E N G I N E E R I N G P L A N N I N G D O C U M E N T



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# SCIENTIFIC INSTRUMENTS FOR LUNAR EXPLORATION
## PART A
## LUNAR ORBITER (UNMANNED)

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## FOREWORD

This document is the first of a series of publications for describing, in considerable detail, the various scientific instruments that can be used for lunar exploration. This document, Part A, discusses those scientific instruments that can be used from an unmanned lunar orbiter; Part B discusses scientific instruments for Surveyors, Roving Vehicles, and Lunar Survey Probes; Part C discusses scientific instruments for the manned phase of lunar exploration.

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# SECTION I

# INTRODUCTION

The Space Science Board of the National Academy of Sciences (Ref. 1) has defined three categories of basic problems concerning the moon. These three categories have been further elaborated upon by defining a number of basic questions that should be answered in a total program of lunar exploration. The Space Science Board Questions encompass virtually all problems of lunar research and should dictate the objectives of lunar exploration. Obviously, however, no one mission, manned or unmanned, can answer all of these basic scientific questions about the moon; thus, the total program for lunar research must involve laboratory studies, as well as lunar impacters, orbiters, hard landers, soft landers, and manned missions.

The Office of Advanced Studies at the Jet Propulsion Laboratory has been asked by NASA Headquarters, Office of Lunar and Planetary Programs, to determine the most effective scientific manner in which all of the required objectives for lunar exploration can be accomplished, and to derive a total lunar exploration program in terms of a mix of specific projects and missions. One part of the above task involves the derivation of an extended list of scientific instruments and objectives. The purpose of this document is to derive such a list for an unmanned lunar orbiter spacecraft.

## SECTION II

## SCIENTIFIC INSTRUMENTS

### A. GENERAL

The lunar orbiter spacecraft is ideally suited for a reconnaissance mission and for observing those parameters of the lunar environment that are subject to temporal or spatial change. A great deal of the environmental information that is desirable to know about the Moon, both from the point of view of answering the Space Science Board Questions and providing data for future missions, is synoptic in nature; therefore the number of scientific experiments that can be accomplished on a mission of this type needs to be limited by some selection process. For this document, the following constraints are imposed:

1) Those scientific experiments that can be done as well on terrestrial orbiters or other space missions are excluded from consideration here; however, several experiments to characterize the energetic radiation near the Moon, with particular emphasis on determining the long-term radiation hazards to manned lunar flights, have been included.

2) The primary mission of the lunar orbiter is reconnaissance and correlation; thus, it should not be considered, generally, as a tool for acquiring absolute data on the physical and chemical properties of the lunar surface at a specific point, but rather as a mode for measuring or detecting variations in a particular property of the Moon with change of surface location.

3) The time period for this mission is up to and including 1973; thus, long lead-time development items are not considered as practical, and instrument availability is limited by current engineering knowledge and state-of-the art.

4) No effort has been made to order or assign priorities to the scientific instruments either in terms of Space Science Board Questions, or recommendations by the Manned Space Science Coordinating Committee (Ref. 2); however, the scientific objectives for each experiment discussed in the text are given.

The requirements of the instruments impose a burden on the design of the vehicle. For example, the attitude control system should not contaminate the measurements of such items as particle density, atmospheric pressure, and composition. For the same reason, care must be used whenever pressurized containers are employed to prevent leakage, and considerations should be given to the outgassing of the vehicle. Outgassing of the vehicle should occur fairly rapidly in space; however, it may be prolific enough to make a delay of instrument operation desirable until it has taken place. In addition, the possible effect on scientific instruments from any onboard radiation source, such as an RTG unit, must not be overlooked.

Placement of the instruments is extremely important. If sensitive magnetometers are used, they must be placed at a sufficient distance from the magnetic materials and electronic components. The wires leading to and from the instrument must be carefully considered. A single turn of wire carrying 10 microamperes produces a field of 1 gamma. This exceeds the error capability of some magnetometers. Instruments used for observing electromagnetic or corpuscular radiation must be placed so as to minimize the effects of secondary radiation or shielding by the vehicle itself. In addition, care must be taken so as not to introduce errors due to the cosmic albedo of the Earth, if the instruments are pointed toward the Earth.

Similar problems exist with such instruments as ionization gauges and mass spectrometers. Since the velocity of the vehicle is comparable with the velocity of gas molecules and the free mean path of these particles are in the order of meters, the satellite tunnels out a rather severe vacuum in its wake. Thus, the instrument will not operate properly if its opening is rear facing. In addition, the openings of this type of instrument must be carefully considered to prevent an enforced separation of gases according to mass. Because of the large mean free paths, the lighter gases enter more quickly than the heavier ones.

Erosion of the outer surface by micrometeorites and radiation may affect the scientific instruments. Sputtering of metal caused by collision with ambient ions or neutral particles can be serious, especially for spacecraft that are expected to perform their mission over an extended period of time, e. g., more than 30 days. Experience gained from the present series of lunar orbiters will be very valuable in solving problems relating to the choice of second generation missions and experiments.

Finally, very special consideration will have to be given to the design of a telemetry link for communications between the lunar orbiter and the Earth. The data rate will be very high if all of the suggested experiments are to be accommodated; thus, some type of on-board data compression technique, either by selection or integration, will be required. Also, the requirements for an adequate buffer or storage device to hold lunar backside information until it can be transmitted should be noted. It appears that the lunar orbiter mission will not be particularly limited by weight and power, nor by the state-of-the-art in sensor or instrument design, but limited rather by the data capacity of the communication link.

## B. INSTRUMENTS OR EXPERIMENTS

In the following paragraphs and in Table 1, a "shopping list" of representative lunar scientific instruments that can be used on an unmanned lunar orbiter spacecraft is presented. It should be noted that virtually all of the experiments considered for terrestrial orbiters, such as the geophysical satellite series and various atmospheric probes, could have an application to lunar orbiter science. Thus, in the case for a lunar atmospheric experiment, only the mass spectrometer has been considered in detail in this report. The Langmiur Probe, for measuring the electron temperature and density, and the Redhead Gage, for directly measuring the atmospheric pressure, are also feasible scientific instruments for a lunar orbiter mission; there are obviously many others. The list of experiments discussed here is certainly not complete; however, it is considered typical and appropriate, under the constraints defined above, for providing the kind of information that is required for mission study purposes.

1. Magnetometer. The scientific objectives are (a) to study the interaction between the solar wind and the weakly magnetized or un-magnetized moon as the case may be and (b) to establish the extent to which the magnetic field of the moon is intrinsic and the extent to which it is an accumulated interplanetary field.

Table 1. Select list of lunar orbiter science

| Instrument or experiment | Weight, pounds | Power, watts | Data rate, bps | Scientific objectives |
|---|---|---|---|---|
| 1. Helium Magnetometer | 5 | 4 | 1 bps minimum (sample every 30 sec)<br>100 bps desired | 1. Map any lunar magnetic field and determine its magnitude, orientation and characteristics.<br>2. Study the flow past the Moon of the solar plasma with its embedded magnetic field. |
| 2. Search Coil Magnetometer | 5 | 2 | 1 bps minimum (sample every 30 sec)<br>100 bps desired | Investigate the hydromagnetic flow of the solar plasma around the Moon and the nature of any interface region. |
| 3. Plasma Detector | 15 | 10 | 50 | 1. To determine the low-energy charged-particle environment of the Moon.<br>2. To aid in the interpretation of the magnetometer data by a study of the interaction of the Moon with the solar plasma and magnetic field. |
| 4. Meteor Dust Detector | 7 | 1 | 1 | To measure the velocity, mass and distribution of dust particles in the vicinity of the Moon. |

Table 1. Select list of lunar orbiter science (contd)

| Instrument or experiment | Weight, pounds | Power, watts | Data rate, bps | Scientific objectives |
|---|---|---|---|---|
| 5. Body Properties | N/A | N/A | N/A | To determine the mass, the mean moment of inertia, and the coefficients in the expansion for the gravitational potential of the Moon. |
| 6. Radar | 50 | 22 | See Text | To provide information about the spacecraft altitude and properties of the lunar surface such as surface roughness, reflectivity, dielectric properties, etc. |
| 7. Gamma-Ray Spectrometer | 25 | 4 | 500 bps | To determine the approximate concentration of radioactive materials present in the lunar surface |
| 8. Thermal Neutrons Detector | 8 | 2 | 50 bps | To measure the energy spectrum of albedo neutrons to determine an approximate value for the concentration of hydrogen in the lunar crust. |
| 9. Thermal Mapping | 25-60 | 55 | 660 bps | To map the temperature of the lunar surface and its emissivity as a function of position and phase angle. See also Infrared Mapping in text. |

Table 1. Select list of lunar orbiter science (contd)

| Instrument or experiment | Weight, pounds | Power, watts | Data rate, bps | Scientific objectives |
|---|---|---|---|---|
| 10. X-Ray Fluorescence | 18 | 2 | 500 bps | To measure the approximate relative abundance of iron and nickel in the material making up the top of the lunar surface. |
| 11. Microwave Surface Imager | 35 | 15 | 250 bps | To measure the three-dimensional temperature distribution of the Moon's crust. |
| 12. Photo-Imaging Experiment | 25 for indexing camera<br>150 for stereo system | 10-30 | $10^3$ bps | To provide basic data on lunar geology as well as information for preparing a base map that will be used to collate the data from the other experiments. |
| 13. Quadrupole Mass Spectrometer | 12 | 10 | 250 bps | To measure neutral mass spectrum, neutral particle pressure, total ion concentration, directed ion flux and ion mass spectrum. |
| 14. Tissue-Equivalent Doismeter | 1 | 2 milli-watts | 5 bps | To provide data on the biological hazards due to energetic radiation resulting from prolonged stays in the vicinity of the Moon. |

Thus far the United States has not made any magnetic measurements in the vicinity of the moon. However, Russian measurements on Lunik I and Luna 10 have shown that the field near the moon is approximately 30 $\gamma$.

This is substantially larger than the interplanetary field (by a factor of approximately 6) but is consistent with theoretical models that predict that the moon will accumulate a magnetic field from the magnetized solar wind. According to this view, the incoming interplanetary field lines will pile up on the sunlit side of the moon until their magnetic pressure, combined with the solar gas pressure, equals the stagnation pressure of the solar wind and a standing bow shock will then result. Only a fraction of the solar plasma will then strike the moon's surface, the rest sliding past the moon carrying irregular magnetic fields with it. The stagnation magnetic field will diffuse into the moon to an extent that depends on its electrical conductivity and on the character of the interplanetary magnetic field.

The question of how much, if any, of the observed field is due to the moon itself has such important implications that it merits careful study. The discovery of an intrinsic field, even though weak, would indicate that the moon still has a molten core.

Alternatively, the interplanetary fields that pile up on the subsolar side of the moon will have to be replenished at a rate that depends on bulk electrical conductivity of the moon. Estimates of the latter, derived from magnetic measurements, would also have implications concerning the moon's internal composition and structure.

In addition, this field replenishment, since it governs the extent to which the solar wind can reach the surface, will strongly influence: (1) the rate at which the moon can accumulate various constituents from the solar wind, (2) the effect on the surface of a continuous or nearly-continuous bombardment by the energetic solar wind protons, (3) the amount of neutral hydrogen and other gases re-emitted by the surface to form a tenuous lunar atmosphere, and (4) the influx of energetic electrons (accelerated at the bow shock) and the subsequent generation of x-radiation when they strike the surface.

Magnetic measurements on a lunar orbiter are well suited to a comprehensive mapping of the magnetic fields near the moon in order to investigate the existence and character of a bow shock and the nature of the fields occurring between such a shock and the surface. Such measurements would nicely complement the magnetometer experiment now planned for the Apollo Lunar Surface Experiment package and could, in fact, prove to be crucial to the interpretation of those data.

The instrumentation that has been exploited to make interplanetary magnetic field measurements should be appropriate for a lunar orbiter experiment. Either a fluxgate or low field vector helium magnetometer could fulfill the requirements associated with the scientific objectives. A standard three axis magnetometer would weigh approximately 5 lbs and require 3 to 5 watts of power. The experiments could advantageously utilize a data rate of 10 to 100 bps. A lower bit rate is possible but not desirable and would probably be unnecessary in view of the high rate data requirements of some of the other orbiter experiments. The most serious constraint on the spacecraft would be associated with minimizing stray magnetic fields. The one pound sensor should be located at the end of a long boom to reduce or eliminate the effect of such contamination.

2. <u>Search Coil Magnetometer</u>. The scientific objective of this experiment is to investigate rapid magnetic field fluctuations in the vicinity of the moon in the frequency range from 1 to 1000 cps. An instrument of this kind has been flown on Earth satellites and has yielded important information regarding waves generated at the bow shock that have frequency components above the proton gyro frequency. In conjunction with measurements of steady and slowly varying magnetic fields by a fluxgate or helium magnetometer, the search coil magnetometer would help to identify unambiguously the various magnetic regimes surrounding the moon such as the shock front, magnetosheath, stagnation region, and magnetic tail.

The search coil magnetometer to be used in this investigation could be similar to equipment designed for the Orbiting Geophysical Observatories. The magnetometer consists of two separate assemblies, one containing the detecting coils and preamplifiers and the other containing a spectrometer, power supply, and associated circuitry. The spectrometer analyzes signals with frequency components in the range from 1 to 1000 cps. It consists of a series of tuned bandpass amplifiers with differing center frequencies, e.g., 3, 10, 30, 100, 300, and 1000 cps. The detector weighs approx 1 lb and the spectrometer weighs approx 4 lbs, so that the total equipment would weigh about five pounds. The equipment utilizes less than two watts of power. The minimum data requirement is approximately 1 bps on the average. However, higher data rates up to 100 bps are desirable and would yield correspondingly more information.

The search coil magnetometer is insensitive to stationary magnetic fields, including those associated with the spacecraft. However, the magnetometer will detect spacecraft-generated magnetic noise with frequency components in the 1 to 1000 cps range. It would be desirable to locate the magnetometer sensor as far as possible from the spacecraft electronics, perhaps by placing it at the end of the solar panel or boom. The effect of narrow-band, spacecraft-generated, magnetic noise can be reduced, or eliminated, by incorporating appropriate rejection filters in the spectrometer electronics.

3. Plasma Detector. The scientific objectives of the plasma detector are:

a) to determine the low-energy charged-particle environment of the moon, and

b) to aid in the interpretation of the magnetometer data by a study of the interaction of the Moon with the interplanetary plasma and magnetic field.

The instrument is expected to measure the charged particle energy spectrum around the Moon as a function of arrival direction, energy, angular distance from the subsolar point, and time.

The ideal instrument for making solar plasma measurements in the vicinity of the Moon would be one similar to the OGO-E plasma probe, which incorporates both a spectrometer (electrostatic analyzer) for making detailed energy measurements and a Faraday cup probe for making flux and direction measurements. A revised design of this instrument has been proposed for Voyager. It weighs 15 lbs, consumes 10 watts if operated continuously, and occupies about 1.5 cubic feet. It is capable of providing much better energy resolution, time resolution, and separation of hydrogen and helium solar-wind components than any plasma probe that has yet been flown. To use such an instrument at its maximum effectiveness, requires a data rate of 10 to 50 bps, since plasma data are most interesting when the plasma properties are changing rapidly, and such events cannot be predicted.

Plasma measurements at data rates that are lower by an order of magnitude would still be valuable, however. If weight and power are at a premium, a less versatile instrument could be supplied that would require about half the weight, power, and volume of the proposed Voyager instrument.

4. Meteor Dust Detector. The purpose of this instrument is to measure the vector velocity and mass distribution of dust particles in the vicinity of the moon with emphasis on particles leaving the moon.

The basic detector is a combination of an acoustic sensor and elements for collecting charge from minute plasma clouds. The particle first penetrates a thin metallic film (500 to 1000 Angstroms thick) and produces a small plasma cloud. The dust particle proceeds down the tubular portion of the detector and impacts on the acoustical sensor. A second plasma cloud is formed at this final destructive impact. The impacting dust particle delivers to the acoustical sensor a mechanical impulse which is closely related to the momentum of the impacting particle. The charged plasma clouds provide the signals from which a time-of-flight measurement is made. The measured momentum and speed determine the mass of each dust particle. The charge collected from the second plasma cloud is related to the kinetic energy of the dust particle. By using the measured speed and kinetic energy, an independent determination of the particle mass can be made. There are three such tubular detectors in the total experiment. Probably two of these detectors should be centered on the Moon's radius vector, one looking towards and the other looking away from the Moon. The third detector should always look at the Moon's horizon, from which it is thought that most of the high speed particles will come.

The instrument will weigh about 7 lbs and use 1 watt of power.

5. Lunar Body Properties. The purpose of this experiment is to determine the mass of the Moon, the moment of inertia of the Moon, and the coefficients in the expansion for the external gravitational potential of the Moon. This experiment is expected to provide the same sort of information about the Moon that Vanguard I has supplied for the Earth, e. g., information about the shape of the Moon, which is important for cartographic purposes; information about differentiation as indicated by a density distribution; information about layering, or departures from hydrostatic equilibrium in the interior; and finally, information about the forces that have acted on the Moon throughout geologic time and the nature of the Moon's responses to these forces.

This experiment is expected to be a continuation of the measurements being carried out by the present lunar orbiter series but with the spacecraft in an orbit of higher inclination, preferably polar. It is desirable to eventually define the gravitational field of the moon to harmonics of the 10th degree. This will require the analysis of data of orbital perturbations of lunar satellites in a variety of inclinations or one in polar orbit with a life-time of several months. This suggests that the opportunities offered by each lunar orbiter mission should be thoroughly exploited by the requirements of this experiment.

Position data, taken as a function of time for a lunar satellite, will yield the following Keplerian parameters defining an instantaneous elliptical orbit around the Moon:

| | |
|---|---|
| $a$ | semi-major axis |
| $P$ | orbital period |
| $e$ | eccentricity of orbit |
| $i$ | angle of inclination of the orbit to the ecliptic |
| $\Omega$ | Longitude of the ascending node |
| $\omega$ | argument of the perigee |
| $T$ | instant of minimum separation of the Moon and the satellite |

The mass of the Moon is then derived from the Kepler relation $GM = 4\pi^2 a^3/P^2$ where G is the universal gravitational constant, and M is the mass of the Moon. The coefficients in the expression for the gravitational potential and the moments of inertia are calculated by means of the equations of motion and knowledge of the angle of inclination of the orbit to the equatorial plane of the Moon, the longitudinal angle between the axis pointing toward the Earth and the line of nodes, and the parameter, $h = \sqrt{GMa(1-e^2)}$, measuring the angular momentum per unit mass.

6. Monostatic Radar. Radar instrumentation on-board a lunar orbiter can provide information of scientific and engineering value. The types of information a radar can provide are, in order of increasing difficulty, average surface radar cross-section, surface roughness correlation functions, altitude measurements, reflectivity, dielectric properties, and aid in determining the chemical content and relative porosity of the surface material. The possibility of a bi-static mode for this experiment should be evident.

A suggested radar system consists of three ranging devices operating at wavelengths of, for example, 8 mm, 80 cm, and 80 meters. The choice of wavelength is somewhat arbitrary as long as they allow a measure of relfectivity as a function of wavelength. The characteristics for the radar experiment are given in Table 2.

Table 2. Characteristics for radar experiment

| | Radar 1 | Radar 2 | Radar 3 |
|---|---|---|---|
| Wavelength (meters) | 0.008 | 0.8 | 80 |
| Peak Power (watts) | 4000 | 400 | 10 |
| Ave. Power (milliwatts) | 1.6 | 4 | 0.4 |
| Receiver Bandwidth (mc) | 1.0 | 0.2 | 0.002 |
| Transmission Type | Pulse | Pulsed-FM | Pulsed-FM |
| Range Accuracy (meters) | 10 | 100 | 500 |
| Ranging range (km) | 30-270 | 75-225 | 75-225 |
| Telemetry bandwidth required (mc) | 3.0 | 1.0 | 0.1 |
| Total telemetry time* required per orbit (real-time mission)** | 0.72 sec. | 0.72 sec. | 0.72 sec. |
| Total Storage* required per orbit (bits) | 50,000 | 20,000 | 20,000 |
| Estimated Total Weight (pounds) | 30 lbs. | 10 lbs. | 10 lbs. |
| Estimated Raw Power (watts) | 15 | 5 | 2 |

*Assuming one measurement set per orbital degree of rotation

**Non-real time transmission will depend on the bit rate of the digital channel.

The 8 mm radar employs a pulse-type transmission and a 1° antenna beamwidth, and has a 10 to 20-meter range accuracy. The 80 cm and 80 meter systems have a relatively wide antenna beamwidth and utilize a pulsed-FM transmission. The radar data will be transmitted in real-time during the time when the spacecraft is visible to the ground telemetry stations. During occultation, a fraction of the data will be stored for subsequent digital transmission. For lunar atmosphere studies, the 80 meter signal may be observed by a ground station during time of occultation.

The principal objective of the radar experiment is to measure the range from the orbiter to the lunar surface to an accuracy of ten meters. This data can be used to determine the general shape of the moon and map a gross profile. The fine structure of the mapping is left to the optical (TV) observations. During real-time transmissions, the orbital elements can be determined in real-time. The major orbital checkpoints can be made as the orbiter passes over the lunar poles, an event which will take place twice on each orbit. The general shape of the moon may be pear-shaped, or egg-shaped, and the radar data in conjunction with orbital calculations should be able to resolve this information. The gross profile data could be used to aid the TV data in lunar mapping by determining the relative altitude of regions widely separated on the lunar surface. Virtually all of the ranging will be done with the 8 mm radar with the 80 cm radar being used as a back-up system at a reduced range accuracy.

The secondary objective of the radar is to measure reflection properties of the lunar surface. From these measurements and measurements made by other experiments such as Magnetometer, TV, and IR Radiometers, it is probable that the surface material can be bracketed, and it is also possible that the porosity of the surface can be established within certain bounds. The coverage of the complete lunar surface will allow different areas to be categorized and studied by future missions.

7. Gamma Ray Spectrometer. The scientific objective of the gamma-ray experiment is to determine the approximate concentration of radioactive materials present on the surface of the Moon. Information from the gamma-ray spectrum generated by lunar surface rocks could provide some information about the composition of this material and the thermal history of the Moon. Since the heat production of a planetary body is largely determined by its content of naturally occurring radioactive isotopes ($K^{40}$, $Th^{232}$, $U^{238}$, and perhaps the radioactive offspring of the last three of these), and since these same isotopes, at least for the Earth, are

concentrated in surface rocks during thermal differentiation, gamma-ray spectroscopy of the Moon from an orbiter appears to be capable of contributing evidence regarding the composition of the Moon, its thermal history and finally if differentiation has occurred.

The gamma-ray spectrometer will consist of a pulse height analyzer, a detector system and a high voltage supply. The high voltage supply provides a potential drop for the photomultiplier tube of the detector. The detector system responds to energy deposited within a scintillator by generating a signal which is fed to the pulse height analyzer. The analyzer performs analog to digital conversion of this signal and subsequently stores it in the appropriate energy dependent channel. The detector system also has the capability of generating a rejection pulse which triggers a gate in the analyzer and prevents desirable signals from entering the analyzer.

The scintillator system of the detector shall face towards the moon without the interposition of the mass of the spacecraft proper; also, the detector and high voltage supply will be at the end of a boom extension no less than six feet from the body of the spacecraft. The instrument will weigh about 25 lbs and require 4 watts of power.

8. Lunar Neutron Flux. Lingenfelter et al. (Ref. 3) have calculated the equilibrium neutron leakage spectrum from the moon for a number of models of the lunar surface composition. They find the spectrum to be quite sensitive to the lunar hydrogen content, the addition of hydrogen reducing the amount of high-energy leakage and increasing the low-energy leakage. This observation led them to suggest that a relatively simple experiment for determining the hydrogen content of the lunar surface material could be performed by measuring the neutron spectrum at or near the lunar surface.

They recommend a minimum of two detectors to do the experiment:

a) a detector with an energy sensitivity varying as 1/v (for example, a $B^{10}F_3$ proportional counter);

b) a detector with a flat response at higher energy (for example, a 1/v counter covered with moderating material so that the energy response is nearly flat from a few Kev to 10 Mev.

For this choice of detectors, the ratio of the count rate in detector (b) to the count rate in detector (a) turns out to be quite sensitive to the hydrogen to silicon atomic ratio. The addition of a third detector would improve the accuracy and provide a check on the internal consistency of the experiment. The two-detector experiment, however, would give reasonable accuracy and could be designed to weigh less than 8 lbs and consume less than 1 watt of power.

The detectors should be mounted as far from the bulk of the spacecraft as possible. If a gamma-ray spectrometer is carried aboard, it is suggested that the neutron detectors be mounted on an extendable boom with it. Then, by measuring the counting rates before and after extension in cislunar space, the effect of the spacecraft on both the gamma-ray and neutron detectors could be estimated.

9. Infrared Mapping of the Surface. Two types of experiments are possible, radiometric and spectro-radiometric. In both, a measurement of energy emitted by the surface is made in specified wavelength bands or over a spectral region. These data may be interpreted in several ways. Radiometric measurements are usually interpreted in terms of surface brightness temperature and together with the theory of heat conduction lead to specific models of the thermophysical properties of the near surface (few cm) materials. Terrestrial observations of this kind, with areal resolution of some 30 km on the Moon's surface, have disclosed very non-uniform cooling behavior over the visible disk during eclipses. The smallest so-called anomaly thus far detected are a few km in diameter, but many smaller ones might be uncovered with finer resolution. Controversy exists over the causes of such anomalous behavior, and many further infrared and photographic observations are required to understand the effect involved.

Spectroradiometric observations may, with caution, be interpreted as variations from place to place of spectral emissivity of the surface material. The apparent spectral emissivities of a surface depend upon its temperature, composition, and surface roughness. If independent knowledge of the temperature and surface geometry are available, then variations in emissivity may be extracted from the data as these are related to composition. Compositional data are of extreme interest geologically.

The most feasible experimental scheme is to combine radiometric and spectroscopic instruments in a single bore-sited package. The detection of thermal anomalies is best accomplished using a thermal scanner. The radiometric experiment may be flown independently of the spectrometer, but the reverse is not true, as thermal data are essential to interpretation of the spectroscopic results.

The expected range of lunar temperatures is between 100 - 400°K. Anomalous behavior is detected during the umbral phase of an eclipse or during lunar night, so that good temperature determinations are needed at low temperatures ≈ 120°K ±5°K. Ground resolution of a radiometric or scanner system should be better than one km.

The overall required sensitivity of the spectrometer is such that S/N > 100. A modest spectral resolution of 10 $cm^{-1}$ is adequate. Short scan times over the region 8-16μ are required to prevent target smear.

Both the above experiments thus require instrumentation of high sensitivity. The present state of infrared technology demands use of cooled detectors to achieve this objective, and this involves use of liquid helium, solid cryogenics, or refrigeration.

Accurate weight and power estimates require specification of the instrumental arrangement. Representative figures are provided in Table 3 for the two experiments.

10. X-Ray Fluorescence. The purpose of this experiment is to make a preliminary measurement of passive X-ray spectra emitted from the lunar surface. When excited by particles and electromagnetic fluxes of sufficient energy, all elements emit X-rays of characteristic energy. Sources of excitation include solar X-rays, solar electrons and protons from flares, or even particles trapped in the Earth's outer radiation belt which the Moon may intercept in its orbit. Data obtained from the spectral measurement of these lunar X-rays could show the chemical nature of the upper millimeter of the rocks on the Moon. When correlated with photographic features, such information could contribute to an understanding of the degree and nature of any lunar differentiation process which may have occurred, and also provide data towards an understanding of erosion rates and surface turnover history resulting from impacts.

A simple, nondispersive technique is proposed for the measurement of lunar X-rays emitted in the 0.7-12Å region. The instrument would consist of a thin window, proportional counter detector and its amplifier which will detect X-rays in an energy range of 1-20 Kev corresponding to atomic numbers 11 through 40; a high voltage power supply; pulse height analyzer; and readout logic. It would weigh about 18 lbs and use 2 watts of power. By combining some of the components with the gamma-ray spectrometer (Experiment Number 7), considerable weight and power savings could be accomplished.

Table 3. Infrared mapping experiments

| | |
|---|---|
| 1. Long Wavelength Spectrometer Radiometer | |
| Weight (without tape recorder) | 60 lbs |
| Power | 55 watts (incl. cooling) |
| Volume | 3.2 $ft^3$ |
| Data rate: | |
| Spectrometer | 19 kilobits/sec |
| Radiometer | 660 bps/sec |
| 2. Infrared Image | |
| Weight | 80 lbs. incl. Cryogenics |
| Power | 20 watts |
| Volume | 1.75 $ft^3$ |
| Data rate | 120,000 resolution elements/channel/sec |
| 3. Simple Radiometer | |
| Weight (without tape recorder) | 25 lbs |
| Power | 12 watts |
| Volume | 1.5 cu ft |
| Data rate | 300 bps-bits/sec |

11. Microwave Surface Imager. This instrument will scan the surface of the Moon along an orbit controlled profile at two wavelengths of 3 mm and 3cm to obtain information about the three-dimensional temperature distribution of the Moon's crust and the thermal and electromagnetic properties of the material. Theory and measurements have shown that different wavelengths penetrate to different depths; thus, at 3 cm the penetration for dry sand is in the order of meters to tens of meters and the measured radiation represents the integrated emission from all the surface material down to that depth. The penetration is a function of the thermal and electromagnetic properties of the material. Shorter wavelengths have correspondingly less penetration, allowing the construction of "isotherms" by the use of multiple wavelength instrumentation that gives the emission contribution of the various layers.

The microwave data should accomplish the following:

a) Permit isolation of lunar surface features such as mountains, plains, and continents

b) Identify thermal abnormalities, such as fault lines and volcanos

c) Yield estimates of gross surface composition and structure

d) Provide a correlation function for use with other experiments.

As the orbiter swings around the Moon, valuable information about the phase effect and hence the overall thermal regime of the Moon will also be obtained. The facts that the Moon rotates with respect to the sun and that its surface thus has a sinusoidal thermal input in time, greatly facilitate the study of the surface and sub-surface materials through differential thermal analysis.

The instrument will weigh about 35 lbs, require a data rate of 250 bps during operation, and use 15 watts of power. The sensing antenna has dimensions of 3-feet by 3-feet by 3-inches. A planetary sensor or spacecraft pointing to orient the antenna along the local vertical to a pointing accuracy of ±1° is needed. The instrument scans its sensor electronically.

12. Photo-Imaging Experiment. The objective of this experiment is to provide basic data regarding the composition and configuration of the lunar surface. As a means of accomplishing this objective, it will be necessary to utilize the data in the preparation of some form of topographic maps. In order to effectively support Apollo and post-Apollo lunar exploration programs, it will be necessary to provide detailed information about selected areas of the surface. Pictorial information with resolution on the order of a few meters and with a potential for providing topographical information with a contour interval on the order of 50 - 100 feet is of value only for interpretation of the more gross features and characteristics of the lunar surface. The more detailed information (resolution approximately 3 feet, contour interval <20 feet) is required for qualification of landing sites for manned spacecraft. In addition, detailed morphological and lunar geologic studies will require better imagery than obtained with the current Lunar Orbiter camera system.

The reduction of significant scientific information from any imaging experiment is directly related to the calibration of the system. For a geodetic/cartographic camera system operating from a lunar orbit, calibrations and operational techniques for the camera system would have to be maximized in order to provide data which would satisfy anticipated Apollo and post-Apollo requirements. In this case, operational techniques refer primarily to stereoscopic, photometric, and general reconnaissance modes for obtaining image information. Directly related to the flight camera system and its calibration requirements is the often overlooked problem of data reduction. In order to maximize the usefulness of any future lunar orbiter objectives, it will be necessary to consider the integration of the system design, operational constraints, calibration, and ground data reduction techniques so as to meet stated scientific objectives.

The objectives of a lunar orbiter imaging experiment should be directed towards providing the following information:

a) Geologic character and history of the lunar surface; including surface materials, tectonic activity, and general lunar astro-geologic investigation.

b) Topographic representation of the lunar surface, including the mapping of topographic features utilizing combinations of stereometric and photometric techniques as well as reference to general reconnaissance-type photography. Primarily for use as basic data for topographic base maps.

c) Detailed mapping (significantly larger scales than b) for landing site investigations for post-Apollo applications as well as for support of a).

d) Selected investigations related to planetary exploration; i.e. photometry, astronomy, color, evaluation of unique imaging systems in a true space environment, etc.

e) Support and surveillance of landed spacecraft both manned and unmanned.

f) Indexing image for relating remote sensor data.

Actual system parameters should not be defined without direct consideration of the overall objectives. General definition of an imaging system, such as by focal length and smallest resolvable distance (object) on the lunar surface, is not sufficient to adequately provide good scientific information required to satisfy the previously described objectives. Only in the broadest sense could some of this type of imagery satisfy objective a). It is imperative that extensive calibration criteria be included in any imaging system design in order to insure its capability of meeting specific scientific objectives. For any future lunar orbiting imaging mission, it is suggested that consideration be given to the specific scientific objectives prior to selection of the imaging system or adaptation of the current Lunar Orbiter Camera System.

13. <u>Mass Spectrometer</u>. It is imperative that the Moon's atmosphere be examined before it is thoroughly contaminated by Apollo exhaust gases, as the character of the original gases should offer some important clues as to the origin of the atmosphere. It is estimated that the total lunar atmospheric mass is about 100 metric tons, and that each Apollo LEM will release up to 5 metric tons of contaminating exhaust gases into this atmosphere (Ref. 2); therefore, it is strongly recommended that on an early orbiter mission, the lunar atmosphere be examined for its neutral mass spectrum, neutral particle pressure, total ion concentration, directed ion flux, and ion mass spectrum.

The instrument presently conceived as suitable for this lunar atmosphere analysis is a quadrupole mass spectrometer. The instrument is expected to weigh 12 lbs and consume a maximum of 10 watts of power. It records data in a digital mode by mass analyzing (a) ions created in its ion source through electron impact on neutral species, and (b) primary ions trapped in an accelerating field with the ionizing electron source inhibited. The mass analyzer portion of the instrument is entirely nonmagnetic being composed of superimposed AC and DC voltages impressed on a set of four parallel rods. Mass scanning of the spectrometer is accomplished by slaving the analyzer voltages to the address register of a multi-channel scaler (MCS). Ion pulses arriving at an electron multiplier detector are amplified and stored in the appropriate MCS channels according to their mass. The data in the MCS is then telemetered. A data rate of approximately 250 bps is desirable.

Since there likely will be a high relative velocity between the mass spectrometer and the atmospheric gases, provision must be made to trap primary ions of this energy as well as focus the neutral particles of the same energy that are ionized in the mass spectrometer. High voltages will be used in the ionizing and trapping region for this purpose. In doing this however, a positive bias voltage must likewise be used on the quadrupole rod assembly so that ions remain a sufficient time in the analyzing field to be sorted according to their mass.

In addition, it is highly desirable to mount the mass spectrometer on a scan platform so that absolute molecular density data can be obtained. It will be necessary to take mass spectral data both in the direction of the spacecraft velocity vector as well as against it.

It would probably be desirable to add a Redhead gage or Trigger gage to this experimental package for direct measurement of the lunar atmospheric pressure. Both instruments have been flown before. It would weigh about 5 lbs and use 1 watt of power. The data output is analog and could be kept very low, e.g., 100 bits per orbit.

14. Dosimeter. In support of the manned program, it would seem desirable to fly an experiment to provide data on the biological hazards from energetic radiations on prolonged lunar flights. A variety of methods are available for instrumenting this experiment, but the instrument used should (a) be "tissue equivalent," that is, it should provide a direct measure of the energy that would be absorbed in human tissue and (b) have a dynamic dose-rate range extending from cosmic ray background up to the dose rate from a large solar proton event (perhaps several hundred rad/hr).

A "tissue equivalent" ionization chamber would be a simple instrument for this experiment. The basic chamber would be spherical in shape and about 3.5 inches in diameter. It could be fabricated to weigh only about a pound and to consume only a few milliwatts of power. It would probably be desirable to fly several of these instruments on a spacecraft in order to simultaneously observe both background and secondary radiation. A bit rate of 100 bps should be adequate.

## C. EXTENDED LIST OF LUNAR EXPERIMENTS

As mentioned earlier, many of the experiments that have been considered for terrestrial orbiters and atmospheric probes could have an application to lunar orbiter science. In addition to these, however, there are several categories of experiments that, while not discussed in the foregoing text, should at least be kept in mind by any group that is considering the question of the types of experiments that can be accomplished on a lunar orbiter mission. Some of these are as follows:

1. Radio Transmission. A radio transmission experiment (either orbiter to surface or orbiter to earth) with wavelengths of the order of tens of meters or greater should be considered in order to investigate the conductivity or dielectric constant of deeper layers of the Moon.

2. Gamma Ray or X-ray Telescope. A gamma ray or x-ray telescope in an appropriate lunar orbit should be useful for studying the occultation of many more cosmic sources than can be done from Earth. The objective of occultation experiments is to make accurate determinations of the angular size of such sources.

3. UV Instruments. An entire class of UV instruments may be of importance. Although little is presently known about it, UV fluorescence in this wavelength region may be useful in detecting the collapse of a lunar bow shock against the surface (which might result from an increase in solar wind pressure) or many of the phenomena associated with unusual lunar emissions. UV imaging and UV spectroscopy of selected areas could become rather high priority experiments.

## REFERENCES


1. Space Research, Directions for the Future, (1965), Part I, Space Science Board, National Academy of Sciences, National Research Council, Washington, D. C.

2. NASA, 1965 Summer Conference on Lunar Exploration and Science (1965), NASA SP-88, National Aeronautics and Space Administration, Washington, D. C.

3. Lingenfelter, R. E., Canfield, E. H., and Hess, W. N., The Lunar Neutron Flux, J. Geophys. Res. 66, pp. 2655-2671 (1961).