only the same as in orbit. There will have to be a close-loop system that detects motions, feeds them back, and re-orients the telescope. For a complex optical system, the optics must remain in collimation or alignment. Whether or not this can be automated is uncertain, but it poses a problem that has not really been solved to any extent with ground-based telescopes.

Finally to achieve really high-fidelity photographs, the focus must be controlled within very narrow limits at all times. It therefore has to be repeatedly checked either on the Moon or in space. Thermal and gravitational effects can change the focal length. Thus some things certainly can and should be automated, but for others it will almost be essential to have a man there a good part, if not all, of the time.

The concept of a 40-inch telescope was endorsed by the Group as providing very good science but it was not thought to be sufficiently developed to include in LESA before 1975.

LARGE SPACE TELESCOPES

A large space telescope should be a major objective for the future. A 100-inch telescope will however be more sensitive to its environment and mode of operation than the smaller instruments discussed above.

Thermal control will be crucial in high-resolution studies. It was noted at the Woods Hole Summer Study that thermal control on the Moon will probably be as much of a problem as it is in Earth orbit. But there may be justification for the opposite assumption that thermal control on the Moon will be better than any thermal control that can be established in either a low Earth orbit or a high Earth orbit if the bulk of the Moon itself is used for thermal shielding.

The Large Space Telescope ideally will require a stabilizing accuracy to a hundredth of a second of arc although a fiftieth of a second is perhaps the most that can be anticipated with a 100- or a 200-inch telescope. Reaching a fiftieth of an arc second stabilization in Earth orbit is going to be exceedingly difficult during this decade, and it is going to continue to be difficult.

The anticipated lead time for establishing a Large Space Telescope on the Moon appears to be about 15 years. Therefore the Group excluded it from the specific discussions of the 1970-1975 time period.

LYMAN-ALPHA RADIATION

Lyman-alpha radiation should be studied to provide basic information. Such a study may or may not require a telescope on the Moon, and therefore it should be done in the LESA program only if space is available.

It has been suggested in the LESA report that a study of Lyman-alpha could be accomplished with a narrow-band tunable filter, or even a monochromator. The suggestion is based on the knowledge that the most abundant element in the universe is hydrogen and that there should be adequate galactic radiation at

Lyman-alpha wavelengths. It should be possible to get a picture, with a cloudy structure, of the nearby neighborhood of the Sun in hydrogen lines. The experiment would add to our knowledge of the mass of hydrogen in the galaxy.

A separate instrument is required for this experiment only in the sense that it is principally an instrumental accessory with the collection optics as a minor part. This could therefore be a completely separate instrument that is set down and goes through an independent scanning mode.

If the experiment can be done anywhere in the near Earth-Moon system, it can be done on the Moon and perhaps in high orbit. If it can be done in high orbit and if there is a system available, the economic factor should decide where it goes; the Moon may offer the maximum probability of success providing that the Moon itself does not have a hydrogen corona. The Group recommended a low priority for this experiment in the LESA program.

EINSTEIN SHIFT

The case for studying the Einstein problem during the LESA program is not clear cut. It should be studied if space and resources are available. The need for such studies is not critical in the sense that experiments have been made. They are in very good agreement, and experiments on the Moon may not yield anything new or different.

The Einstein problem is a suitable experiment for an observatory on the Moon because the size of the telescope required is very small (i.e. a 5-inch aperture). Two focal lengths of 8 feet and 12 feet would be adequate. The very limited atmosphere on the Moon would be an advantage. However, as an experiment it may be rather difficult to carry out successfully.

Schemes proposed for investigating the Einstein problem utilize the natural eclipse of the Earth, the setting of the Sun, either below the horizon or at a crater wall, and an occulting disk. The natural eclipse of the Earth offers the minimum change in the star field from one picture to the next. Because of thermal expansion problems, the occulting disk method may not be possible. The use of an occulting disk inside the instrument would involve the same problem as that on Earth; namely, when a picture is taken near the Sun, the instrument is in one thermal state, and when a calibration picture, without the Sun, is taken later the instrument is in another thermal state. The use of an occulting disk outside the telescope is difficult to accomplish geometrically.

The very character of the data required precludes repetition of the Einstein experiment in unmanned satellites. So if a major breakthrough in the experiment is to be made, the Moon may be the place that it has to be done. A telescope on the Moon is an independent method compared to an eclipse observed from the Earth, and large numbers of plates can be taken. It probably requires a man to be there, unless a complicated system of changing the plates is available.

The Group recommended that a low priority be given to this experiment as far as the LESA program is concerned.

CORNER REFLECTOR (optical)

Another method for getting data similar to that obtainable from a radio transponder has been suggested in recent years, namely an optical corner reflector on the Moon. A corner reflector on the Moon however would not give the integrated electron density data that could be expected from a radio experiment. If the corner reflector can measure to distances of centimeters, as has been proposed, then it would be valuable and should be studied further.

One use of the corner reflector lies in the possibility of measuring continental drift which has not yet been quantitatively established even with our best astronomical instruments. The best that can now be determined is to measure relative positions perhaps to an accuracy of 1 meter. The accuracy required to determine drifts is in the order of centimeters. For instance at the San Andreas Fault in California, where the drift is most clearly apparent, it amounts to only centimeters per year.

However, if distances can be measured with lasers between the Moon and two points on the Earth, across a continent, and an accuracy of say 5 centimeters can be achieved, this will be an enormously valuable tool which will improve the accuracies of libration constants, the astronomical unit and astrometry and geodetics in general.

The Group acknowledged the potential of an optical corner reflector on the Moon but did not recommend a high priority in the 1970-1975 time period.

X-RAY AND GAMMA-RAY ASTRONOMY

X-RAY ASTRONOMY

An X-ray occultation experiment on the surface of the Moon would be a worthwhile experiment. This technique has been employed on the Earth using the Moon as an occultation disk for observation of the Crab Nebula.

It is suggested that a comparatively small X-ray telescope be set up, possibly in the bottom of a large crater, for observing the rise and set of X-ray sources on the rim. The wall of the crater would have to be surveyed to determine the angle above the crater floor so the position of the horizon would be known accurately in two coordinates.

If the rim should be about 50 kilometers from a detector with a vertical dimension of 10 centimeters, the subtended angle would be half a second of arc. Because the Moon rotates relatively slowly (compared to the Earth), the occultation angle would be covered in about 2 seconds of time. This would permit the accumulation of a large count by a detector of a few square feet area. The counter should be collimated to restrict the field of view in a vertical direction but should accept a wide field in the horizontal direction in order to scan a broad band of the sky.

It will be important to measure the X-ray background on the Moon. Since this will not be done on Apollo, it will be a requirement on the AES. The level of emission from the surface and from the solar wind must be determined, including an investigation of whether there is shielding on the surface except during strong bursts of wind.

Man would have several tasks in occultation studies. One task would be to calibrate the X-ray observations by timing the occultation of visible stars with an optical telescope in order to determine the azimuthal position of the occulted source. Judgment would have to be exercised in altering the geometry of the occultation apparatus to balance detection sensitivity with resolution.

GAMMA-RAY ASTRONOMY

The Moon is not an advantageous location for conducting higher-energy gamma-ray astronomy observations because the surrounding material presents rather bad background problems. Since potassium would be one of the major sources of gamma-ray background in the MeV range, it is important to know whether the potassium is evenly distributed throughout the Moon or is concentrated at the surface.

No gamma-ray experiments are planned for the Surveyor or Apollo programs. However, an experiment using a sodium iodide detector has been proposed for the follow-on Lunar Orbiter program. High-energy gamma-ray instruments are expected to weigh on the order of 200 pounds.

APPENDIXES

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APPENDIX A

TELEMETRY AND TELEVISION

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INTRODUCTION

This report presents a general description of the capability of Apollo spacecraft systems that have possible application for support of scientific experiments. The report describes the Command Module (CM) and Lunar Excursion Module (LEM) telemetry, the television capability, voice communications capability, and a preliminary description of the Apollo Lunar Surface Experiments Package (LSEP) telemetry.

CM AND LEM TELEMETRY

General

The telemetry equipment for both the CM and LEM is designed for the primary purpose of gathering and processing operational data. This includes biomedical data on the astronauts and information on the spacecraft systems.

Although there is little room for experiment data, experiments are being accommodated, particularly on the CM in Earth orbit. Whether an experiment flies depends on several factors, among which are the experiment requirements and their effect on the spacecraft. If an experiment is given priority, necessary new supporting subsystems are provided. This is currently true for an X-ray astronomy experiment now in design.

Adding new experiments to the LEM is more difficult because of stringent weight limitations. The limit may be eased if contingencies now provided can be removed after the first flights. The LEM does, of course, carry experiment hardware and other subsystems that will provide scientific data.

The following description of the telemetry provides information on the hardware with which an experiment might interface. The CM capability will be described first. The CM has a pulse code modulation (PCM) system, and three subcarrier oscillators.

Command Module Pulse Code Modulation

The CM PCM system samples analog and digital information. These samples are encoded, formatted, and sent via the spacecraft S-band transmitters and antennas to receiving equipment on Earth. The PCM equipment can process both analog and digital inputs at sampling rates from 1 to 200 samples per second. There are 365 high level channels which accept 0 to 5 volt analog signals having a maximum source impedance of 5000 ohms. These analog data are digitized in the PCM equipment with an 8 bit resolution, plus or minus 2 bit accuracy, and placed serially on the output wave train.

The digital channels consist of a 40 bit serial channel and parallel channels varying from 8 to 32 bits in length. The serial channel is reserved for inputs from the Apollo guidance computer and is used to indicate spacecraft position, velocity, attitude, etc. The parallel channels require voltage levels of plus 4 to plus 10 volts for a binary one and 0 plus or minus 0.5 volts for a binary zero. The required source impedance is 5000 ohms maximum from DC to 200 cps.

The PCM equipment can operate at two bit rates as determined by the selected mode of the equipment. The Normal Data Rate Mode transmits data at 51 200 bits per second and the Reduced Data Rate Mode transmits at 1600 bits per second. A fixed format is provided for sampling each channel at a given rate for each bit rate mode.

The Normal Data format consists of a 128-eight bit word main frame. The frame rate is 50 frames per second. Selected words in this frame are super-commutated or sub-commutated to provide sampling rates of from 1 sps to 200 sps. Table 1 indicates the quantities and sampling rates of the available analog and digital channels.

The Reduced Data format consists of a 200, eight-bit word frame which occurs at a rate of once per second. Table 2 indicates the quantity and sampling rates of the available channels.

CM Subcarrier Oscillators

Three subcarrier oscillators (SCO's) are also provided which can be considered for experiments' use. These subcarrier oscillators are located in the CM Pre-modulation Processor. These SCO's have center frequencies of 95 kc, 125 kc, and 165 kc and have frequency responses (analog signal bandwidth) of 2850, 3750, and 4950 cps, respectively. Input voltages produce a center frequency deviation of from minus 7.5 percent to plus 7.5 percent for input signal levels of 0 to 5 volts.

Lunar Excursion Module Pulse Code Modulation

The LEM uses the same techniques as the CM to telemeter data. The LEM PCM is basically the same as that of the CM with the exception of the number of input channels. It has 386 high level analog inputs and has 792 bits of digital data input. Also it has 55 low level analog inputs. These input levels vary from 0 to 40 millivolts. Table 3 shows the normal bit rate format. A table for the 1600 LEM bit rate is not available for this report.

TELEVISION

General

The Apollo television camera and ground scan conversion equipment will provide commercial quality television pictures compatible with home television receivers. In addition, a high resolution mode is provided for scientific purposes.

The camera will be operated in the CM during the prelaunch, launch, Earth orbit, and translunar phases. It will then be transferred to the LEM and will not be operated until the LEM has landed on the Moon and the high gain antenna has been erected by the astronaut. It can be operated within the LEM or carried and operated outside the LEM. Toward the end of lunar stay, the camera will be carried back onto the LEM and later transferred to the CM; where it will be operated periodically during the trans-Earth phase. The percentage of time the camera will be operated is not firm because of operational and mission planning considerations and the determination of scientific requirements.

Technical Description

The video bandwidth allowed for the TV signal is 500 kc/s, which compares with the commercial bandwidth of 4 mc/s. Consequently, certain compromises are necessary. Specifically, the frame rate has been lowered and the number of scanning lines (or resolution) selected accordingly. The low frame rates mean that motion rendition will be degraded, and, therefore, the camera must be held firm to obtain a clear picture.

The two frame rates are 10 frames/sec and 0.625 frames/sec. It is estimated that 10 frames/sec will yield a resolution on a typical home receiver that is about 80 percent of the commercial resolution (525 lines per frame). The frame rate of 0.625 gives a resolution of 500 lines, which is the vidicon limit. This is about 170 percent better than commercial television. This mode should be must useful for scientific purposes. A tripod is required to ensure the camera is steady. Scan conversion equipment is planned for several Earth locations so the picture can be viewed without flicker. The scan converted video will be edited at MSC, and released for public viewing.

Other parameters of the TV system that may be of interest are:

1. SEC vidicon used for image sensor

2. Optics -

Lunar surface, first mission: single fixed focus lens, focal length 25 mm, aperture 20 inches. The complete LEM can be seen at 80 ft.

Within LEM: Narrow angle lens (4^{o} field of view)

3. Camera is astronaut-operated.

COMMUNICATIONS

A brief comment on available communications is probably in order. There are two situations:

1. Before erection of high gain antenna by the astronaut

No TV capability from LEM. Full communication conference capability between LEM, the Extra-Vehicular Astronaut (EVA) on the Moon and Earth.

2. After erection of high gain antenna

Full TV capability

Full communication conference capability between LEM, EVA and Earth.

LSEP TELEMETRY

General

In-house and contract studies were initiated over a year ago to define an appropriate telemetry system. Certain assumptions had to be made since little information on experiment output characteristics existed. Questionnaires were submitted to some potential experimenters and industry experiment knowledge was obtained. The data subsystem definition proceeded, with flexibility as a requirement, in order to accommodate different experiment sets. This definition effort was completed in August 1965, and will result in system, equipment, and interface specifications and technical backup for the recommended system.

The data subsystem effort will continue as part of the total LSEP effort, an integrated system effort. Some changes in the subsystem definition may be made as a result. However, there is strong support for the data subsystem design as presently conceived.

The data subsystem will be digital (PCM). Several bit rates, selected by command, will be available. The normal rate will be 1280 bits/sec. A high bit rate of 10 240 bits/sec can be used for high data activity if an 85 ft receiving antenna is available. A word length of 8 bits is planned.

Tape recorder storage is not presently planned because of the required power, weight, and volume. However, buffer storage of 50 to 100 kilobits will be available.

The data subsystem including antenna, transmitters, self thermal control, is estimated to weigh 40 pounds. The power consumption is 18.5 watts, and the volume is about 2 cu ft. The integrated experiments-data subsystem-Radioisotope Thermoelectric Generator (RTG) design approach for the LSEP may decrease these numbers.

The data subsystem processes analog and digital inputs into a time-multiplexed PCM signal that modulates an S-band transmitter. The bit rate, sampling rates, and numbers and types of inputs are variable. The transmission format can be changed either by Earth command or an experiment signal. Different modes of operation are available for real time or storage. Timing signals are available to the experiments for synchronization or signal multiplexing. Time information is inserted into the format for accurate correlation on Earth.

A main frame of data consists of 64 words. Two word slots are assigned to analog subcommutation and one to digital.

The signals expected from the experiments are digital data, analog data, bi-level signals, and activity sensing signals. Not all experiments are expected to have all of these outputs.

Signals available to the experiments are of the pulse type and state type. Pulse type signals give the word rate, bit rate (shift pulse) frame rate, and sub-frame rate. State type signals give word gate, format, mode, and bit rate.

Telemetry-Experiment Interface

Signals from Experiments

A digital one shall be a 10 μsec pulse, synchronized with the bit rate pulse from the data subsystem, having an amplitude of 4 volts with a current capability of 4 ma. A digital zero shall also be synchronized and have an amplitude of zero volts.

Analog data shall be from 0 to +5 volts in amplitude with a source impedance less than 2 kΩ.

All analog outputs from a single instrument for the main frame shall be on one line (multiplexed by experiment); those for the subcommutator shall be on another line.

A similar statement holds for digital data outputs.

The fault voltage shall not lie outside ± 10 volts.

Bi-level signals shall be either 4 or 0 volts.

The activity sensing signal shall be either 4 or 0 volts.

Signals to Experiments

The amplitudes and duration of the signals available to the experiments are similar.

Latching and momentary power commands are also available to the experiments.

It must again be noted that some of the above numbers may change as a result of the LSEP effort. It is recommended that experimenters check with MSC before they commit their design on the basis of the above description.

TABLE I. —NORMAL DATA FORMAT, COMMAND MODULE

[Total - 6400 words/sec (maximum capability, 6400); Bit Rate = 51 200 bits/sec]

Quantity	Samples per sec	Type	Bits per word	Words per sec (one word = 8 bits)	Notes
4	200	Analog	8	800	0-5 V full scale
2	200	Digital	8	400	Bit parallel
16	100	Analog	8	1600	0-5 V full scale, 5K source impedance
15[a]	50	Analog	8	750	0-5 V full scale, 5K source impedance
1[b]	50	Digital	40	250	Bit serial
1	50	Digital	8	50	Bit parallel
180	10	Analog	8	1650	0-5 V full scale, 5K source impedance
1	10	Digital	32	40	Bit parallel
31	10	Digital	8	460	Bit parallel
150	1	Analog	8	150	0-5 V full scale, 5K source impedance
1	50[c]	Format ID	8	50	Internal programmed
Sync and identification	50	Digital	32	200	Bit parallel

[a]One of these inputs is from the Low Level PCM Telemetry Commutator Equipment.

[b]Requires start, stop and bit sync pulses.

[c]Format ID shall only be inserted once per second. Two of the remaining 49 times slots may be used for output register check.

TABLE II

REDUCED DATA RATE FORMAT, COMMAND MODULE

[Total = 200 words/sec (maximum capability, 200);
Bit Rate = 1600 bits/sec]

Quantity	Samples per sec	Type	Bits per word	Words per sec (one word = 8 bits)	Notes
1[a]	10	Digital	40	50	Bit serial
100[b]	1	Analog	8	100	0–5 V full scale
1	10	Digital	8	10	Bit parallel
1	1	Digital	32	4	Bit parallel
31[c]	1	Digital	8	31	Bit parallel
1[c]	1	Format ID	8	1	Internal programmed
Sync and identification	1	Digital	32	4	Bit parallel, programmable

[a]Requires start, stop, and bit sync pulses.

[b]Two of the time slots may be used for output register check.

[c]The 100 channels at 1 sample per second are made up (from the following) of normal format; 50 of the 165 channels at 10 cps, 50 of the 50 channels at 1 cps.

TABLE III.—DATA FORMAT NO. 1

[Bit Rate = 51 200 bits/sec]

Quantity	Samples per sec	Type[a]	Bits per word	Word times (one word = 8 bits)	Words per sec	Notes
6	200	AHL	8	1	1200	Groups of 1 bit on-off (applies to 400 words/sec only)
1	200	DPE	16	2	400	
4	100	AHL	8	1	400	
1	100	DP	16	2	200	
7	50	AHL	8	1	350	
2	50	DP	16	2	200	
1	50	DP	32	4	200	Sync and ID
1[b]	50	DS	40	5	250	
1	50	DP	8	1	50	
74	25	AHL	8	1	1850	
2	25	DP	16	2	100	
2	25	DP	8	1	50	
65	10	AHL	8	1	650	
5	10	ALL	8	1	50	
4	10	DP	8	1	40	BCD "TIME"
1	10	DP	16	2	20	
1	10	DP	32	4	40	
230	1	AHL	8	1	230	Groups of 1 bit on-off measurements (applies to 50 words/sec DPE only)
50	1	ALL	8	1	50	
50	1	DPE	8	1	50	
20	1	DP	8	1	20	

[a]Type: AHL Analog High Level; ALL Analog Low Level; DS Digital Serial; DP Digital Parallel; DPE Digital Parallel Event

[b]Requires start, stop and bit sync pulses.

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APPENDIX B

APOLLO MISSION

R. Walter Cunningham
NASA Astronaut

My last 20 months have been spent in training as an astronaut. This training takes place in a rather broad area which I will call Astronaut Activities: One aspect of this activity is monitoring and providing an operational input to some technical area or areas associated with the Apollo and/or Gemini Programs. For the last 12 months this has meant for me the sequential and electrical systems and lunar surface activities.

The only justification for my speaking to you today is that I am one of the persons most familiar with the operational aspects of the lunar surface activities and can be expected to give a crew member's view of many factors affecting those activities.

This morning I would like to serve as a devil's advocate for awhile and, hopefully, accomplish several things: (a) place lunar surface activities in perspective with the overall mission and point out some overriding priorities; (b) point out various limitations and constraints which pace lunar surface work and (c) make some suggestions of my own.

I realize that some of you are very familiar with the overall Apollo Program, and the lunar landing mission itself was reviewed here yesterday. Also, some of you have heard some of my thoughts on the subject in small groups or on geology field trips.

I am going to describe some of the events taking place during one portion of the mission. This portion includes the lunar stay time which we are going to talk about in greater detail. I will run through the specific phases in the design reference mission from the third mid-course correction on the translunar flight to the completion of trans-Earth injection. All of these events or periods require special training of one kind or another.

We pick up the mission at approximately 63 hours after lift-off.

Third midcourse correction: last chance to correct trans-lunar errors and set-up for nominal lunar orbit insertion.

Preparation for lunar orbit insertion.

Lunar orbit insertion: initiation of lunar operations.

Lunar orbit coast: all three crew members in the Command Module and lunar observations being made.

Preparation for LEM separation: Manning the LEM and checking it out.

> Keep in mind that the propulsion system burns are critical events when all crew members must be awake and strapped in, but it is the preparation periods when the problems are being solved and the work is being done.

CSM solo lunar orbital operations: One crew member mans the CSM until rendezvous.

LEM/CSM separation: undock and utilize LEM reaction control system.

CSM lunar orbit coast to rendezvous.

LEM preparation for descent.

Transfer orbit insertion: going from circular to elliptical orbit.

Coast to initiation of powered descent.

Powered descent to beginning of visibility: a retro maneuver taking you down to acquire the lunar horizon.

Beginning of visibility to hover: roughly 50 000 ft to 600 ft.

Hover to touchdown: maximum length of 2 minutes; limited by fuel.

Post landing checkout: preparation for immediate launch or abort from the surface.

Lunar exploration: active exploration and emplacing Apollo Lunar Scientific Experiment Package.

Prelaunch preparation: time critical launch.

Powered ascent through transfer orbit: assuming here a parking orbit rendezvous plan.

Insertion: to parking orbit.

Coasting lunar ascent to first mid-course correction.

First mid-course correction.

Coast to second mid-course correction.

Second mid-course correction.

Coast to third mid-course correction.

Third mid-course correction.

Coast to terminal rendezvous.

Terminal rendezvous: visual phase.

Begin dock.

Hard dock: transfer crew and samples to CSM.

Coast to LEM jettison: ascent stage left in lunar orbit.

Jettison LEM.

Preparation for trans-Earth injection.

Trans-Earth injection.

If I seemed to pass over the lunar scientific activities, it is because this is but one of many phases in the 24 to 48 hour period I have just described. And I also bear in mind that the overall mission is some 200 hours long, liberally sprinkled with critical events and crucial operations. The lunar surface exploration is one of the most important phases because it represents the most immediate tangible payoff for the Apollo mission. However, it is not the most crucial mission phase from an operational standpoint. It is this view of the total mission which has the biggest effect on my thinking and leads to what sometimes appears to be an unsympathetic reaction which some of you may have noticed in the past year.

I ask that all of you keep in mind the overall mission as you work on your special phase of that mission.

While we are on the subject, I think it wise to bring up the scientific measurements themselves and mention some overriding priorities.

Leaping right into the fire, I would say that on the LEM the first concentration is crew safety, or survival and mission completion; second is obtaining the operational and systems parameters measurements; and third comes the scientific data.

I doubt if there can be much disagreement with the first priority. Many things could go wrong or be eliminated from the flight and there would still be a large degree of mission success if the crew returns safely to terra firma. This is one reason why the reliability requirements for crew safety items are an order of magnitude higher than for mission success.

I must confess that at one time I would have taken exception to the second priority, operational and systems measurements. But I hope you will agree that for the long view science has the most to gain by getting the best qualified people to the place where the observations are being made. This can only be done by developing the means of transportation which can accomplish this. This is what the operational and systems measurements are for and the reason for their high priority. As the operation of the vehicle becomes more commonplace the operational people's claim on such items as telemetry will diminish and science's share will be larger.

These same operational requirements which generated our systems have left us with constraints and limitations which bear on the scientific activities. I would like to spend a little time bringing some of these to your attention.

Some of the most obvious are those presented by operating in a pressurized suit and depending on a back pack (portable life support system, PLSS) for life support. I will not dwell on the physical problems of working in what we call a hard-suited environment. This is something you can experience yourself by working a little while in the suit, and I believe some of Gene Shoemaker's group is going to do just this next October in Flagstaff. The suit is undergoing a continuing development and gets better every day. Nevertheless, it still restricts your mobility considerably and work must continually be done against the suit. This has a bearing on exploration activities in a less obvious way, also. The 3-hour exploration period is based on O_2 usage at an average work output of 1200 Btu/hr. This is roughly equivalent to your walking on Earth at a rate of 3.5 miles per hour. Anything exceeding this level of energy expenditure starts reducing the time on the surface, and all work done against the suit reduces that available for scientific tasks.

The radius of exploration is also limited by the walking velocity and the size of the tolerable suit leak which this PLSS can supply. This radius is presently on the order of 0.5 mile. Any effort to enlarge this radius of action will be limited by the lifetime of the PLSS. This, in my mind, is one of the most critical items of development if we are to extend our exploration activities. As it now stands, the failure of a small roving vehicle must occur within the distance that a man can walk in 3 hours. The PLSS is the ultimate insurance that our explorer can return safely to the LEM.

There is also a requirement, and a good one, for launching from the Moon with one partially charged PLSS. This is to affect extra vehicular transfer to the Command Module, if necessary, and might require you to stop exploration activities sooner than otherwise in order to retain a safe amount of consumables.

The use of these PLSS's is also regulated by having only room for one PLSS recharge station in the LEM.

This whole problem of PLSS's and exploration periods has become more critical since the decision was made to go to a gaseous oxygen LEM. Having much less oxygen on board means we will be limited to four repressurizations to 5.2 Psi. This, in conjunction with the 6 PLSS recycles available, poses a problem. It could mean remaining 8 hours in a hard suit, and our office now believes this is too long, except in an emergency.

The whole business of one or two men at a time on the lunar surface has an obvious effect on exploration. The present communications system cannot accommodate two men on the surface as well as one man. This communications system utilizes one frequency for transmitting and another for receiving by the extravehicular astronaut. Should either one of the two astronauts on the surface be transmitting the telemetry which carries the biomedical and suit parameters, then the other one is effectively out of voice contact. The solution without redesigning this part of the communications system, is affected by operational procedures (time-sharing of telemetry). Our present position is that we want the operational flexibility of either one or two persons at a time on the surface. If the decision is made for two at a time, it will not necessarily be to improve exploration efficiency; it will be an operational decision. It is entirely possible efficiency may go down, i.e., two people might have a requirement to stay close to each other and, consequently, get less done than if operating independently. However, to maintain operational flexibility, the tasks should be laid out for one-man operation whenever possible.

Taking a look at the telemetry system, we see that only a small amount of LEM TM is available for scientific data. There is more available to the high bit rate than on the low, but the high bit rate will hardly be used on the lunar surface. The reason for this is the 80 watts of additional electrical power required. Electrical power is a critical consumable, and the budget does not plan on more than about 10 percent usage of high bit rate on the lunar surface.

The electrical power situation is better in some ways and worse in others, now that we've gone to the all-battery LEM. There is less total electrical energy available, but we can now sustain a descent stage battery failure (in most instances) and still continue the mission. However, each battery loss will shorten lunar stay time approximately 6 hours.

Even the service propulsion system on the CSM and the ascent stage propulsion system has an effect on the situation. These two systems restrict the early landings to 5.5 degrees of lunar latitude at 0° longitude for a free return trajectory. The probability of hitting a predetermined spot is inversely proportional to the latitude.

The next topic is one I feel very strongly about. It is one constraint on the most complex system aboard the spacecraft. The system is man and the subject is work/rest or work/sleep cycles. This subject has been studied thoroughly and will be looked into further on Frank Borman's and Jim Lovell's GT-7 flight. Our most recent input was the GT-4 flight. I believe our doctors and the astronauts themselves are in close agreement on this subject. The maximum time scheduled to go without sleep should be 16-18 hours and the minimum sleep period, 4 hours —preferably 6-8 hours. This should be the limit of the working envelope. None of the other systems are required to operate at maximum design levels continuously, and neither should man. The 18 hours without sleep should be only a contingency situation.

What this boils down to is spending approximately 12 hours per day sleeping, eating, and taking care of bodily functions. I believe this cycle is one that would work over the long haul, (at least for 8 days).

Applying this to the events in the first part of my talk, we find the following situation: it is some 7 hours from the last mid-course correction to lunar landing and approximately 6 hours from lunar lift-off to trans-Earth injection if things run nominally. Therefore, any stay of more than 3 or 4 hours will require a sleep period on the surface. I disagree thoroughly with those persons who maintain that if we are only going to stay 10-12 hours we should spend every minute of it performing scientific investigations. At that stage we still have 3.5 days ahead of us to complete the mission, and the events that take place on the way home are every bit as important to us as the exploration activities. In many ways, these events are more crucial and will require more of our skill than the surface exploration.

The scientific activities should be planned around such sleep periods. The decision to have such a surface sleeping period will be one of operations and mission planning just as the decision of where to land, of when to get out of the LEM and when to leave the surface. The scientists planning lunar surface activities should not conflict with such operational decisions. You would not want operations people deciding investigations to perform on the lunar surface and, in turn, you should not attempt to do their operational planning.

Along these lines, I would urge you to establish priorities for the various tasks as well as possible. Not only does this insure that the most important things are done first, but allows the astronaut to better decide what to delete should it become necessary. For example, what priority does the activation of the Apollo lunar surface experiment package have with respect to the field geology? These decisions should be inter-disciplinary. So far, it appears that only the geologists and maybe the geophysicists have really tried to run with the ball. Let's see some of the other fields concerned with the lunar investigation start pressing for time and priority. It's later than you think!

One thing that should definitely not be late is delivery of the working models for astronaut training and the associated training plans. The demands on a flight crew's time for training for 6 months to a year prior to launch are so restrictive that the early incorporation of experiments is the only way to insure adequate training in their use. It may be hard for you to imagine such a schedule, but it might be interesting to note that flight crew training was the pacing item for scheduling the GT-5 launch. This situation will become more critical for Apollo crews.

With the short duration of lunar stay and the many important tasks to be performed, the scientific training of the astronauts is one of the most important aspects of mission training. This is obviously why a good share of our training in the past 19 months has been aimed at performing well the lunar surface exploration. Most of the emphasis has been on field geology, and I believe the training is going very well. While the program recently selected its first "certified" geologist, I believe we will have many qualified field geologists in our own ranks by the time of the first lunar landing. These should be people fully acceptable to the lunar geologists working on this problem. Many of the men we have in the program now either are, or have the capability of becoming, more than a sensor or a manipulator or an evaluator. They are among the more inquiring people I have known. If we are to utilize the capacities of man to the fullest on all of the lunar landings, he must function as an investigator as well as sensor, manipulator and evaluator. There is nothing mysterious about these qualities which precludes an aviator and test pilot from possessing all of them. I believe they are there in many of the present members of the program. I believe that one of the best ways to encourage the development of, and utilize these capabilities, is to see that the flight crews are, or are offered the opportunity of becoming, members of the scientific investigating teams. The talent is there, and it will only be used to the fullest should you look upon the first lunar explorer's function as more than that of a technician or laboratory aide for a group of investigators back on Earth.

In closing, I would like to describe a breakdown of what I envision as the first lunar stay. Neither the length of stay or utilization of the time is firm yet, but I believe the following description is a representative one.

Both the LEM crew members will have been at duty stations from prior to the third mid-course correction until lunar touchdown. This is nominally 7 hours.

The first item on the agenda after landing will be checking out the spacecraft and preparing it for an immediate departure. This should take approximately 0.5 hour.

A period of lunar exploration would be the next item and would consist of the following: both crew members would be hard-suited with the first crew member manning the upper hatch. His function would be to make the initial visual reconnaissance of the area, spend as much time as necessary on a geological description of the area, taking photographs from horizon to horizon, panning the TV camera, etc. These can all be best performed from the upper hatch, which might be the best vantage point in the area. While this is going on, the second crew member can be unstowing all equipment that would be used on the lunar surface (geological hand tools, engineering equipment, LSEP, etc.), and commencing the prescribed geological tasks. Many of these tasks would be in the near vicinity of the LEM. When the first crew member was finished on top of the vehicle, he would join the second and continue the assigned tasks until the expenditure of 75 percent of the consumables on the PLSS (3 hours).

After awaking from the sleep period, it would be desirable and well within the physiological constraints to spend another 3-hour scientific investigation period on the surface. With the confidence gained during the first exploration, it might be possible to operate both men on the surface simultaneously and independently for this second period. On the other hand, should it seem desirable, the two men might continue to operate only in the near proximity to each other. The use of the "buddy system" or the independent operation should be a flexibility left open to the lunar landing crew. The latter part of this second period would be concerned with a check on the security, calibration and operation of the LSEP, and the stowing of the 80 lb of assorted samples and data which are to be returned to the Command Module. Since one of the PLSS's should be available for extravehicular transfer of the two astronauts to the Command Module should the need arise, every effort would be made to insure that at least one-fourth of the consumables is left unused in one backpack.

The pre-launch checkout and preparation period follows:

Nominally, it takes approximately 7 hours from lift-off until injection into a trans-Earth orbit.

To the times already enumerated, we should add at least one eating period of 1 hour duration. Allowing for the time in changing over from one phase to another on this stay, it totals approximately 14 hours.

APPENDIX C

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