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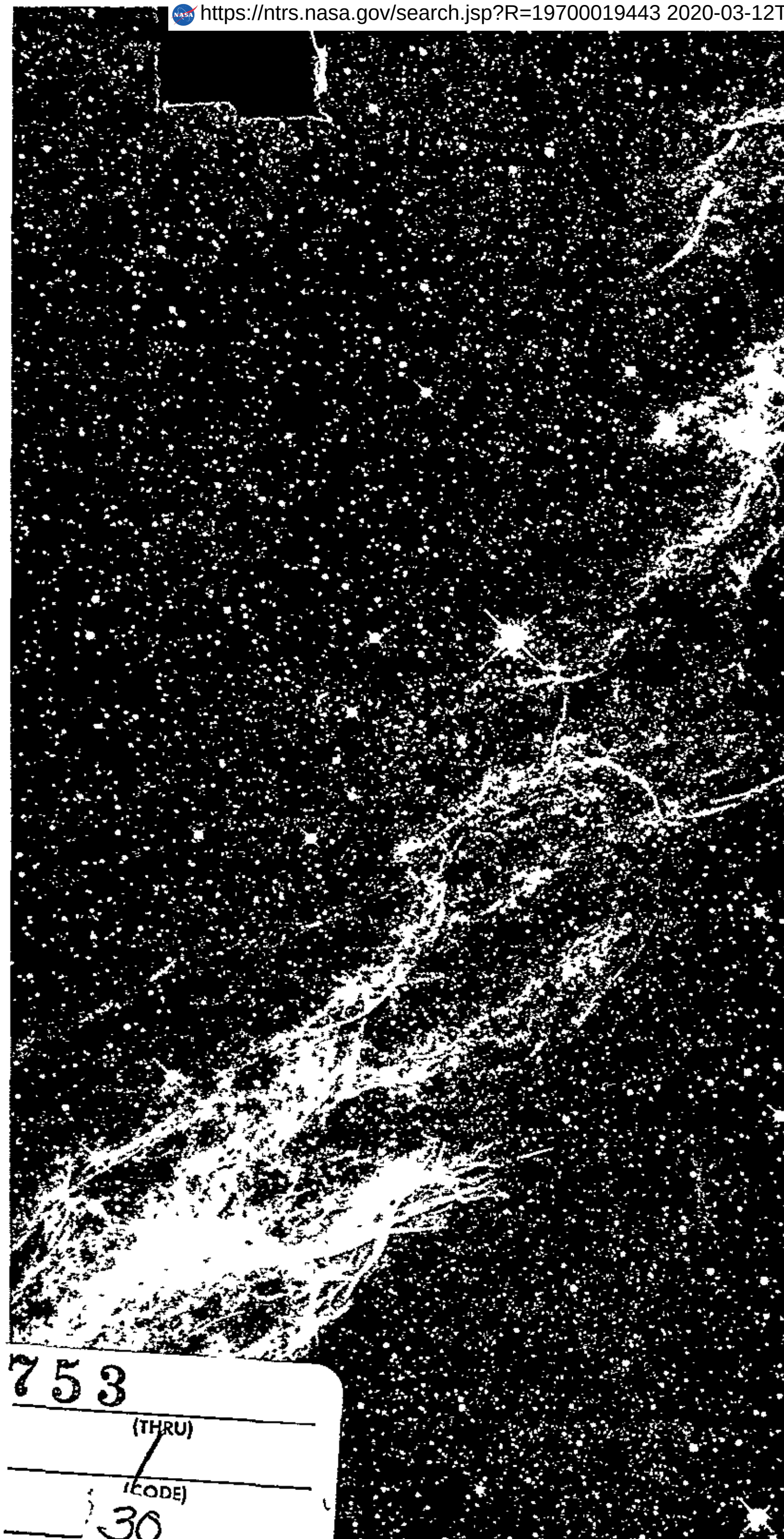

Report No. P-32

OBJECTIVES OF PERMANENT LUNAR BASES

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Report No. P-32

OBJECTIVES OF PERMANENT LUNAR BASES

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SUMMARY

It is being seriously considered that a permanent lunar orbiting base and a permanent lunar surface base be constructed during the next 10 to 20 years. The purpose of this report is to study the objectives of these two lunar base concepts.

In this report we first provide a detailed review of AS/IITRI Report No. P-29, "Logic for Lunar Science Objectives", which outlines, from an overall viewpoint, lunar science objectives and available measurement techniques, and proposes a strategy of lunar exploration based on four "levels":

Level 1: Overall Reconnaissance

Level 2: Sampling of Representative Systems

Level 3: Determination of Feature Related Processes

Level 4: Comprehensive Regional Exploration and Exploitation.

We then examine, primarily from a scientific point of view, the advantages and disadvantages of lunar bases. After this examination, we conclude that (1) scientifically, there is no strong justification for a manned lunar orbital base; such a base should be established only if there are compelling non-scientific reasons for doing so; and (2) we are entirely in favor of a manned lunar surface base; man's capacity to understand, investigate, and discover phenomena, not to mention his ability to set-up and operate instruments and equipment, are vital to both exploration and exploitation of the lunar surface.

The justification for the above conclusions are as follows:

(1) Lunar orbital science can be satisfactorily performed by near state-of-the-art, automated spacecraft (or satellites) which would not

require nearly as much technological development or cost as a manned orbiting base.

(2) The analysis of lunar surface samples should be performed on earth (as opposed to lunar orbit) where a large team of scientists and supporting equipment can more realistically provide the necessary level of detail.

(3) Detailed, long duration exploration of the Moon (Level 4), although necessary, will be so complicated, and will require so many scientific specialists for so long a time, that a surface base is a mandatory item.

Besides the scientific reasons, there are other compelling reasons for extending man's domain to the Moon (Hess and Hinners 1969). There are many reasons related to human adventure, and national prestige. There are also non-lunar science applications (astronomy, physics experiments, terrestrial study). We recommend that planning for a surface base be started well before final decisions are made, and scientific objectives be carefully considered from the outset.

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OBJECTIVES OF PERMANENT LUNAR BASES

1. INTRODUCTION

The goal of Project Apollo was to put men on the Moon as quickly as possible. During the next decade the emphasis will probably shift to reusable spacecraft, with a corresponding decrease in cost per flight. It is being seriously considered that man and supplies will travel in (1) a space shuttle between earth surface and earth orbit, (2) a nuclear shuttle between earth orbit and lunar orbit, and (3) an LM-B between lunar orbit and lunar surface; all of these would be reusable. Also being seriously considered are a permanent lunar orbiting base and a permanent lunar surface base. The purpose of this report is to study the objectives of these two lunar base concepts.

Review of ASC/IITRI Report No. P-29, "Logic for Lunar Science Objectives"

One of the major considerations in a lunar base study is, of course, science. ASC/IITRI Report No. P-29, "Logic for Lunar Science Objectives", has recently treated this question. That report approaches lunar exploration from the point of view of basic lunar science. Its authors feel that, in the past, too much emphasis has been given to exploration capability, and too little to fundamental scientific objectives. Since an understanding of its approach is necessary for an understanding of this report, we present here a detailed review of it.

The purposes of Report P-29 are to provide (a) from the point of view of basic lunar science, an overall outline of the categories and interrelationships of lunar science objectives, (b) a detailed summary of how much we now know about each of these objectives, (c) a detailed statement of the next several steps necessary to reach more and more complete understanding of these objectives, (d) an outline of present measurement techniques, (e) a suggested overall strategy of lunar exploration, with detailed explanations of how this strategy incorporates the available techniques in increasing our knowledge of the objectives, (f) a correlation of objectives, techniques, and levels, showing how each relates to the overall task of lunar exploration, (g) an explanation of how the suggested strategy can be expanded or contracted, so as best to complement expanded or contracted NASA mission schedules, in a way that will, in the future, insure a maximum scientific return per dollar, whatever the level of NASA funding, (h) a specific example: how the suggested strategy directly pertains to the remainder of the Apollo program. Report P-29 serves as a basis for other ASC/IITRI reports (including this one) which discuss further specific aspects of the overall approach to lunar exploration.

Report P-29 starts from the viewpoint of basic lunar science. The most interesting questions about the Moon relate to that body as a whole: How and when did it originate? What has happened to it since? How do its origin and evolution relate to the origin and evolution of the entire solar system? Is there, or has there ever been, life on the Moon? Accordingly, lunar science is divided into three main "Science Areas": Origin, Evolution and the Search for Life. These areas are then further sub-divided according to those present properties or features of the Moon which would most likely give information regarding the Science Areas; these catagories are termed "Broad Objectives". They are finally subdivided into the "Specific Objectives" to which measurement techniques are directly applicable.

Available measurement techniques are then discussed and correlated with the scientific objectives, and a strategy for exploration is proposed, based on a framework of four levels of capability:

Level 1: Overall Reconnaissance
Level 2: Sampling of Representative Systems
Level 3: Determination of Feature-Related Processes
Level 4: Comprehensive Regional Exploration and Exploitation

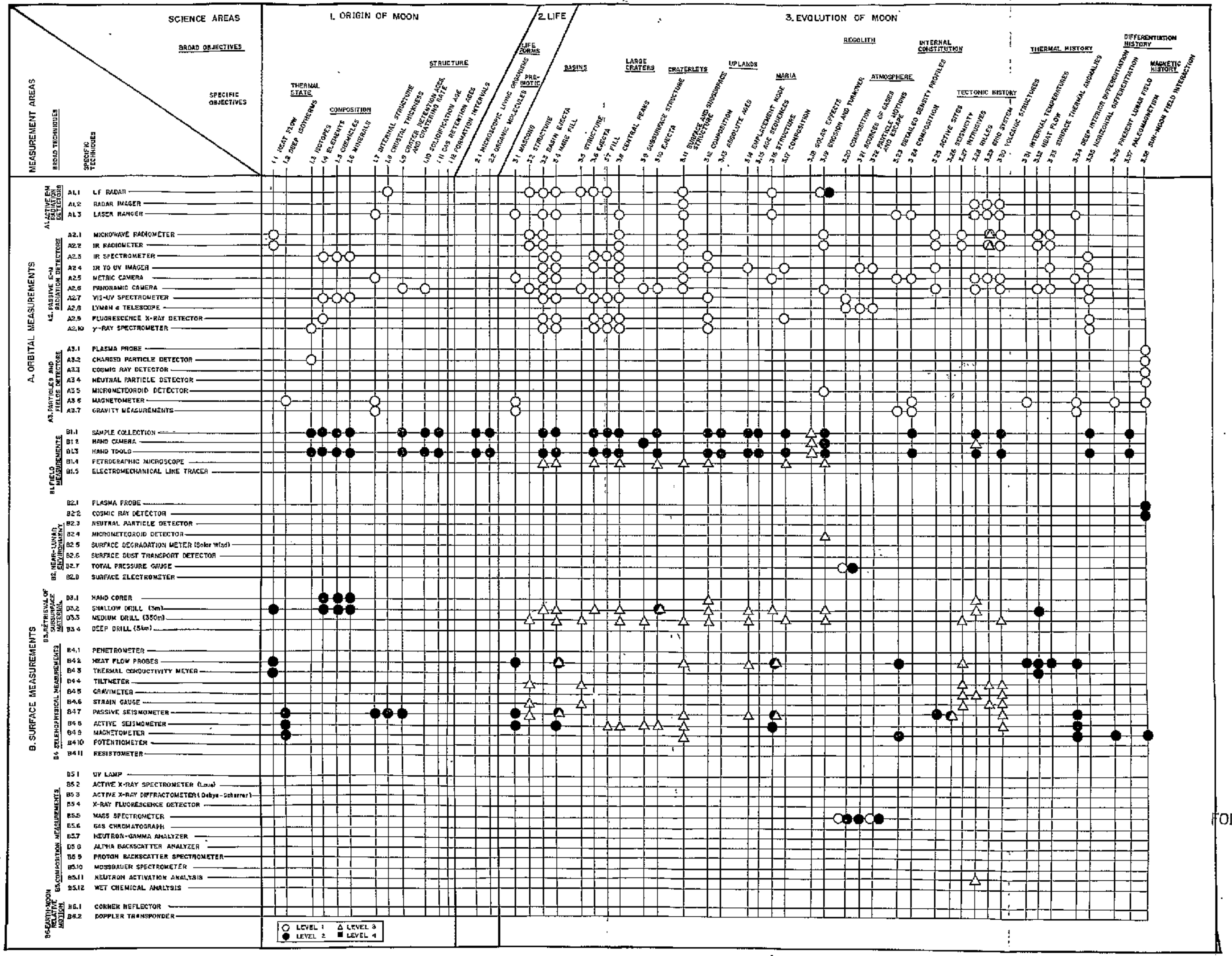
The major scientific goals of the levels correspond roughly to the capabilities, respectively, of: lunar orbiting speacecraft, Apollo (landings), Post-Apollo, and a Lunar Surface Base.

Next, the overall correlation of objectives, techniques, and levels is discussed, with a view toward finding which techniques are most applicable to the scientific objectives, which objectives are most readily studied with the techniques available, and how the "four-level" scheme helps maximize the rate of scientific return. This is summarized in Table 1. A major result of this correlation is a priority list for measurement techniques, illustrated in Figures 1 and 2. The exact ordering of techniques cannot be guaranteed but the approximate ordering is valid: for example, it is evident that a laser ranger is much more applicable to lunar science than a neutral particle detector.

The analysis can and should be used in lunar mission planning regardless of the level of funding. Of course, more funds mean a faster rate of scientific return, less funds mean a slower rate.

As an example of the usefulness of Report P-29, it is applied to the remainder of the Apollo program. The conclusion is that, although Apollo has been living up to its potential in the field of surface science, it has not been doing so for orbital science.

The overall conclusion is that scientific objectives should be a major input in the planning of any lunar mission, from its inception. Measurement techniques should be allocated



FOLDOUT FRAME 1

FOLDOUT FRAME 2

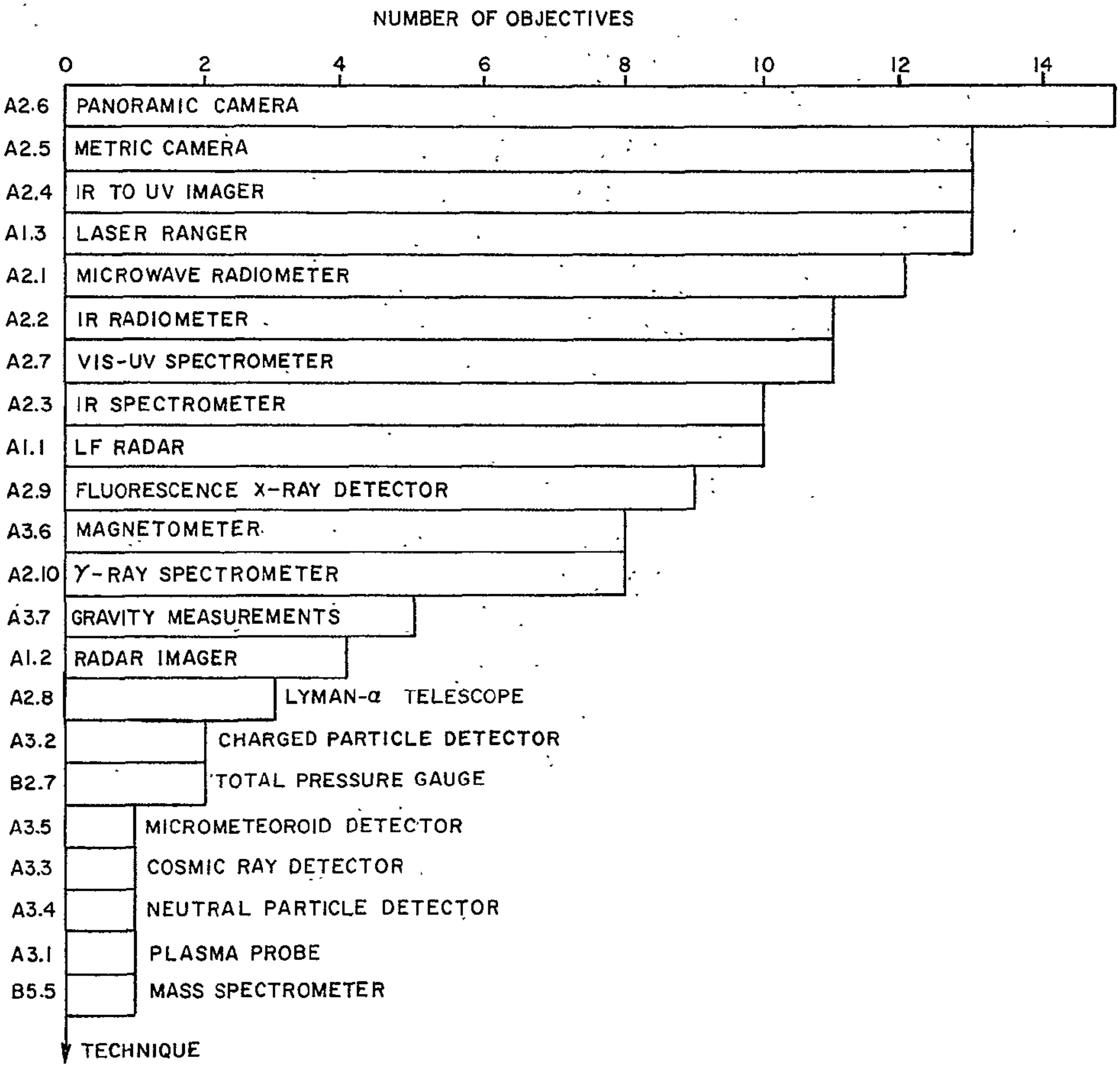


FIGURE 1. APPLICABILITY OF ORBITAL TECHNIQUES TO OBJECTIVES, LEVEL 1.

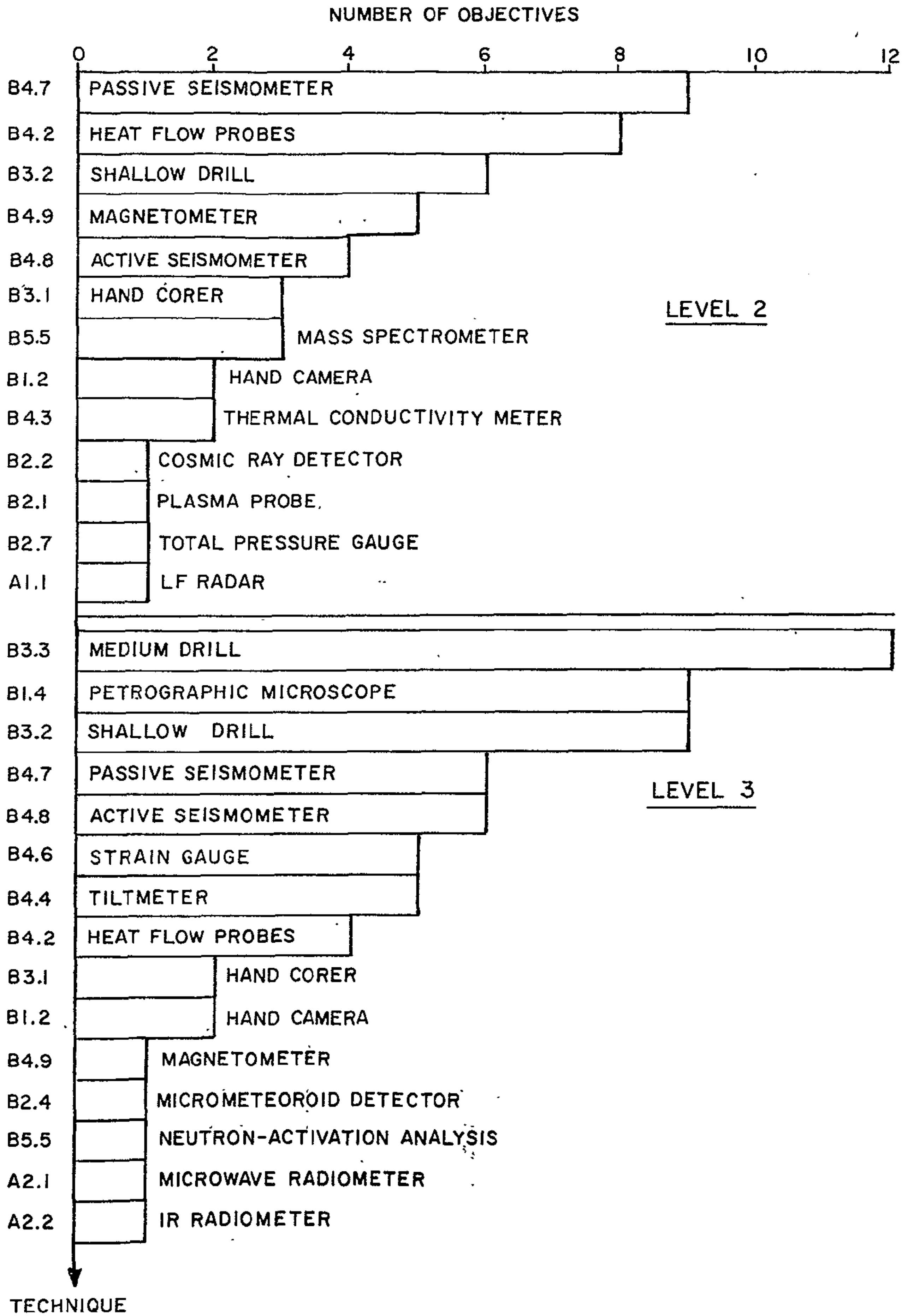


FIGURE 2. APPLICABILITY OF TECHNIQUES TO OBJECTIVES, LEVELS 2 & 3.
(Not including sample collection (B1.1) and hand tools (B1.3))

to future Apollo and Post-Apollo missions according to their value in testing scientific objectives. It is recommended that this be done for any Post-Apollo program, and for all possible remaining Apollo missions. It is especially recommended that a much greater role be accorded the CSM in orbital science.

2. LUNAR ORBITAL BASE

2.1 General Characteristics (NASA)

NASA's tentative thoughts regarding men in lunar orbit are the following. The Apollo spacecraft will make nine trips to the Moon (Apollo 11 through 19; as of this writing 11 and 12 have been successfully completed). Each mission, of course, will involve a CSM in lunar orbit. On Apollo 11 through 15, there will be (has been) no lunar orbital science performed other than photography. On Apollo 16 through 19, some significant orbital science will be conducted, but only for three, relatively low-inclination orbits in each mission. Such experiments will be useful for determining the general features of the parameters studied; however, they will not scan the entire Moon, and cannot accomplish more than about 30 percent of the orbital science desired (Level 1). One of their most important aspects is, in fact, to help specify the next stage of orbital experiments.

Following Apollo, a dry workshop (DWS) of the AAP variety may be placed in lunar orbit. It may be capable of supporting 3 men for about 3 months. Later a space station module (SSM) may be put in lunar (polar) orbit. (SSM's are also tentatively scheduled to be placed in Earth orbit, and on the lunar surface). It would have a capacity of 6 men for 2 years (autonomously), and would be 22 feet in diameter, 40 feet long, and would weigh 50,000 pounds. Two such SSM's may be joined together to form a 12-man module. From the SSM, LM-B's would visit the lunar surface, each carrying 3 men and 20,000 lbs of discretionary payload (or alternatively possessing a 40° plane change capability and carrying no discretionary payload). The SSM would be supported either by QCSM's (extended CSM's which can exist in a quiescent mode for a year) from Earth, or by nuclear shuttles, each with a capability of 80,000 pounds of discretionary payload.

The orbital base (either DWS or SSM) could perform both scientific research and serve as a mission operations base to the lunar surface. The present study considers only the scientific objectives of such bases.

2.2 Detailed Definition of Orbital Measurement Techniques

As described in Report P-29, orbital measurements will perform a vital role in overall scientific understanding of the Moon. They will form a major part of Level 1 - Overall Reconnaissance. This level will consist of complete selenodetic, selenographic, and selenologic surveying and mapping of the lunar surface. Specifically, this activity will identify and classify major surface features and general surface composition, and will characterize the Moon's near-space, particle and field environments. The purpose of this level is to provide data for the selection of sites for first-hand exploration in later levels, and to provide a comprehensive framework of hypotheses concerning the Moon's origin and evolution, with which to evaluate and correlate the data resulting from later levels. Surface features will be compared with terrestrial features; particle and fields analysis will characterize the Moon's interaction with the solar plasma; and perturbations of the lunar magnetic field will be used to form concepts of the Moon's interior. Selenologic analysis should provide initial indications of those areas most probably conducive to biologic or prebiologic formation and support.

Level 1 demands a complete orbital survey capability around the Moon which will map the surface in all wavelengths of interest (radio through γrays) and provide complete particle and fields environmental data. Spatial resolution is required in successive orders of magnitude beyond that which earth-based observations can achieve. Lunar Orbiter has provided photographic coverage of much of the Moon at a resolution of 100 meters, and of small areas at 1 to 10 meters. This should be extended to

1-meter resolution with full coverage in the visible spectrum, and to about 10-100 meters at all other wavelength regions of interest.

Ideally, remote sensing should provide for all regions and all phase angles. To observe all regions, a polar orbit capability is essential. The entire Moon is then scanned, in daylight, every 28 days. All sun angles are obtained every 6 months. (Actually, for each lunar region, sun elevation angles from 0° to 90° are obtained every three months; for most features, this would probably be adequate, although some asymmetric features might require elevation angles from 0° to 180°). The period of an object in low circular orbit about the Moon is about 1 hour 50 minutes, during which period the Moon rotates 0.97°, or about one degree. The surface of the Moon moves laterally about 30 km in this amount of time. For the field of view of an instrument on a 100 km - high spacecraft to include an area 30 km wide, the instrument's total fiew of view must be about 17°. Thus, if a 100 km high spacecraft, in polar orbit, carries an instrument with a 17° (or greater) field of view, looking straight down, the instrument will scan the entire Moon, at approximately constant sun angle, in one month.

We now turn our attention to specific measurement techniques. We have started from the viewpoint of basic scientific objectives, not from the viewpoint of available state-of-the-art instrumentation. Accordingly, we have considered first the scientific objectives to which a given measurable (physical quantity measured) applies, and our present knowledge of these objectives; next our present knowledge of the measurable; next what instrument is ideally necessary, in lunar orbit, to improve our knowledge of this measurable, and how much improvement would represent our reaching "the next plateau" in such knowledge; then the best available instrument, and how it compares with the ideal; next the increased knowledge of the measurable which would result from such an experiment; finally the increased knowledge of the objectives which would result from this new knowledge of the measurable. In Part II we present a series of detailed sheets giving this information for all the measurables considered.

Table 2 summarizes the techniques, in order of their scientific applicability (Figures 1 and 2), giving the objectives to which they pertain, approximate range, resolution, and data rate; and orientation, attitude, and orbital requirements. Lighting is critical for techniques A2.6, A2.5, A2.4, A2.2, A2.7, A2.3, A2.9 and A2.8; for these, therefore, 3 to 6 months may be necessary for complete coverage. For the others, only one month is necessary.

If data-rate problems exist, this time may be proportionately longer. Such problems may occur, since the spacecraft moves at about 1.5 km/sec, and therefore scans about 45 km^2 of the lunar surface per second. At 1 meter resolution, assuming 10 bits per resolution element, the data rate for an instrument is 0.45 billion bits per second (see Table 2), which is very high.

Therefore, a spacecraft in low, polar orbit, whose attitude is stabilized to 1' of arc (and known to 1" of arc), carrying all the instruments outlined in Table 2, each with a field of view of at least 17° (achieved either steadily or with scanning), and the data-handling capability indicated, would be able to complete Level 1, satisfactorily at all sun angles, in six (perhaps even three) months.

2.3 Scientific Uses of the Lunar Orbital Base

In this section we examine, from a scientific point of view, the advantages and disadvantages of a lunar orbital base. After this examination, we conclude that, scientifically, there is no strong justification for a lunar orbital base, and that such a base should not be established unless there are compelling non-scientific reasons for doing so. Our reasoning follows.

Two of the more commonly hypothesized scientific justifications for a lunar orbital base are (1) to perform orbital

TABLE 2

SUMMARY OF TECHNIQUES *(See Part II)

	Technique	Number of Objectives	Objectives	Range	Resolution	Data Rate +	Orientation Requirements	Orbit Requirements	Attitude Control ++
A2.6	Panoramic Camera	15	1.9,1.10,3.2,3.3,3.5,3.9 3.10,3.11,3.19,3.25,3.28 3.30,3.32,3.33,3.35		1/2 m	1.6×10^{9}bps	Able to point to any region within sight of spacecraft	Polar, circular, low altitude	1'
A2.5	Metric Camera	13	1.7,3.1,3.3,3.4,3.8,3.11 3.16,3.23,3.24,3.28,3.29 3.30,3.34		2 m	10^{8} bps	Able to point to any region within sight of spacecraft	Polar, circular low altitude	4'
A2.4	IR to UV Imager	13	3.3,3.4,3.6,3.8,3.11,3.12 3.14,3.17,3.21,3.22,3.25 3.33,3.35	0.1-30μ	1 m (spatial)	4×10^{9}bps	Pointed at Moon	Polar, circular low altitude	2'
A1.3	Laser Ranger	13	1.7,3.1,3.3,3.4,3.8,3.11 3.16,3.23,3.24,3.28,3.29 3.30,3.34	$\sim10^{-12}$ of Earth based laser	± 1n sec (± 15cm)	4×10^{8}bps	Pointed at Moon	Polar, circular low altitude	1'
A2.1	Microwave Radiometer	12	1.1,3.2,3.3,3.8,3.11,3.19 3.25,3.27,3.29,3.30,3.32 3.33	~150°K eff. Temp. 30μ-30cm	± 5°K (10 km spatial)	100 bps	Pointed at Moon, 3 min pointed at same spot	Polar, circular low altitude	1°
A2.2	IR Radiometer	11	1.1,3.2,3.3,3.8,3.11,3.19 3.25,3.27,3.29,3.30,3.33	0.01-10w/cm^2 at 6.7μ 10^{-5}-1w/cm^2 at 32μ	10% in energy 1-100 m	4×10^{7}bps	Pointed at Moon, 3 min pointed at same spot	Polar, circular low altitude	2'
A2.7	Vis-UV Spectrometer	11	1.4,1.5,1.6,3.3,3.4,3.6 3.7,3.8,3.12,3.20,3.35	100-7000 A°	1%(wave-length) 100 m (spatial)	10^{7} bps	Pointed at Moon, 3 min pointed at same spot	Polar, circular low altitude	1°
A2.3	IR Spectrometer	10	1.4,1.5,1.6,3.3,3.4,3.6, 3.7,3.8,3.12,3.35	0.7-40μ	0.01μ (λ) 100 m (spatial)	4×10^{6}bps	Pointed at Moon, 3 min pointed at same spot.	Polar, circular low altitude	1°
A1.1	LF Radar	10	1.8,3.2,3.3,3.4,3.5,3.6 3.7,3.11,3.16,3.19	$\sim10^{-12}$ Earth based device	100 m	1000 bps	Pointed at Moon (Does not scan every point)	Polar, circular low altitude	1°
A2.9	Fluorescence X-ray Detector	9	1.4,3.3,3.4,3.6,3.7,3.8 3.12,3.17,3.35	0.01-100/cm^2 sec 0.1-10Kev	10% in energy 100m	1000 bps**	Rotate ~1rpm about axis ∥ Lunar surface and ⊥ Moon-Sun line	Polar, circular low altitude	1°
A3.6	Magnetometer	8	1.2,1.7,3.1,3.24,3.31, 3.34,3.36,3.38	0.01-100γ	0.5% or 0.01γ (whichever is greater)	15 bps	None	Polar, circular low altitude	1°
A2.10	γ-ray Spectrometer	8	1.3,3.3,3.4,3.6,3.7,3.8, 3.12,3.35	0.01-100/ cm^2-sec 0.1-10Mev	10% 100m	100 bps**	Rotate ~1 rpm about axis ∥ Lunar surface and ⊥ Moon-Sun line	Polar, circular, low altitude	1°
A3.7	Gravity Measurements	5	1.7,3.1,3.23,3.24,3.34	—	—	100 bps	—	Polar, circular, low altitude	
A1.2	Radar Imager	4	3,11,3.28,3.29,3.30	$\sim10^{-12}$ of Earth based Radar	100 m	10^{5}bps	Pointed at Moon	Polar, circular, low altitude	1°
A2.8	Lyman-α Telescope	3	3.20,3.21,3.22	λ = 1216A°; 10^{-5} to 1w/cm^{-2}	10% flux density 100 m	0-10^{5}bps	Pointed at Moon, 3 min pointed at same spot	Polar, circular, low altitude	1°
A3.2	Charged Particle Detector	2	1.3,3.38	1ev-500MeV 0-10^{3}cm^{-2}S^{-1}	±10% energy and flux	10^{4}bps	All Directions	Polar, circular, low altitude	1°
B2.7	Total Pressure Gauge	2	3.20,3.22	10^{-14}-10^{-10} Torr	10%	100 bps	None	Polar, circular, low altitude	-
A3.5	Micrometeoroid Detector	1	3.19	Mass $>10^{-4}$g, size >50μ Velocity 10 m/sec-100km/sec; Flux: 10^{-7}-10^{-4}/m^2-sec-str.	10%	100 bits per day	Pointed away from Lunar surface, in direction of motion	None	1°
A3.3	Cosmic Ray Detector	1	3.38	0.05-50MeV (electrons) 0.3-500MeV (protons) 1-10^{10}/cm^2-sec	±10%	10^{6}bps	All Directions	Highly elliptical, low periapse	1°
A3.4	Neutral Particle Detector	1	3.38	0-1/cm^2-sec .1-10 Kev	10%	100 bps	Toward sun for neutron; Toward Moon for Albedo; all directions-atmosphere	Polar, circular, low altitude	1°
A3.1	Plasma Probe	1	3.38	10^{5}-10^{11}/cm^2 sec-sr-Kev Electrons: 3ev-300ev Protons: 120ev-5Kev	± 2%	10^{6} bps	Toward direction of solar wind; toward Moon for albedo	Highly elliptical low periapse	1°
B5.5	Mass Spectrometer	1	3.20	Mol. wts. 1-100	10%	100 bps	Along spacecraft's Velocity vector	Polar, circular, low altitude	1°

* Note. This table describes desired instruments, not available instruments.

** Limited by count rate, not spatial resolution.

\+ Assuming whole Moon must be observed in one month.

++ Assume attitude known to 1/60 this value.

science, and (2) to perform cursory or even detailed analysis of lunar surface samples.

We examine both of the above issues in detail.

(1) Orbital Science

As described in Section 2.2 and Part II, lunar orbital science is very important. We shall first examine the relative advantages and disadvantages of manned and unmanned spacecraft for performing these Level 1 measurements.

An advantage of a manned vehicle (we assume that some scientists are on board) is that scientists are available to add their skills and insight to the routine performance of unmanned instruments. Whenever instruments find values of characteristic parameters outside expected limits, the scientists could "watch" that area of the Moon, with all their instruments, for a longer period than planned, interpret data in real time, revise instrument functions (e.g., change scales on instruments), etc. On the other hand, the disadvantages of manned vehicles are that they produce a dirty "atmosphere" around them, thus degrading measurements of lunar atmospheric composition; and in addition, because of the men moving around inside them, their attitude is less stable. With respect to this latter point, Table 2 shows that, for some orbital measurements, the attitude control must indeed be quite accurate: 1' of arc or better.

The orbital science, except for photography, can be performed as well, or better, from an unmanned, non-returning spacecraft. With respect to photography, a need evidently exists for a camera system which does not use film but which can achieve the same resolution and geometric accuracy as a camera which does use film, and can telemeter its photographs to the Earth. Effort should be spent to develop or obtain such a camera. If this fails, an unmanned subsatellite or spacecraft should take the photos and return the film to Earth or a CSM (or advanced counterpart).

In either case the cost should be considerably less than that of a manned orbital base.

We wish to stress that we are entirely in favor of manned expeditions to the lunar surface, where man's capacity to understand, investigate, and discover phenomena, not to mention his ability to set up and calibrate instruments, are vital to both scientific exploration, and exploitation, of the lunar surface. But, comparatively, orbital science is expected to be a rather routine gathering of information from all lunar regions.

Considering all of the above, we definitely feel that, from a scientific point of view, a manned orbital base is not sufficiently superior to an unmanned orbital science spacecraft to warrant the huge extra cost involved. Given an equivalent amount of money to be spent on lunar science, we would probably choose to spend some of it on one or several unmanned orbital spacecraft, and the rest on more surface science.

If we assume that an orbital base will be established for non-scientific reasons, but that scientific instruments and personnel can be included, we recommend that the orbital base be used for orbital science, since (by assumption) it will exist anyway. In this case, at least some of the men should be scientists, if this is compatible with the primary mission of the base; they will be trained to understand and interpret the observations they are making, and will greatly enhance the scientific return of the base.

(2) Lunar Sample Analysis

It has been suggested that lunar samples be analyzed in orbit. If this were done, the base would have to contain a well-outfitted laboratory. Table 3 contains a list of those scientific objectives amenable to treatment by sample analysis, along with the appropriate measurables, and instruments for laboratory analysis; the instruments themselves are listed in Table 4.

TABLE 3

RELATIONSHIP OF LUNAR SAMPLE ANALYSIS TO SCIENCE OBJECTIVES

Objective		Measurable (via Sample Analysis)	Chief Instrument(s) (see Table 4)
1.3	Isotopes	Isotopic Comp.	N,O,R,T
1.4	Elements	Elemental Comp.	H,I,K,L,M,P,R
1.5	Chemicals	Chemical Comp.	C,F,G
1.6	Minerals	Mineralogical Comp.	A,D,E,Q
1.7	Internal Structure	Gross Properties of material	U,V,W
1.10	Solid Age	Radioactive isotope ratios	T
1.11	Gas Ret. Age	^{40}K - ^{40}A ratios	T
2.1	Micro-organisms	Micro-organisms	Q,F,X,Y
2.2	Organic molecules	Organic molecules	Q,F,X,Y
3.3	Basin ejecta	Comparative Composition	A,C,D,H,K,S,T, etc.
3.4	Mare fill	Comparative Composition	A,C,D,H,K,S,T, etc.
3.5	Lg. Crater Struc.	Comparative Composition	A,C,D,H,K,S,T, etc.
3.6	Lg. Crater Ejecta	Comparative Composition	A,C,D,H,K,S,T, etc.
3.7	Lg. Crater Fill	Comparative Composition	A,C,D,H,K,S,T, etc.
3.8	Central Peaks	Comparative Composition	A,C,D,H,K,S,T, etc.
3.9	Craterlet Structure	Comparative Composition	A,C,D,H,K,S,T, etc.
3.10	Craterlet Ejecta	Comparative Composition	A,C,D,H,K,S,T, etc.
3.11	Uplands Structure	Comparative Composition	A,C,D,H,K,S,T, etc.
3.12	Uplands Comp.	Comparative Composition	A,C,D,H,K,S,T, etc.

Table 3 (Continued)

Objective	Measurable (via Sample Analysis)	Chief Instrument(s) (see Table 4)
3.13 Uplands Ages	Solid and Gas Ret. Ages	T
3.15 Maria Ages	Solid and Gas Ret. Ages	T
3.17 Maria Comp.	Comparative Composition	A,C,D,H,K,S,T, etc.
3.18 Regolith Solar Effects	Physical properties, Rare gas content	A,D,H,J
3.20 Atm. Composition	Atm. Comp. (if any)	H,J
3.28 Rilles	Compar. Comp. Search for Volatiles	A,C,D,H,K,S,T, etc.
3.30 Volcanic Structures	Compar. Comp.	A,C,D,H,K,S,T, etc.
3.35 Horiz. Differentiation	Compar. Comp.	A,C,D,H,K,S,T, etc.
3.37 Paleomagnetism	Remanent Magnetism	S

TABLE 4

LABORATORY EQUIPMENT

FOR LUNAR SAMPLE ANALYSIS

(Note: We recommend against its use in lunar orbit.)

A Petrology lab equipment (lens, etc.)

B Scale (perhaps a problem in zero g)

C Wet chemical analysis

D Petrological stereomicroscope (with crossed nicols, etc.)

E UV lamp

F X-ray spectroscope (Laue)

G X-ray diffractometer (Debye-Scherrer)

H Mass spectroscope

I Electrostatic analyzer

J Gas chromatograph

K Neutron activation analyzer

L Alpha backscatter analyzer

M Proton backscatter analyzer

N Mössbauer analyzer

O Nuclear magnetic resonance

P Electron spin resonance

Q Electron microscope

R Optical spectroscopic equipment

S Ferromagnetism detector

T Radiation-lifetime detectors (single and coincidence)

U Equipment to determine stress-strain characteristics (Young's modulus, Poisson ratio, yield point, tensile and compressive strength, speed of sound, etc.)

V Electrical Conductivity Meter

W Thermal Conductivity Meter

X Pyrolysis-flame ionization detector

Y Biological samples (tissue cultures, paramecia, plants, germ-free mice, etc.)

This list is not intended to be exhaustive, but rather to provide a preliminary idea of the sort of instruments which may be applicable. In fact, in the preliminary analysis of Apollo 11 samples, most of these techniques were used (LSPET 1969), and the complete analysis (Science, 1-30-70) involved many others. Because of the large number of instruments needed for sample analysis, and the large number of skilled personnel required to obtain and interpret the data, it would be impractical to try to miniaturize the listed instruments and install them in an orbital base. Rather, once the effort has been spent to lift lunar material off the Moon, it should be returned quickly to Earth, where a complete study can be performed by many groups of scientists of various disciplines. The facilities and personnel available in an orbital base could not possibly compare with the extensive facilities and personnel available on Earth.

Therefore, we recommend against performing any sample analysis in lunar orbit. The only exception to this might occur if, for reasons of logistics, lunar samples were (unfortunately) required to remain in lunar orbit for a few months; e.g., awaiting a nuclear shuttle to take them to Earth; in this case, some preliminary analysis might be justified, for timely availability of results.

In passing, it is worth noting that very preliminary analysis on the lunar surface would be a valuable contribution, because available material could be sorted, and the most interesting samples could be chosen for Earth return. Short half-life isotopes could also be studied. In other words, an adequate cursory analysis of the samples, if performed on the surface, would be much more practical then if performed in orbit.

Since we have recommended against lunar sample analysis in orbit under almost any foreseeable circumstances, we obviously recommend against in-orbit analysis or data processing of lunar sample data. However, if a lunar orbital base is established for non-scientific reasons, since we have recommended that orbital science be performed, and that scientists be present, we also recommend that the scientists be provided with some equipment (computer, plotter, etc.) to analyze and interpret data from orbital measurements.

2.4 Summary of Conclusions and Recommendations

A. We conclude that lunar orbital measurements are extremely important and should be vigorously pursued, but with unmanned (returnable or non-returnable) spacecraft or satellites. A manned orbital base is not sufficiently superior to an unmanned spacecraft to warrant the huge extra cost involved. We recommend that a lunar orbital base not be established unless there are compelling non-scientific reasons for doing so.

B. We recommend against performing any lunar sample analysis in a lunar orbital base (except possibly on samples constrained, for reasons of logistics, to remain in lunar orbit for a period of months).

C. Nevertheless, if an orbital base is established for non-scientific reasons; and if the option exists of including orbital science instruments, data analysis equipment, and scientists trained to understand and interpret the measured phenomena; then we recommend that this option be exercised.

3. LUNAR SURFACE BASE

3.1 General Characteristics (NASA)

NASA tentatively plans to establish a Lunar Surface Base within 10 to 20 years. It would consist of a space station module (SSM), 22 feet (diameter) by 40 feet, which could support 6 men for 2 years. The 50,000 lb SSM would be lowered to the lunar surface by an LM-B, which would use up all of its fuel in the landing and could not return to orbit (without being refueled on the Moon).

The base concept has been discussed by a number of authors; a review and bibliography is given by Hess and Hinners (1969). They discuss the possibility of a base becoming a new national goal. They point out advantages of a base both for lunar science and non-lunar science, the latter consisting of astronomy (optical, radio, X-ray, γ-ray) and particle and field studies. A base, they speculate, also might eventually be used for communication with interplanetary spacecraft, as a refueling and launch station (if fuel can be manufactured from lunar materials), for manufacturing materials to be needed in synchronous earth orbit (the ΔE is less; see Fig. 3), even for various industrial applications which could utilize the vacuum and 1/6 g environment. They point out that the LESA study (1965) proposed three successive phases of bases:

(1) 3 men for 3 months; several modules, 1 vehicle,

(2) 6 men for 3 years; laboratory shelter, 2 vehicles, power plant,

(3) 12 men, 5-10 years (of course, various individuals would rotate); 2 lab-shelters, optical and radio astronomy observatories, 2 vehicles.

The present report extends this thinking, and makes it more definite. It re-emphasizes the need for a base as the aforementioned documents have done. It then goes on to consider the importance of site selection. Next a specific

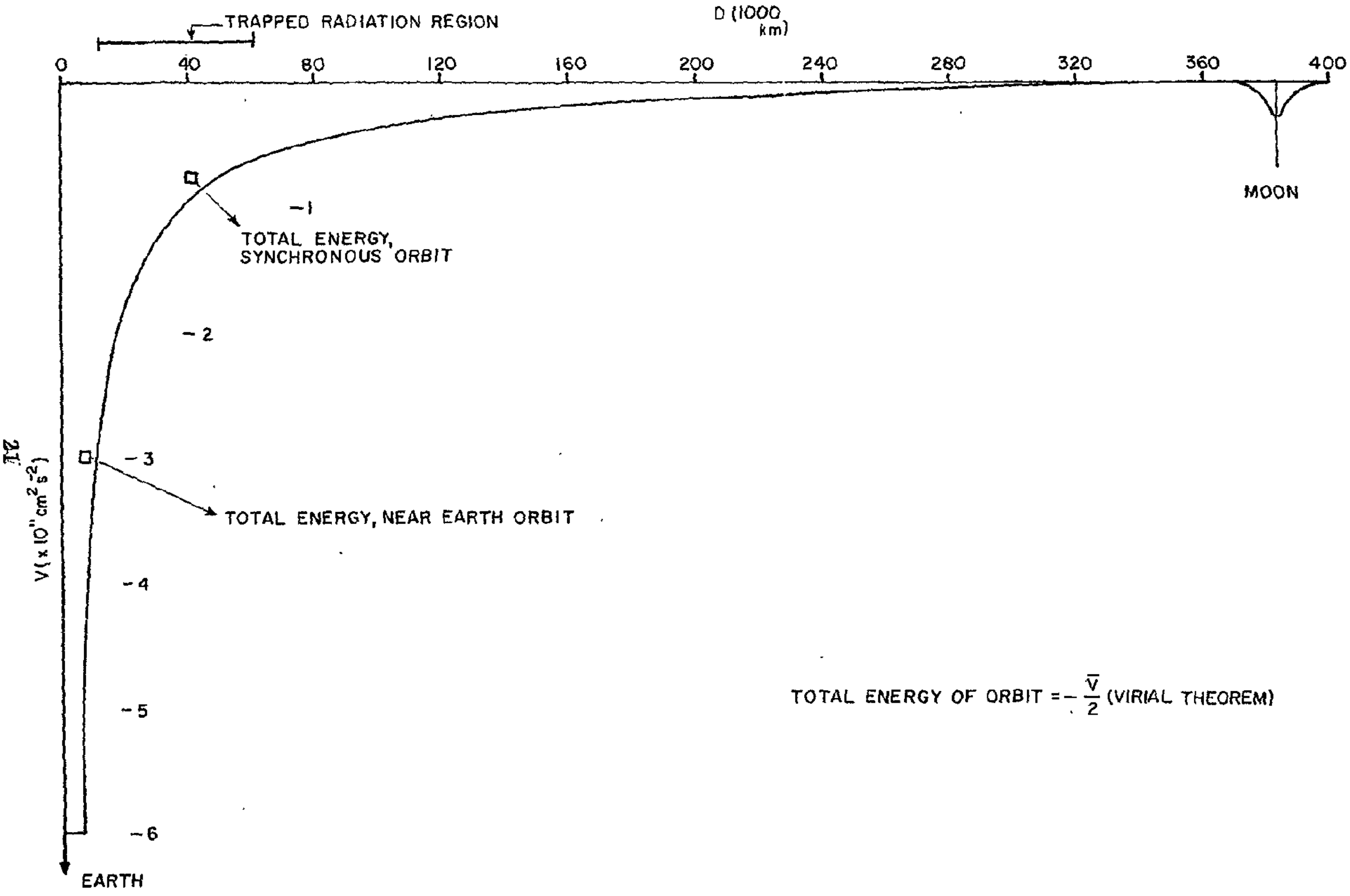


FIGURE 3. POTENTIAL ENERGY OF EARTH-MOON SYSTEM

possible site is examined: Mare Orientale; this is an excellent site scientifically, although difficult to land at, with the present systems. The advantages of multiple bases are then considered. Specific scientific projects for a base are also proposed, although this must necessarily be fairly vague at this stage, since the wealth of information returned by Apollo (and Post-Apollo, hopefully) will undoubtedly change our ideas about lunar science to a great degree. Finally we examine other, non-scientific aspects of a base.

3.2 Uses of a Base for Surface Science

3.2.1 Need for Surface Base

It is difficult to be specific about the scientific objectives, site selection criteria, or support requirements for the base, because the base is years ahead and many of its characteristics must depend on the findings of orbital, Apollo, and subsequent exploration. However, there are extensive scientific needs for a base. Almost by definition man will play the crucial role. J. Verhoogen pointed out during the 1965 LESA study that the objective of a lunar base demands "a long term project ... and that the instrument of greatest value in the investigation is man." We shall discuss the base with reference to the "level" scheme of overall exploration (Section 1). In the very nature of Level 2 and 3 exploration, lunar astronauts are limited in the three-dimensional range of their operations. Therefore there is a maximum scale of structural features that can be investigated by the time that Level 3 (process-oriented science) begins to give way to Level 4 (permanent occupation of the Moon). These dimensions will be of the order 400 km horizontally, and tens of meters vertically. Larger features, such as lunar basins and the lunar interior, will have had only cursory study.

3.2.2 Importance of Site Selection

The most crucial decision in establishing the permanent lunar base is its location, because this will affect the problems studied over the next several decades. Three principles on site selection are apparent.

(1) The scale of accessible structures should be larger than that of those of the Level 3 studies. Level 3 allows us to make a first-order study of multi-kilometer features such as craters, rilles, faults, flows, etc., but longer-term studies will be required to piece together the properties of the 1000-km, multi-ring basin systems or the detailed structure of the lunar interior and "crust". Level 4 should be optimized for studying planet-wide features of the Moon.

(2) The second principle in site selection is that the types of accessible structures will determine the content of knowledge to be gained. For example, we anticipate that it would be an error to place the permanent base inside the crater Copernicus, because studies of the local structures and crustal interior would then not teach us about lunar endogenic evolution but rather about a single exogenic impact event. Study of a feature such as Copernicus, while of interest, would better be done by a localized mission of the Level 3 type; full-time pre-occupation with a single crater would waste the potential of the lunar base.

(3) The third principle of site selection is that the variety of accessible structures should be maximized. Thus, it should remain possible to study moderate-sized structures of many types, such as craters, rilles, faults, lava flows, crater chains, lineaments, etc., refining studies begun in Level 3. Small-scale structures, such as hectometer-scale craters, strewn boulders, and glass spherules will be available at all sites, since the regolith is presumably almost universal.

3.2.3 Example of a Possible Base Site

The Orientale Region appears in many ways an ideal base site (as best we can judge at this early date). The scale of structures is appropriate to Level 4. The types of exposed structures give a good cross section of important problems (the best basin system with concentric and radial structures; varied mare deposits, some along fault scarps; complex rilles; etc.). The variety of structures is as great as at any site on the Moon, including immense faults, arcuate mare patches along them, radial valleys and crater chains; a large, fresh crater in the central mare; an older, large, flooded crater nearby; rilles ringing the central mare; and the freshest basin ejecta blanket. Though Orientale is near the limb, base sites on the east side would remain in direct line-of-site with Earth even during times of high western libration. The possibility of operations beyond the limb to the west or in valleys out of sight of the Earth, effected by mobile teams or a temporary base site, might be advantageous from certain points of view, e.g., radio astronomy.

3.2.4 Possibility of Multiple Bases

NASA should not become committed by default to the concept of a single permanent base. The LESA study - probably the most thorough study directed at long-term lunar occupation - suggested multiple bases to allow study of varied terrains (LESA, 1965). The geosciences panel in that study recommended a minimum of three different long-term stations, not necessarily simultaneous, prior to a more complex single base.

The triple base concept would have several advantages: (1) It allows traverses along three inter-base routes instead of constraining traverse to out-and-back paths. This improves exploitation of the large-scale structural patterns that will come under study in Level 4. (2) It provides redundancy in the event of catastrophic accidents or failures that might render a single base uninhabitable. (3) It provides havens of safety during mobile studies, which will probably concentrate in the triangle or polygon formed by the bases. (4) The different bases could be located one in each type of terrain. In the Orientale example, one could be located on the mare floor, one near a major fault scarp, and one outside on the striated upland ejecta blanket. It is not necessary, of course, for the multiple bases to be of equal size or importance. Bases 2, 3, ... could be regarded as "outposts."

3.2.5 Specific Lunar Science

Many scientific projects will involve continuation of studies begun in Level 3. If the earlier levels are correctly performed, Level 4 projects can involve refinement of pre-existing concepts. Table 5 gives a summary of probable lunar science activities.

This then, represents the culmination of the "four-level" exploration approach; at the end of Level 4 we should know as much, or more, about all details of the Moon as we now know about such details of the earth. As we said before, present thinking about Level 4 must necessarily be imprecise. Thus Table 5 is meant to consist of indications and examples of lunar science, and not to contain an exhaustive list of projects.

3.3 Role of a Base in Utilization of the Moon

3.3.1 Non-Technical Aspects of a Base Role

Extending man's domain to the Moon by establishing a permanent lunar base is a national goal recognized by the Space Task Group under Vice President Agnew. In that phase of lunar exploration, science objectives become intimately mixed with human objectives. The goal is no longer simply study of the Moon but its utilization. The problem of long-range philosophy was raised recently at the December 28, 1969 meeting of the American Association for the Advancement of

TABLE 5

LUNAR-ORIENTED SCIENCE FOR THE LUNAR BASE

Program	Remarks
Detailed structure of lunar interior	High-energy active seismology and long-term monitoring for passive seismology (dependent on Apollo results).
Study of major basin concentric faulting	Traverses, geophysical surveys. Is origin due to slumping during lava emplacement?
Study of basin radial systems	Traverses, field mapping, petrofabrics. How much due to faulting? To volcanism? To base-surge deposits?
Study of basement beneath basins	Geophysical traverses. Depth of lava; extent of breccia, fractures.
Isostasy, effects of thermal history, equilibration of figure	Refinement of Level 1-3 physical and selenodetic data.
Origin of craters, sinuous rilles, linear rilles, crater chains, etc.	Refinement of Level 1-3 data. Base site must be chosen to facilitate access to these features.

Science where participants included Gordon MacDonald, Carl Sagan, Lewis Branscomb, and Fred Singer. MacDonald stressed that Congress is demanding a clearer ordering of national science priorities than science has given in the past. No longer will the ability to carry out an advanced program be sufficient reason for doing so. He questioned explicitly whether the value of the Viking program is really equal to 1-1/2 years' funding for the National Science Foundation and by implication whether extended lunar exploration will compete with an attack on the environmental problems facing earthbound man. Sagan and Branscomb, on the other hand, listed a permanent capability of man in space as necessary (1) to increase our awareness of man's need to cooperate in preserving the Earth, (2) to check our premises on how the Earth's meteorology, geology, etc. function, and (3) to reinforce public interest and participation in the adventure of exploring new frontiers. Singer stressed the need for man as a key to exploration. Science is not the only goal of man in space, he argued; the sense of adventure is a very real need for man. "If we keep de-emphasizing man in space, we may soon find ourselves with no space program at all," because exploration by instrument will not fulfill this need.

We can agree that there are compelling human reasons to carry out Level 4 - i.e., to extend our domain to the Moon.

3.3.2 Scientific and Technical Programs

Technical Support. These include operations not strictly scientific but contributing to lunar knowledge and man's mastering of the Moon. Examples are search for lunar water (pending results from Apollo); recovery of oxygen from lunar rocks; and development of cast-basalt or similar technology to utilize lunar materials on the Moon. By 1971, a substantial study might be aimed at this problem, using Apollo studies of lunar rock samples as a guide.

TABLE 6

SELECTED NON-LUNAR SCIENCE FOR THE LUNAR SURFACE*

Area	Program	Advantage of Moon Over Near-Earth Orbit
Geo-physics (of Earth)	Photography of surface structures under selected lighting and lack of clouds.	Long view times at constant aspect. Aspect angle changes rapidly from near-earth orbit.
Astronomy	High-resolution spectroscopy of faint objects.	Low velocity. Long integration times may produce unacceptable Doppler shifts if performed in near-earth orbit.
	High-resolution imaging of faint objects; sequential imaging of planets.	Distant from Earth. Occultation every 45 min. in near-earth orbit may be unacceptable or at least inconvenient.
Space Science	Cis-lunar solar wind.	Must be outside Earth magnetosphere.
	Earth aurora.	Simultaneous monitoring of both terrestrial poles.
Radio Astronomy	Radio telescope operation.	Lunar shielding.
Exobiology	Survival and evolution of organisms in non-earth environment.	Availability of sub-surface rock layers to provide shielding and simulate early planetary bodies.

* Drawn from summary in LESA Final Report, 1965. This list represents a "residue" after potential near-earth orbit experiments are eliminated.

Non-lunar Science. Forecasting Level 4 science is difficult, as noted. Whole areas of non-lunar science such as stellar astronomy, physics experiments, and terrestrial studies may be carried out from earth-orbit instead of from the lunar base, depending on the demonstrated efficiency of orbital observing. The increasing attention being given to earth-orbit applications of the space program makes this increasingly likely. Thus, major portions of lunar base science which have been contemplated (e.g., in the LESA 1965 study - meteorology, oceanography, astronomy, etc.) may never reach the Moon. Nonetheless, certain suggestions made in the LESA study, such as simultaneous monitoring of both the north and south polar areas of Earth for auroral activity, may yield non-lunar science programs ideally suited to the lunar base. Table 6 gives a selection of non-lunar science (taken from the LESA summary) that may remain ideal for the lunar surface even in the event of a major science program in near earth orbit.

A possible advantage of the Moon for these programs is that they may require long-term residence by the scientists and supporting staffs. Life on the lunar surface in a gravity field may be more attractive and conducive to productive work than life in orbit. Astronaut experience tentatively suggests this.

Further evaluation of trade-offs for orbital vs. lunar deployment of non-lunar science is in order.

3.4 Recommendations

The following recommendations are made with respect to a Lunar Surface Base.

1. Studies of detailed base operations should not be premature. Those outlined in LESA (1965) are probably as complete as we should use until after Apollo results are evaluated, and experience is gained with research in earth orbit.

2. By about 1971, an effort should be made to define the possibility of extracting water and oxygen from lunar rocks and of utilizing lunar materials to support base construction and life support. This effort can utilize Apollo results.
3. By about 1974, a study should be made to choose between a single permanent base, a primary base with "outposts", or multiple bases. The study can utilize late Apollo experience. At the same time, a parallel study should define the optimum number of scientists and technicians and to determine their distribution by discipline, sex, stay-time, and experience.
4. In mid-70's, decisions should be made concerning which experiments will be deployed at the base and which in earth orbit.
5. Site selection should be deferred until the mid to late 70's to utilize experience with lunar sciences gained by Post-Apollo exploration.

PART II

DEFINITION OF ORBITAL MEASUREMENT TECHNIQUES

The individual measurement techniques are described in detail on the following pages.

The instrument requirements given herein are approximate and serve only to give the reader a general idea of the measurement concept in question.

The requirements are not based on the current state of the art, but rather on the characteristics of the measurable and our present knowledge thereof. This is not to say that an instrument of lesser capability is useless. If the requirements exceed the state-of-the-art, then the best available instrument should be used, since any significant improvement toward the stated requirements is always worthwhile. If the state-of-the-art exceeds the requirements, it would probably still be prudent to use "state-of-the-art" instrumentation, but only if this did not involve excessive disadvantages (cost, availability, etc.) over "required-resolution" instrumentation.

Obviously, the better the instrument, the better the results. The best available instrument should always be used unless good reasons (e.g. high cost) exist to the contrary.

PART II

DEFINITION OF ORBITAL MEASUREMENT TECHNIQUES

A1.1 LF Radar
A1.2 Radar Imager
A1.3 Laser Ranger

A2.1 Microwave Radiometer
A2.2 IR Radiometer
A2.3 IR Spectrometer
A2.4 IR to UV Imager
A2.5 Metric Camera
A2.6 Panoramic Camera
A2.7 Vis-UV Spectrometer
A2.8 Lyman α Telescope
A2.9 Fluorescence X-ray Detector
A2.10 γ-ray Spectrometer

A3.1 Plasma Probe
A3.2 Charged Particle Detector
A3.3 Cosmic Ray Detector
A3.4 Neutral Particle Detector
A3.5 Micrometeoroid Detector
A3.6 Magnetometer
A3.7 Gravity Measurements

A1.1 LF RADAR

Objectives: (1.8) Crustal thickness, (3.2) Basin subsurface structure, (3.3) Basin ejecta, (3.4) Large crater structure, (3.5) Large crater ejecta, (3.6) Large crater fill, (3.7) Mare fill, (3.11) Uplands structure, (3.16) Mare structure, (3.19) Regolith erosion and turnover.

Measurable: Delay of radar pulse as a function of frequency; different frequencies reflect from different depths. The pulse reflects essentially when it encounters particles on the order of its wavelength. LF radar would presumably penetrate the regolith and be reflected from bedrock or the mantle.

Present Knowledge of Measurable: The Moon has been mapped with radar using the delay Doppler technique at 70 cm (Thompson and Dyce 1966) showing that uplands reflect 1-1/2 to 2 times as efficiently as maria, and that some (young) craters reflect up to 10 times as much as their environs. From radar measurements, these authors (and others they quote) determined the dielectric constant of lunar surface material and correctly predicted "a tenuous layer with a relative dielectric constant of 1.5 to 2.0 overlying a base layer with a dielectric constant of 5.0." At 23 cm, radar reflections have shown an average slope of 10° (Evans and Hagfors 1966). A detailed radar study of the floor of Tycho at 3.8 and 70 cm has shown it to be very rough (Pettengill and Thompson 1968).

Instrument Requirements:

Range: Low power ($\sim 10^{-12}$ of earth-based device).

Resolution: 100m for 3' beamwidth.*

Data Rate: ~1000 bps.

Orient. Req: Pointed at Moon. (Does not scan every point)

* In general = $\frac{\lambda h}{D}$, where λ = wavelength, h = altitude, D = detector aperture.

A1.1 LF RADAR (Cont'd)

Orbit Requirements:	Polar, circular, low altitude.
Candidate Instruments:	Standard LF Radar
Resulting Increased Knowledge of Measurable:	A detailed map of lunar subsurface topography and layering will result.
Resulting Increased Knowledge of Objectives:	This map will provide detailed information about the subsurface structure of each objective.

A1.2 RADAR IMAGER

Objectives: (3.11) Uplands structure, (3.28) Rille origin, (3.29) Grid system, (3.30) Volcanic structures.

Measurable: Delay of radar pulses. Rapid scan produces image. Different frequencies reflect from different depths.

Present Knowledge of Measurable: Same as LF Radar (A1.1).

Instrument Requirements:

- Range: Low power ($\sim 10^{-12}$ of earth-based radar).
- Resolution: 100m spatially for 3' beamwidth.*
- Data Rate: $\sim 10^5$ bps.
- Orient. Req: Pointed toward Moon.

Orbit Requirements: Polar, circular, low altitude.

Candidate Instruments: Standard Radar Imager

Resulting Increased Knowledge of Measurable: A radar-image map of the lunar subsurface, with 100m resolution, will result.

Resulting Increased Knowledge of Objectives: Subsurface structure of the objectives will result, revealing information about their nature and origin.

* See note for A1.1

A1.3 LASER RANGER

Objectives:	(1.7) Internal structure, (3.1) Mascons, (3.3) Basin ejecta, (3.4) Mare fill, (3.8) Central peaks, (3.11) Uplands subsurface structure, (3.16) Mare structure, (3.23) Density profile, (3.24) Internal composition, (3.28) Rille origin, (3.29) Grid system, (3.30) Volcanic structures, (3.34) Interior differentiation.
Measurable:	Time for pulsed laser beam to reflect from lunar surface, and return.
Present Knowledge of Measurable:	A pulsed laser beam (ruby, 6943 Å) has successfully been reflected and returned from the retro-reflector left on the Moon by the Apollo 11 astronauts. Measurements of the lunar distance can now be made $\pm$ 15 cm ($\pm$ 1 nsec of total travel time (Faller et al. 1969)).
Instrument Requirements:	
Range:	CW laser power needs to be only $\sim 10^{-12}$ of the earth-based laser (which emitted 7-8 joules per 60 nsec pulse every 3 sec).
Resolution:	$\pm$ 1 nsec in travel time ($\pm$ 15 cm in distance); spatially 100m for 3' beamwidth, 1m for 2" beamwidth.
Data Rate:	$\sim 4 \times 10^8$ bps
Orient. Req:	Pointed at Moon.
Orbit Requirements:	Polar, circular, low altitude.
Candidate Instruments:	Scanning laser, pulsing about once per µsec for about 60 nsec.

A1.3 LASER RANGER (Cont'd)

Resulting Increased Knowledge of Measurable:	Detailed topography (altitude vs. latitude, longitude) of Moon.
Resulting Increased Knowledge of Objectives:	The result would be a detailed topographic map, providing direct information regarding some lunar objectives (3.3, 3.4, 3.8, 3.16, 3.29) and indirect evidence regarding others (3.1, 3.11, 3.28, 3.30). The overall lunar figure would help determine interior parameters (1.7, 3.23, 3.24, 3.34), possibly including departure from normal isostasy.

A2.1 MICROWAVE RADIOMETER

Objectives: (1.1) Heat flow, (3.2) Basin subsurface structure, (3.3) Basin ejecta, (3.8) Central peak origin, (3.11) Uplands structure, (3.19) Regolith erosion and turnover, (3.25) Active sites, (3.27) Intrusives, (3.29) Grid system, (3.30) Volcanic structures, (3.32) Heat flow, (3.33) Surface thermal anomalies.

Measurable: Microwave radiation.

Present Knowledge of Measurable: Earth-based μ-wave measurements indicate a lunar temperature of

$$T \cong T_o + T_1 \cos (\alpha - \beta)$$

where α = lunar phase (0 = full moon), $\beta \cong 40°$, $T = 230°K$, $T_1 = 15°$ to $75°K$, depending on wavelength (Troitsky 1962). Measurements of specific lunar regions during eclipses (Reber and Stacey 1969) show that they cool at about 24°K hr^{-1}, after starting from a brightness temperature of 317°K to 350°K.

Instrument Requirements:

Range: $\geq$ 150°K effective temperature, 30μ - 30 cm.

Resolution: $\pm$ 5°K; 10 km spatial.

Data Rate: ~100 bps.

Orient. Req: Pointed at Moon, able to "watch" specific regions for ~3 minutes.

Orbit Requirements: Polar, circular, low altitude.

Candidate Inst: Standard microwave radiometer.

Resulting Increased Knowledge of Measurable:	The result will be a map of the Moon's temperature, at several μ-wave frequencies, with 10 km resolution, for all lunar phases and (possibly) an eclipse.
Resulting Increased Knowledge of Objectives:	A temperature map will indicate (3.33) surface thermal anomalies, such as (1.1 and 3.32) heat flow or (3.25) active sites. Thermal anomalies will also give clues regarding other objectives.

A2.2 IR RADIOMETER

Objectives: (1.1) Heat flow, (3.2) Basin subsurface structure, (3.3) Basin ejecta, (3.8) Central peaks, (3.11) Uplands subsurface structure, (3.19) Regolith erosion and turnover, (3.25) Active sites, (3.27) Intrusives (3.29) Grid system, (3.30) Volcanic structures, (3.32) Heat flow, (3.33) Surface thermal anomalies.

Measurable: Absolute IR flux.

Present Knowledge of Measurable: The Moon behaves roughly as a black body with daytime temperature ~430°K and nighttime temperature ~90°K. This corresponds to an emission of: by day, 0.2 w cm^{-2}, peak 6.7μ; by night, 3.8 x 10^{-4} w cm^{-2}, peak 32μ. Some features are 1-7° cooler, some are ~10° warmer. Eclipse data yield a very low thermal inertia ($\lesssim$ 0.1 that of Earth rock) (Mackin 1967, p. 52). During eclipses, "hot spots" persist long after the rest of the Moon has cooled (Shorthill and Saari 1965, Hunt et al. 1968, Allen and Ney 1969, Waldbaum 1969). Hayakawa et al. (1968) found the IR albedo to be greater than the visible.

Instrument Requirements:

Range: 0.01-10 w cm^{-2} at 6.7μ, 10^{-5} - 1 w cm^{-2} at 32μ.

Resolution: 10% in energy; 1-100m spatially.

Data Rate: ~ 4 x 10^7 bps

Orient. Req: Pointed toward Moon; capable of "watching" an interesting site for ~3 minutes.

Orbit Requirements: Polar, circular, low altitude.

Candidate Instruments: Standard IR Radiometer

A2.2 IR RADIOMETER (Cont'd)

Resulting Increased Knowledge of Measurable: The result will be an IR map of the Moon, for all parts of the surface, for all times of lunar day and night (also perhaps for an eclipse), to an accuracy of 10% in effective temperature, and of 100m in spatial resolution (1m in anomalous areas).

Resulting Increased Knowledge of Objectives: Surface thermal anomalies, (3.33) will be mapped. Cooling rates of hot spots will tell whether or not they represent heat flow (1.1), or active sites (3.25) such as volcanic structures (3.30). Maps of thermal inertia, and of thermal anomalies, will give clues regarding structure of lunar features (3.2, 3.3, 3.8, 3.11, 3.19, 3.27, 3.29).

A2.3 IR SPECTROMETER

Objectives: (1.4) Elements, (1.5) Chemicals, (1.6) Minerals, (3.3) Basin ejecta, (3.4) Mare fill, (3.6) Large crater ejecta, (3.7) Large crater fill, (3.8) Central peaks, (3.12) Uplands composition, (3.35) Horizontal differentiation.

Measurable: IR spectrum.

Present Knowledge of Measurable: Cruikshank (1969) reported lunar IR spectra from 0.8 to 2.1μ: "The craters Kepler and Aristarchus exhibit absorption bands suggestive of orthopyroxene, whereas the background mare material shows a band probably due to olivine." Van Tassel (1968) reported an earlier attempt.

Instrument Requirements:

- Range: 0.7-40μ.
- Resolution: 0.01μ (wavelength), 100m (spatial).
- Data Rate: $\sim 4 \times 10^6$ bps
- Orient. Req: Pointed toward Moon; capable of "watching" an interesting site for ~3 minutes.

Orbit Requirements: Polar, circular, low altitude.

Candidate Instruments: Standard IR Spectrometer

Resulting Increased Knowledge of Measurable: The result will be an IR map of the Moon, for all parts of the surface, to an accuracy of 0.01μ in energy resolution, and of 100m in spatial resolution.

A2.3 IR SPECTROMETER

Resulting Increased Knowledge of Objectives:	By correlating observed spectra with known spectra of lunar and terrestrial samples, various aspects of surface composition (1.4-1.6) can be determined for many types of areas (3.3, 3.4, 3.6, 3.7, 3.8, 3.12, 3.35).

A2.4 IR TO UV IMAGER

Objectives:	(3.3) Basin ejecta, (3.4) Mare fill, (3.6) Large crater ejecta, (3.8) Central peaks, (3.11) Uplands subsurface structure, (3.12) Uplands composition, (3.14) Mare emplacement mode, (3.17) Mare composition, (3.21) Sources of gas, (3.22) Particle motions, (3.25) Active sites, (3.33) Surface thermal anomalies, (3.35) Horizontal differentiation.
Measurable:	IR and UV images.
Present Knowledge of Measurable:	Visual photography, from Earth (resolution 1 km), Ranger (10 cm isolated regions), Lunar Orbiter (5m whole Moon) and Apollo (1m isolated regions), is quite detailed. The best IR images are by Shorthill and Saari (1965) and Hunt et al. (1968) ($\sim$15 km). Whitaker has contrasted UV and red photos to map subtle details such as lava flows and rays (Kuiper 1965).
Instrument Requirements:	
Range:	0.1-0.4μ and 0.7-30μ.
Resolution:	1 meter (spatial).
Data Rate:	$\sim 4 \times 10^9$ bps
Orient. Req:	Pointed at Moon, able to find specific targets of interest.
Orbit Requirements:	Polar, circular, low altitude.
Candidate Instruments:	U. of Michigan scanning.

A2.4 IR TO UV IMAGER

Resulting Increased Knowledge of Measurable:	IR and UV image maps of the Moon will result, for all parts of the surface, for all times of lunar day, to a spatial resolution of 1m.
Resulting Increased Knowledge of Objectives:	Active sites (3.25) and other surface thermal anomalies (3.33) will be detected and accurately located on IR images. Composition of various types of regions will be easier to determine, by comparison of IR and UV images with known terrestrial ones (3.3, 3.4, 3.6, 3.8, 3.11, 3.12, 3.14, 3.17, 3.21, 3.22, 3.35).

A2.5 METRIC CAMERA (2m)

Objectives: (1.7) Internal structure, (3.1) Mascons, (3.3) Basin ejecta, (3.4) Mare fill, (3.8) Central peaks, (3.11) Uplands structure, (3.16) Structure of maria, (3.23) Internal density profile, (3.24) Internal composition, (3.28) Rille origin, (3.29) Grid system, (3.30) Volcanic structure, (3.34) Internal differentiation.

Measurable: Photography with a metric camera, i.e., a camera highly corrected for distortion so as to record a geometrically accurate image (resulting in some loss of resolution).

Present Knowledge of Measurable: No metric photography has been taken of the Moon from lunar orbit.

Instrument Requirements:

Range:

Resolution: 2m.

Data Rate: $\sim 10^8$ bps

Orient. Req: Able to point at any interesting regions within sight of the spacecraft, particularly the horizon.

Orbit Requirements: Polar, circular, low altitude.

Candidate Instruments: Metric camera

Resulting Increased Knowledge of Measurable: The lunar surface, and shape of the selenoid, will be mapped with good geometrical accuracy.

A2.5 METRIC CAMERA (Cont'd)

Resulting Increased Knowledge of Objectives: Accurate measurements of the selenoid will yield information regarding the Moon's interior (1.7, 3.23, 3.24, 3.34). Metric measurements of surface features (3.1, 3.3, 3.4, 3.8, 3.11, 3.16, 3.28, 3.29, 3.30) will help explain their origin and structure.

A2.6 HIGH-RESOLUTION "PANORAMIC" CAMERA (1/2 m)

Objectives:	(1.9) Crater retention ages, (1.10) Solidification age, (3.2) Basin structure, (3.3) Basin ejecta, (3.5) Large crater structure, (3.9) Craterlet subsurface structure, (3.10) Craterlet ejecta, (3.11) Uplands structure, (3.19) Regolith erosion and turnover, (3.25) Active sites, (3.28) Rille origin, (3.30) Volcanic structures, (3.32) Heat flow, (3.33) Surface thermal anomalies, (3.35) Horizontal differentiation.
Measurable:	High-resolution photography, regular and stereo.
Present Knowledge of Measurable:	The Moon's near side has been photographed from Earth (1 km resolution), by Ranger (10 cm very isolated regions), Lunar Orbiter (5m most of Moon, including most of far side), and Apollo (1m isolated regions).
Instrument Requirements:	
Range:	
Resolution:	1/2 m.
Data Rate:	$\sim 1.6 \times 10^9$ bps
Orient. Req:	Able to point at any interesting regions within sight of the spacecraft.
Orbit Requirements:	Polar, circular, low altitude.
Candidate Instruments:	Panoramic camera
Resulting Increased Knowledge of Measurable:	The result should be a photographic map of the entire Moon to 1/2 m resolution.

Resulting Increased Knowledge of Objectives: More detailed photographs of these surface features will produce a better understanding of their nature and origin, and, more important, provide base maps and specific site objectives for surface studies.

A2.7 VISUAL-UV SPECTROMETER

Objectives:	(1.4) Elements, (1.5) Chemicals, (1.6) Minerals, (3.3) Basin ejecta, (3.4) Mare fill, (3.6) Large crater ejecta, (3.7) Large crater fill, (3.8) Central peaks, (3.12) Uplands composition, (3.20) Atmospheric Composition, (3.35) Horizontal differentiation.
Measurable:	UV and visible spectra.
Present Knowledge of Measurable:	Although Apollo astronauts see very little color on the Moon, faint coloring does exist, e.g. Mare Tranquillitatis is bluish, Oceanus Procellarum is reddish, Wood's Region near Aristarchus is quite reddish, etc. UBV photos have been taken (Baldwin 1963, pp. 256-58). There may be some correlation with solar activity. Whitaker has had considerable success in mapping subtle features by contrasting red and UV images (Kuiper 1965).
Instrument Requirements:	
Range:	100-7000 Å.
Resolution:	1% (wavelength), 100m (spatial).
Data Rate:	$\sim 10^7$ bps
Orient. Req:	Pointed toward Moon, able to "watch" an interesting region for 3 minutes.
Orbit Requirements:	Polar, circular, low altitude.
Candidate Instruments:	Spectroscope, plus film or hodoscope of photodiodes.
Resulting Increased Knowledge of Measurable:	The result will be a UV-visible spectroscopic map of the Moon, for all parts of the surface, for all times of lunar day and night (possibly including an eclipse), to an accuracy of 1% in wavelength, and of 100m in spatial resolution.

A2.7 VISUAL-UV SPECTROMETER (Cont'd)

Resulting Increased Knowledge of Objectives: Spectroscopic observations of absorption (and fluorescent emission?) lines will yield information regarding composition (1.4, 1.5, 1.6) of interesting regions (3.3, 3.4, 3.6, 3.7, 3.8, 3.12) and a possible atmosphere (3.20). Resulting information about horizontal differentiation (3.35) may clarify the observed color differences within maria.

A2.8 LYMAN-ALPHA TELESCOPE

Objectives:	(3.20) Atmospheric composition, (3.21) Sources of gas, (3.22) Particle motions.
Measurable:	Lyman-α radiation.
Present Knowledge of Measurable:	Lyman-α radiation (1216 Å, UV) results when an electron in a hydrogen atom falls from the L shell to the K shell. Its presence is a sure sign of hydrogen. There has been no search for far-UV radiation from the Moon.
Instrument Requirements:	
Range:	$\lambda \cong 1216$ Å; 10^{-5} to 1 w cm^{-2}.
Resolution:	10% in flux density; 100m spatially.
Data Rate:	0-10^5 bps.
Orient. Req:	Pointed toward Moon; capable of "watching" an interesting site for ~3 minutes.
Orbit Requirements:	Polar, circular, low altitude.
Candidate Instruments:	Lyman-alpha telescope
Resulting Increased Knowledge of Measurable:	The result will be a Lyman-α map of the Moon, for all parts of the surface, for all times of lunar day and night (also perhaps for an eclipse), to an accuracy of 10% in flux density, and 100m in spatial resolution. Most or all lunar regions will probably yield only an upper limit.

A2.8 LYMAN-ALPHA TELESCOPE (Cont'd)

Resulting Increased Knowledge of Objectives: If Lyman-α is detected, it will probably represent the hydrogen gas component of lunar atmospheric composition (3.20). The map will indicate sources (3.21) and paths of motion (3.22) of this gas.

A2.9 FLUORESCENCE X-RAY DETECTOR

Objectives: (1.4) Elements, (3.3) Basin ejecta, (3.4) Mare fill, (3.6) Large crater ejecta, (3.7) Large crater fill, (3.8) Central peaks, (3.12) Uplands composition, (3.17) Maria composition, (3.35) Surface horizontal differentiation.

Measurable: X-rays from Moon.

Present Knowledge of Measurable: Loh and Garmire (1969) have estimated that the solar wind will produce fluorescence X-ray lines, the strongest being from oxygen at 23.62 Å, with a flux of 1.38×10^{-10} ergs cm^{-2} s^{-1} (0.087 kev cm^{-2} s^{-1}). This is much weaker than could be detected at Earth.

Instrument Requirements:

Range: 0.01-100 cm^{-2} s^{-1}, 0.1-10 kev.

Resolution: 10% in energy, 100m spatially.

Data Rate: ~1000 bps, compressible (limited by count rate)

Orient. Req: Should rotate ~1 rpm about an axis ∥ lunar surface and ⊥ Moon-Sun line, to scan both sub-spacecraft point and specular solar reflection point.

Orbit Requirements: Polar, circular, low altitude.

Candidate Instruments: Proportional counter, Li-drifted Ge detector, X-ray image telescope, Bragg crystal spectrometer.

Resulting Increased Knowledge of Measurable: The magnitude and energy spectrum of the X-ray flux from the Moon will be determined, for all parts of the lunar surface, for all Sun angles.

A2.9 FLUORESCENCE X-RAY DETECTOR (Cont'd)

Resulting Increased Knowledge of Objectives: Any element between $Z \cong 4$ (Be) and $Z \cong 30$ (Zn) should be detected if it comprises more than 5% of the surface material. The resulting map will provide information on the other objectives.

A2.10 γ-RAY SPECTROMETER

Objectives: (1.3) Isotopes, (3.3) Basin ejecta, (3.4) Mare fill, (3.6) Large crater ejecta, (3.7) Large crater fill, (3.8) Central peaks, (3.12) Uplands composition, (3.35) Horizontal differentiation.

Measurable: γ-rays from Moon.

Present Knowledge of Measurable: The Russian orbiting spacecraft Luna 10 has made the only γ-ray observation to date. It found that the total intensity at the lunar surface is "1.5-2.0 times higher than over terrestrial rocks of the granite type," but that at least 90% of these are due to cosmic rays; less than 10% comes from the natural radioactivity of K, U, and Th, meaning that, in this respect, lunar rocks correspond to terrestrial basalts (Vinogradov et al. 1966). The radioactivity of granite is $r \cong 6 \times 10^6$ cal y^{-1} g^{-1} (Howell 1959, p. 57) or $r \cong 5$ Mev s^{-1} g^{-1}, mostly from ^{40}K (1.33 or 1.63 Mev), ^{238}U (4.25 Mev), and ^{232}Th (4.05 Mev) (Jacobs et al. 1959, pp. 109-10); this corresponds to a surface emission rate of

$$f \cong \frac{1}{6} rx = \frac{1}{6} (5 \text{ Mev } s^{-1} g^{-1}) (2 \text{ g } cm^{-2})$$

$$\cong 2 \text{ Mev } cm^{-2} s^{-1},$$

where x is the radiation length for these γ-rays in granite ($\overline{Z} \cong 13$). Thus the total rate from the lunar surface is 3-4 Mev cm^{-2} s^{-1}, with $\overline{E} \sim 4$ Mev. This is consistent with Apollo 11 samples (LSPET 1969).

Cosmic rays interact with nuclei in the lunar surface material, to produce characteristic γ-rays; lines corresponding to O, Mg, Al and Si were observed by Luna 10 (COSPAR Transactions No. 5, 1968, p.204).

Instrument Requirements:	
Range:	0.01-100 cm^{-2} s^{-1}, 0.1-10 Mev.
Resolution:	10% in energy; 100 m spatial
Data Rate:	~100 bps (limited by count rate)
Orient. Req:	Should rotate ~1 rpm about an axis ∥ lunar surface and ⊥ Moon-Sun line, to scan both sub-spacecraft point and specular solar reflection point.
Orbit Requirements:	Polar, circular, low altitude.
Candidate Instruments:	NaI(Tl) detector, Li-drifted Ge detector.
Resulting Increased Knowledge of Measurable:	The magnitude and energy spectrum of the γ-ray flux from the Moon will be determined, for all parts of the lunar surface, for all Sun angles.
Resulting Increased Knowledge of Objectives:	(1.3) Isotopes: radioactive isotopes, such as K, U, Th, etc., should be detected if their concentration exceeds 2 x 10^{-7} g g^{-1}; an isotope map of the Moon (resolution ~10 km) will result. Cosmic-ray induced radioactivity from isotopes of other elements (e.g. O, Mg, Al, and Si) should also be detected. The resulting isotope map will give information on the other objectives.

A3.1 PLASMA PROBE

Objective:	(3.38) Sun-Moon field interaction.
Measurable:	Plasma in vicinity of Moon.
Present Knowledge of Measurable:	The solar wind directly hits the sunlit side of the Moon (no magnetosphere); a solar wind "shadow" with umbra and penumbra, is created on the dark side (Ness et al. 1967, Lyon et al. 1967). The composition at the lunar surface is essentially the same as in interplanetary space (Buhler et al. 1969).
Instrument Requirements:	
Range:	10^5-10^{11} cm^{-2} s^{-1} sr^{-1} kev^{-1} Electrons: 3 ev-300 ev. Protons: 120 ev-5 kev.
Resolution:	$\pm$ 2% flux and energy.
Data Rate:	$\sim 10^6$ bps, compressible.
Orient. Req:	Toward direction from which solar wind comes $\cong$ toward Sun. Also toward Moon to measure albedo.
Orbit Requirements:	Highly elliptical, low periapse.
Candidate Measurements:	Faraday cup and electrostatic analyzer (Lyon et al. 1967); Pioneer F/G - type detector (J. H. Wolfe et al., Ames Research Center).
Resulting Increased Knowledge of Measurable:	More detailed mapping of the Explorer 35 type.
Resulting Increased Knowledge of Objectives:	More detailed theoretical understanding of the interaction between the solar wind and the (non-magnetized) Moon.

A3.2 CHARGED PARTICLE DETECTOR

Objectives: (1.3) Isotopes, (3.38) Sun-Moon field interaction.

Measurable: Charged particles associated with the Moon, such as trapped radiation, albedo, or radioactive byproducts.

Present Knowledge of Measurable: Explorer 35 yielded no evidence for trapped radiation (Ness et al. 1967, Ness 1969). It also placed an upper limit on radon in the lunar atmosphere, which in turn implied an upper limit on alpha particle emissivity of 0.128 cm^{-2} s^{-1} str^{-1}. This indicates, as do the gamma-ray results, that the amount of ^{238}U in the regolith is much less than that in granite, though consistent with that in basalt (Yeh and Van Allen 1969).

Instrument Requirements:

Range: 1 ev-500 Mev, $0\text{-}10^3$ cm^{-2} s^{-1}.

Resolution: $\pm$ 10% energy and flux.

Data Rate: 10^4 bps, compressible.

Orient. Req: All directions, especially toward Moon.

Orbit Requirements: Polar, circular, low altitude.

Candidate Instruments: Totally depleted gold-silicon barrier detector (for alphas); Geiger tubes, solid state telescopes, etc. for electrons and protons.

Resulting Increased Knowledge of Measurable: A more detailed search will be made for any trace of charged particles associated with the Moon.

A3.2 CHARGED PARTICLE DETECTOR

Resulting Increased Knowledge of Objectives: More detailed knowledge will result concerning charged particles associated with the Moon (3.38). Also, detection of lunar endogenic alpha-particles would yield a map of the concentration of ^{238}U (1.3). Search will be conducted for lunar ionosphere and Rn gas emission.

A3.3 COSMIC RAY DETECTOR

Objective:	(3.38) Sun-Moon field interaction.
Measurable:	High-energy particles in vicinity of Moon.
Present Knowledge of Measurable:	The Moon has no detectable magnetosphere; therefore, one would not expect trapped high-energy particles (Ness et al. 1967). The only high-energy particles expected are the normal extra-solar cosmic rays.
Instrument Requirements:	
Range:	0.05-50 Mev (electrons), 0.3-500 Mev (protons), $1\text{-}10^{10}$ cm^{-2} s^{-1}
Resolution:	$\pm$ 10% energy and flux.
Data Rate:	$\sim 10^6$ bps, compressible.
Orient. Req:	All directions, especially parallel to magnetic field.
Orbit Requirements:	Highly elliptical, low periapse.
Candidate Instruments:	There are many proven cosmic ray detectors, e.g. Lepedea, Geiger tube telescopes, solid state telescopes, Cerenkov detectors, etc. A typical assortment is scheduled for Pioneer F/G.
Resulting Increased Knowledge of Measurable:	A more detailed search will be made for any trace of lunar trapped radiation.
Resulting Increased Knowledge of Objectives:	Same.

A3.4 NEUTRAL PARTICLE DETECTOR

Objective:	(3.38) Sun-Moon field interaction.
Measurable:	Neutral particles in lunar environment.
Present Knowledge of Measurable:	There is no evidence for neutral particles in the lunar environment. The most likely candidate is solar neutrons, or neutron albedo from Moon; or else a tenuous, probably transient, lunar atmosphere.
Instrument Requirements:	
Range:	0-1 cm^{-2} s^{-1}, 0-10 kev
Resolution:	10% energy and flux.
Data Rate:	~100 bps, compressible
Orient. Req:	Toward Sun to search for primary neutrons; also toward Moon to search for albedo. All directions for atmosphere.
Orbit Requirements:	Polar, circular, low altitude.
Candidate Instruments:	BF_3 counter (neutrons), mass spectrometer (atmosphere).
Resulting Increased Knowledge of Measurable:	More details will result on the possibility of neutrons in the lunar environment, and on the possibility of a lunar atmosphere.
Resulting Increased Knowledge of Objective:	Same

A3.5 MICROMETEOROID DETECTOR

Objective: (3.19) Regolith erosion and turnover.

Measurable: Micrometeoroids in vicinity of Moon. Also perhaps ejecta from meteorites.

Present Knowledge of Measurable: The micrometeoroid flux near the Earth is of the order of 10^{-7} to 10^{-4} m^{-2} s^{-1} str^{-1}, for particles of mass $\gtrsim 10^{-9}$g (Nilsson et al. 1969).

Instrument Requirements:

- **Range:** Mass $\gtrsim 10^{-9}$ g, size $\geq 50\mu$, velocity 10 m s^{-1} to 100 km s^{-1}, flux 10^{-7} to 10^{-4} m^{-2} s^{-1} str^{-1}.
- **Resolution:** 10% in everything.
- **Data Rates:** $\lesssim 100$ bits per day.
- **Orient. Req:** Pointed away from Moon's surface, particularly in Moon's direction of motion.

Orbit Requirements: No special requirements.

Candidate Instruments: Puncture cans, piezoelectric microphones, capacitor detectors, light transmission detectors, etc. (Corliss 1967, p. 534). "Sisyphus" instrument chosen for Pioneer F/G (Grenda et al. 1969).

Resulting Increased Knowledge of Measurable: More detailed knowledge regarding the micrometeoroid environment of the Moon.

Resulting Increased Knowledge of Objective: More detailed knowledge concerning the role micrometeoroids play in regolith erosion and turnover. Possibly clues to tektite origin.

A3.6 MAGNETOMETER

Objectives: (1.2) Deep isotherms, (1.7) Internal structure, (3.1) Mascons, (3.24) Internal composition, (3.31) Internal temperatures, (3.34) Deep interior differentiation, (3.36) Present lunar field, (3.38) Interplanetary field and particle interaction.

Measurable: Moon's magnetic field.

Present Knowledge of Measurable: There is no magnetic field $>0.1\gamma$ at 800 km altitude in the Earth's equatorial plane. Lunar magnetic moment $< 4 \times 10^{20}$ gauss cm^3 (= 10^{-5} of Earth). There is no capture of interplanetary field (electrical conductivity = $\sigma < 10^{-5}$ mho/m) (Ness et al. 1967, Explorer 35 results). At Apollo 12 site, B = 30γ (Aviation Week 12/1/69, p. 21), higher than expected.

Instrument Requirements:

Range: $0.01\text{-}100\gamma$

Resolution: 0.5% or 0.01γ, whichever is greater.

Date Rate: ~15 bps

Orient. Req: 3-axis instrument; no preferred orientation.

Orbit Requirements: Polar, circular, low altitude.

Candidate Instruments: Vector He, fluxgate, or Rb vapor magnetometer.

Resulting Increased Knowledge of Measurable: Any overall lunar magnetic moment $> 10^{18}$ gauss cm^3 will be detected. Anomalous surface magnetic moments $> 10^{15}$ gauss cm^3 will be detected; since the magnetization of iron is 1700 (gauss cm^3) cm^{-3} (Condon and Odishaw 1958, p. 4-134), this is equivalent to a cube of ferromagnetic iron, 100 meters on a side, lying on the lunar surface.

Resulting Increased Knowledge of Objectives:

The present lunar field (3.36) will be measured in more detail, providing direct information about the interplanetary field and particle interaction (3.38).

The Moon's electrical conductivity σ may be determined by measuring the characteristic time τ for interplanetary field lines to diffuse out:

$$\tau = 4\pi \ \mu \ \sigma \ L^2$$

(Cowling 1957, p. 5); μ = magnetic permeability, L = lunar diameter. If $\sigma = \tau = 0$, the field lines pass through the Moon and are unaffected by it. If $\tau \neq 0$, the lines are distorted near the lunar surface by an angle θ, given by $\tan \theta \sim v\tau/L$; $\tau \sim (L/v) \tan \theta = (1 \text{ hr}) \tan \theta$, where v is the Moon's orbital speed. From Explorer 35, we know only that

$$\tan \theta \lesssim 5.$$

If, from an orbital measurement, we can infer θ (surface) to within 5°, we can measure (or place an upper limit on) σ to within $\pm$ 3 x 10^{-7} mho m^{-1}.

Given σ, one can place limits on the temperature T; the upper limit is presently 900°C from magnetometry (Gilvarry 1969, Ness 1969). More detailed knowledge of σ will provide more detailed knowledge of (3.31) internal temperature and (1.2) deep isotherms, which in turn will provide information regarding other properties of the interior (1.7, 3.24, 3.34).

Magnetic anomalies will be studied for possible relationship to mascons (3.1) and other surface and near-surface phenomena.

A3.7 GRAVITY MEASUREMENTS

Objectives: (1.7) Internal structure, (3.1) Mascons, (3.23) Detailed density profile, (3.24) Internal composition, (3.34) Internal differentiation.

Measurable: Gravitational field.

Present Knowledge of Measurable: The model of the Moon's field used to discover the mascons was a triaxial one (Muller and Sjogren 1968), i.e., that of an ellipsoid with 3 unequal axes; this is equivalent to adding, to the monopole term, only the quadrupole or second harmonic term in the spherical harmonic series (Roy 1968, p. 86; Baldwin 1963, Chapter 10, "The Problem of the Moon's Motion and Shape"). The known values of further terms in the series are summarized by Kaula (1969). Apollo 12 found small mascons under Ptolemaeus and Albategnius (M. Molloy, private communication).

Instrument Requirements: The mascons were discovered by analyzing the Doppler shift of Lunar Orbiter signals, i.e., the velocity component along the Earth-Moon line. More accurate data would result from the knowledge (with time) of the spacecraft's total velocity (vector), and absolute position in space, on both sides of the Moon. This should be done with laser ranging and photographs. It could also be done with a gravity-gradient satellite.

Kaula (1969) points out:

> "The problem of how to use the lunar satellite most effectively to determine the gravitational field on the back side of the Moon must be regarded as still unsolved. Possible solutions are: (i) a greater variety of orbital inclinations, (ii) a satellite - to satellite tracking system, (iii) satellite-borne laser altimetry, or (iv) satellite-borne measurements (sic) of gravity gradients."

Orbit Requirements: Polar, circular, low altitude.

Resulting Increased Knowledge of Measurable: A more detailed determination of spherical harmonic coefficients, and a more detailed map of lunar gravitational anomalies, will result.

Resulting Increased Knowledge of Objectives: Knowledge of the spherical harmonics will contribute to a further understanding of the Moon's interior (1.7, 3.23, 3.24, 3.34). Gravitational anomalies, including large, positive anomalies (mascons (3.1)), will be mapped in more detail.

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