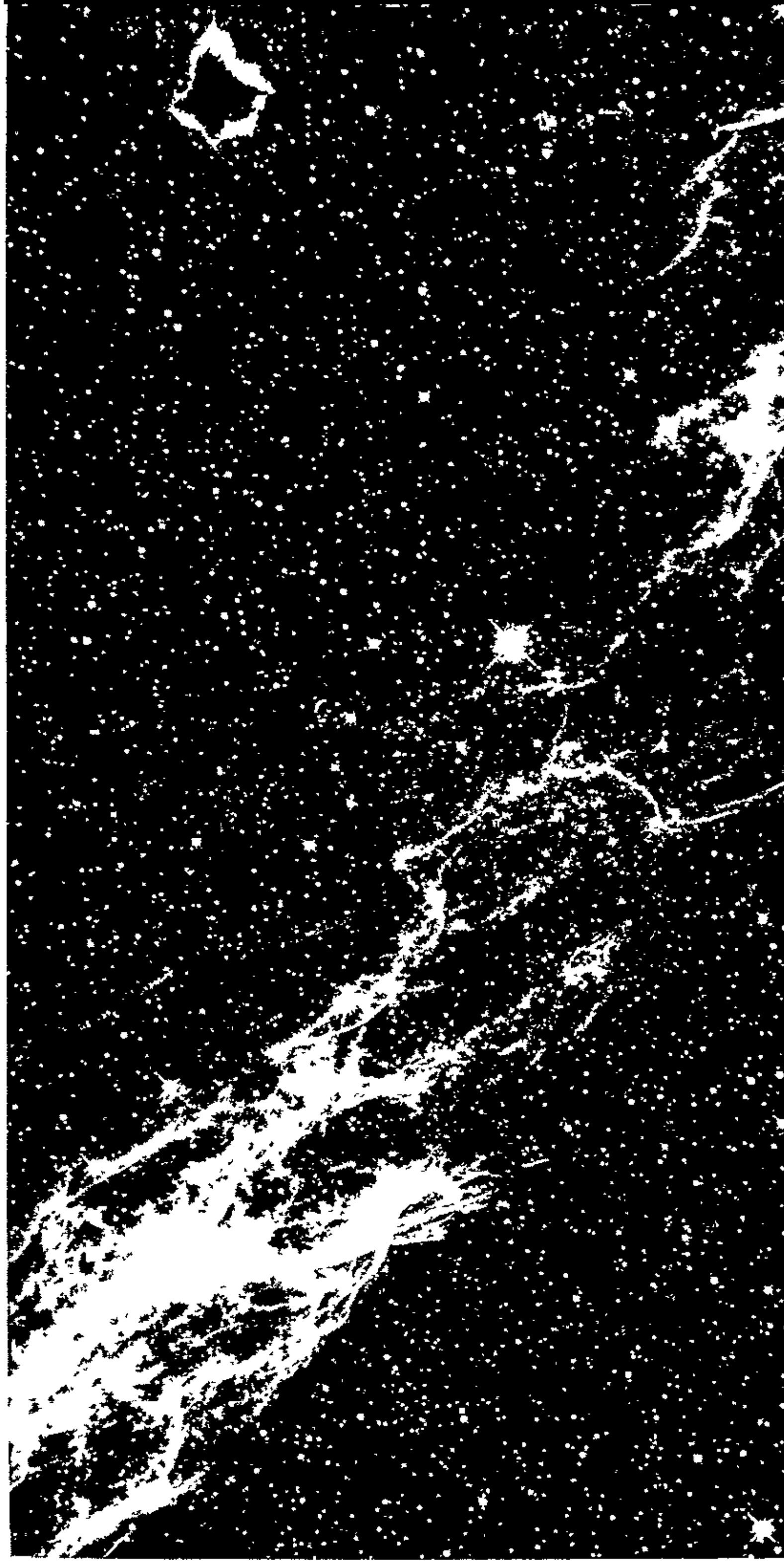
ASC

ASTRO
SCIENCES
CENTER

#70-01145



N70-28754 (ACCESSION NUMBER)
61 (PAGES)
CR-110260 (NASA CR OR TMX OR AD NUMBER)
1 (THRU)
(CODE)
30 (CATEGORY)
FACILITY FORM 602

Report No. P-31

LUNAR SURFACE SCIENTIFIC EXPERIMENTS AND EMPLACED STATION SCIENCE

RECEIVED MAY 1970

IIT RESEARCH INSTITUTE
10 West 35 Street
Chicago, Illinois 60616

DISTRIBUTION A

NASA HDQ.

R. Allenby, MAL
D. Beattie, MAL
A. Crobaugh, PT
S. Dimaggio, MAR
J. Hanley, MAL
R. Kraemer, SL
M. Mitz, SL
M. W. Molloy, MAL
W. O'Bryant, MAL
L. Scherer, MAL
N. Sirri, SL
A. Strickland, MAL
R. Toms, MAL
B. Milwitzky, MA

NASA HDQ. Via MAL

R. Petrone, MA
H. Smith, SS
W. Stoney, MA
W. Von Braun, AAD

MSFC

J. Downey
W. Huber, BN4
R. Spencer, PD-MP-P
E. Stuhlinger, AD-S

MSC

A. Calio, TA
D. E. Fielder, FA
J. Harris, TA
J. D. Hodge, HA
B. G. Jackson, TE
R. Johnson
J. P. Loftus, PS4
A. J. Meyer, HA
A. P. Sanders, TB
G. Simmons
R. Wilmarth

MAD/AMES

P. Swan

JPL

R. G. Brereton, 111-100
J. D. Burke, 111-122
F. H. Felberg, 180-901
P. H. Haurlan 111-100
R. Mackin, 183-301
D. Nash, 183-501
H. J. Stewart, 111-100

BELLCOMM

Noel Hinners
D. B. James

LPMB LUNAR PANEL MEMBERS

Astro Sciences/IITRI

Contract No. NASW 1861
Dr. M. W. Molloy

DISTRIBUTION B

NASA HDQ.

E. Davin, MAL

B. Doe, MAL

R. Green, MAL

L. Pomeroy, MAL

D. Senich, MAL

W. Shirey, MAL

MSFC

J. A. Belew, PM-SAT-LRV

J. Brewer

W. Powers

W. Wales, S&E-ME-VJ

MSC

P. Gast

J. Sasser, TH3

BELLCOMM

Farouk El-Baz

James Head

GLEP MEMBERS

Via MAL

USGS

H. Masursky

A. Chidester

Report No. P-31

LUNAR SURFACE SCIENTIFIC EXPERIMENTS AND EMPLACED STATION SCIENCE

by

W. K. Hartmann

of

Astro Sciences
IIT Research Institute
Chicago, Illinois

for

National Aeronautics and Space Administration
Washington, D. C.

Contract No. NASW 1861

APPROVED BY:

D L Roberts

D. L. Roberts, Manager
Astro Sciences

March 9, 1970

SUMMARY

The report is intended to summarize the relation of emplaced science stations (of the ALSEP type) to the total conglomerate of lunar science in the late Apollo and post-Apollo periods. Section 1 describes the purpose, background, and viewpoint of the report. Section 2 describes how we drew up a comprehensive list of scientific objectives and measurement techniques from which to draw the experiments and fit them to the various landing sites. Section 3 discusses the different phases of lunar exploration and the specific type-sites and experiments to be considered for each. Emphasis is on Apollo and the immediate post-Apollo period, though orbital and permanent surface base operations are considered.

Section 4 contains the crux of the report: the experiments, the sites, and the rationale of lunar research are established and the surface science experiments are selected. Section 4 also describes criteria to be used in selecting experiments for specific missions and then lists the experiments site by site. Lists are then given ranking the experiments by "importance" first for Apollo, (Table S1) and then for post-Apollo (Table S2) missions. Finally, the emplaced station experiments are ranked by importance as shown in Table S3.

Section 5 considers the possible needs for remote unmanned landers, unmanned and manned rovers, and flying units. Manned rovers and flying units are found most useful. The overall conclusions and recommendations are as follows:

1. Flexibility is of crucial importance in planning, especially in the Apollo phase. Early experimental results must impact on and modify later experiments. Sufficient time must be allowed between flights to absorb the significance of results; the delay of Apollo 13 is a proper step.

2. Separate Apollo missions and their landing sites conceptually from post-Apollo missions and their sites. Do not attempt to force the Apollo astronauts to perform field studies of geologically complex sites before the range of basic lunar parameters has been defined. Early Apollo sites should be the clearest possible examples of uncontaminated lunar structures.

3. Present single-frame photography on Apollo missions should be replaced with stereo photography, even at the cost of reducing the total number of scences. Variable baselines (lens separations) should be used, so that distant scenery can be scaled and interpreted in stereo. Absence of distance-indicating haze on the moon makes stereo photography essential in indicating distance. For distant (a mile or so) details such as ridges, separations on the order of hundreds of yards are needed, implying two shots with the same camera from different positions, rather than an ordinary stereo camera.

4. The ratio of instrument deployment time to simple observation time (photography, visual observing, sample collection) should decrease as more complex sites are visited late in Apollo.

5. It is crucial to obtain the maximum possible lifetime of emplaced instruments. This is the cheapest way to increase lunar data. An example comes from seismometers: three must be operating simultaneously to get a "fix" on any seismic event. With only two landings a year, a minimum lifetime of 1½ years is needed to get any overlap at all.

6. 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.

7. In the mid 70's, studies should begin to review which non-lunar (astronomical, physical, biological, etc.) experiments should be performed on the lunar surface and which in earth orbit or lunar orbit.

8. Site selection for a permanent base or bases should be deferred to the late 70's to utilize experience with lunar science gained by post-Apollo exploration.

9. There is an apparent need for lunar reconnaissance which can utilize a long range automated rover. We are not convinced that the contribution that an automated rover adds over orbital missions is worth its development.

10. Experiments in Apollo and early post-Apollo programs should emphasize Moon-directed science in preference to experiments in areas such as space science, interplanetary particles and fields, observations of other planets, astronomy, pure physics, etc. In brief, non-lunar experiments should not be hauled all the way to the Moon unless there is a compelling reason.

11. Emplaced stations will be required on all Apollo missions but will not be required on all post-Apollo missions.

12. No need is found for unmanned landers (Surveyor-type vehicles) during Apollo or post-Apollo exploration <u>if manned-landings are continued</u>.

13. Flying units with total vertical range of 25,000 ft. are needed for observing and deploying emplaced stations.

14. Further mission planning should be based on "repeated iteration" with feedback among scientific objectives, landing sites, vehicle constraints, and experiment choices; rather than by fixing one group of parameters before proceeding to the next.

TABLE S1: APOLLO LUNAR SURFACE SCIENCE EXPERIMENTS IN ORDER OF IMPORTANCE

Experiment	No. sites
Sample collection equipment	17
Cameras (stereo better than non-stereo)	17
Passive seismometer	17
Core-sampling drill (to 3 meters)	17
Active seismometer	12
Close-up stereo camera	10
Hand corer	9
Heat flow probes	9
Soil characteristics	9
Gravity meter	5
Strain gauge	4
Penetrometer	4
Solar wind degradation and bleaching monitor	3
Fluorescence detector	3
Search for organics with detector on surface	2
Survival of micro-organisms	2
Surface dust transport and small scale mass wasting	2
Temperature-density probe	2
Thermally isolated disks	2
LM ascent plume effects	2
Meteoroid environment detector	2
Meteorite impact detector	2
Magnetometer	2
Biomedical tests	2
Hazard due to soil ejecta	2
Retro-reflector	2
Locomotor activity	1
Lunar navigation system	1
Radiation environment	1
Earth-shine photometer	1
Backside communications & long distance surface comm.	1
Star-rise and -set effects	1
Lunar sky brightness	1
Synthesis of food from wastes	1

Note: This table is based on the combined IITRI and Letters-of-Intent List - (see p. 8)

TABLE S2: POST-APOLLO LUNAR SURFACE SCIENCE EXPERIMENTS IN ORDER OF IMPORTANCE

Experiment	No. man-hours at sites	No. Sites
Sample collection equipment	739	55
Cameras (stereo better than non-stereo)	648	54
Active seismometer	702	36
Gravity traverse	685	31
Close-up stereo (Gold) camera	545	40
Drill (100-300m)	465	39
Observing and mapping traverse	223	16
Trenching for stratigraphic study	194	24
Passive seismometry	193	19
Drill (1-5km)	296	6
Drill (3-20m)	148	11
Tiltmeter	131	13
Stain gauge	115	9
Magnetometer traverse	182	5
Heat flow	89	10
Gas analysis	40	10
Total gas pressure gauge	33	7
Mass transport measurement	20	8
Hand corer	48	2
Meteoroid environment detector	21	7
Neutron-gamma traverse	22	3
Gas detector	9	2
Thermal probe	7	3
Visual & IR spectrometer	3	1

TABLE S3: AUTOMATED EMPLACED EXPERIMENTS LISTED BY IMPORTANCE

Experiment	Recommended No. Sites Apollo	Post-Apollo
* Passive seismometer	10	21
* Tiltmeter		13
Heat flow	8	8
* Strain gauge	4	8
* Meteoroid environment (mass dependence)	2	7
* Gas analysis		7
* Total gas pressure		7
* Surface dust transport & mass wasting	2	6
* Solar wind degradation & bleaching	3	1
Thermal probe		3
* Gas detector		3
Retro-reflector	2	
* Survival of micro-organisms	2	
LM ascent plume effects	2	
* Magnetometer	2	
* Meteorite impact detector	2	
Thermally isolated disks	2	
Hazard due to soil ejecta	1	

* Indicates experiments where long operating lifetime (~ 2 years) is critically important either because of necessary integration time or infrequency of events monitored by instrument.

TABLE OF CONTENTS

LIST OF TABLES

LUNAR SURFACE SCIENTIFIC EXPERIMENTS AND EMPLACED STATION SCIENCE

1. INTRODUCTION

The purpose of this report is to summarize the relation of emplaced science to the total conglomerate of lunar science in the late Apollo and post-Apollo periods. Emplaced science is defined as that either left behind after astronauts have left the moon or deposited by unmanned spacecraft to function in an automatic mode.

To describe the role of emplaced science we find it necessary to review the overall pattern of lunar research and then pick that part which can profitably be used in an automated mode, rather than randomly discussing the various instruments that could be designed for ALSEP-like packages. Emplaced science can be approached rationally only in the context of total lunar exploration. Such a systematic approach to lunar exploration is presented in an accompanying IITRI document[1] from which we will draw freely.

In that document we have outlined an exploration program which if followed would yield a step-by-step increase in lunar knowledge, yet if interrupted at any point due to funding or other considerations would yield fundamental if limited survey of the moon instead of a "scattergun" set of measures from assorted landing sites. This program delegates a fundamental role to man, which at once constrains the role of emplaced science. Some reasons for emphasing man's role in lunar exploration are:

---

1. "Logic for Lunar Science Objectives" ASC/IITRI Report P-29 Binder A. B., Hartmann W. K., Roberts D. L., Sullivan R. J., January 1970.

(i) Completely automated lunar exploration, minimizing man's role, would be a dead-end program. At the end of a decade or two we would have limited knowledge of the moon but a series of obsolete spacecraft. A manned exploration program will produce a capability for a man to operate on other planetary bodies, a recognized national goal.

(ii) We agree with the oft-stated argument that man is vastly superior to any instrument in sensing his environment, choosing individual structures for study, and reacting to unforseen instrumental or environmental inputs. The Apollo 11 and 12 landings have demonstrated this and that man's exploration capability on the moon exceeds most prior estimates.

(iii) Man's role in space is not to serve science alone. As was repeatedly pointed out recently at symposia of the American Association for the Advancement of Science, December 26-30, 1969, by speakers such as Walter Orr Roberts, Carl Sagan, Fred Singer, and Lewis Branscomb, the astronaut plays an important role in expanding man's experience, pushing back his frontier, and making the conquest of space a human enterprise shared by all of us. Purely automated space exploration does not do this. As Dr. Singer put it, "If we keep deemphasizing man in space, we may end up with no space program at all."

These arguments do not minimize the importance of emplaced science but rather accentuate the need to dovetail automated instruments into the program in the way which best uses their specific capability to <u>monitor</u> events and <u>integrate</u> over long time periods.

2. COMPREHENSIVE LIST OF OBJECTIVES AND MEASUREMENT TECHNIQUES

A comprehensive list of scientific objectives for lunar exploration was drawn up by the IITRI lunar group. This is shown in Table 1 and is broken down into several levels of detail. This provides the basis for our study and definition

TABLE 1: OBJECTIVES OF LUNAR EXPLORATION

SCIENCE AREA	BROAD OBJECTIVE	SPECIFIC OBJECTIVE
ORIGIN OF MOON	THERMAL STATE	HEAT FLOW
		DEEP ISOTHERMS
	COMPOSITION	ISOTOPES
		ELEMENT
		CHEMICAL
		MINERALOGICAL
	STRUCTURE	INTERNAL STRUCTURE
		CRUSTAL THICKNESS
	AGES	CRATER RETENTION
		SOLIDIFICATION
		FORMATION INTERVAL
		GAS RETENTION
LIFE	LIFE FORMS	BIOTA
	PREBIOTICS	ORGANICS
UTILIZATION OF MOON	SUPPORT RESOURCES	H_2O IN ROCKS
		PERMAFROST
		OXYGEN
		MINERALS
		CONSTRUCTIONALS
	NON LUNAR SCIENCE	CIS-LUNAR SCIENCE
		ASTRONOMY
		PHYSICS
		BIOMEDICINE
		CHEMISTRY
	PLANETARY EXPLOR.	HARDWARE DEVEL.
		ENVIRONMENTAL TESTS

TABLE 1: OBJECTIVES OF LUNAR EXPLORATION (Cont'd)

EVOLUTION OF MOON	BASINS	MASCONS
		SUBSURFACE STRUCT
		EJECTA
		MARE FILL
		ABS. AGES
	CRATERS	SUB SURF STRUCT.
		EJECTA
		CENTRAL PEAKS
		ABSOLUTE AGES
	HIGHLANDS	STRUCTURE
		COMPOSITION
		ABS. AGES
	MARE	EMPLACEMENT
		AGE SEQUENCE
		STRUCTURE
	REGOLITH	BLEACHING, DARKENING
		EROSION
		TURNOVER
		METEOROIDS
		THICKNESS
	ATMOSPHERE	PERMANENT COMP.
		SOURCES OF GAS
		PARTICLE MOTION
	INTERNAL CONSTITUTION	DENSITY PROFILES
		COMPOSITION VARIATIONS
		PHASE PROFILES
	TECTONIC ACTIVITY	ACTIVE SITES
		SEISMICITY
		INTRUSIVES
		RILLES
		GRID SYSTEM
		VOLCANICS
	THERMAL HISTORY	INT. TEMPERATURE
		HEAT FLOW
		THERMAL ANOMALIES
	DIFFERENTIATION	DEEP COMPOSITION
		DIFFERENTIATION
	MAGNETIC HISTORY	LUNAR FIELD
		PALEOMAGNETISM
		EARTH-MOON INERACT.

of lunar sciences; i.e. these are the areas of scientific investigation of the Moon.

Note that we segregate at this stage "utilization of the Moon". There are many investigations such as solar wind studies, astronomy, and the search for useful minerals which will be important in later phases of the exploitation of the Moon, but should be given low priority on the first flights when measurements should be directed only toward the Moon and science that can best be done on or near its surface.

The second step in our study was to draw up a master list of measurement techniques, i.e. instruments on which scientific experiments could be based. This was correlated with the primary science objectives from Table 1 and is shown in Table 2. Table 2, described more fully in ASC/IITRI Report P-29, displays our plan for lunar research. For each science objective, the instruments used are listed and the parameters for their deployment are described. P-29 is issued as a separate IITRI document, since it is of use in many different studies of the lunar program.

In the present study we will rely on these master lists to review systematically lunar science and the kinds of lunar experiments to be deployed.

We found in P-29 that lunar exploration naturally subdivided into several stages, called "levels". From studies of each level, lists of surface emplaced science will be drawn. The levels will be discussed separately in the following section, and then the surface experiments suitable for Apollo and post-Apollo will be presented in part 4.

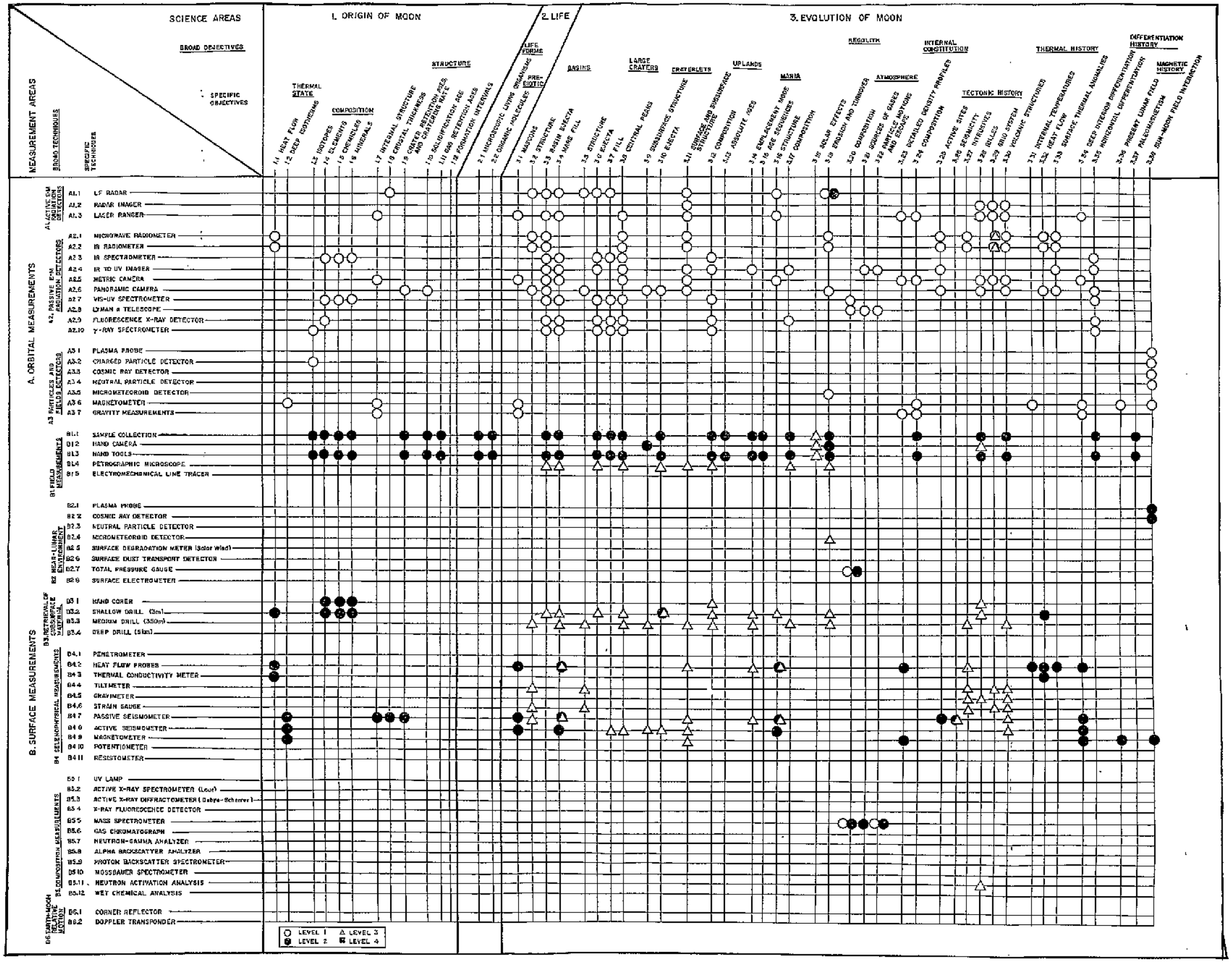
3. OVERVIEW OF LUNAR EXPLORATION

Lunar exploration has been subdivided into four levels which are discrete but complementary. They are:

(i) Reconnaissance

(ii) Sampling of homogeneous systems

FOLDOUT FRAME 1



FOLDOUT FRAME 2

(iii) Determination of feature related processes

(iv) Comprehensive regional exploration and exploitation.

Each level is discussed below.

3.1 Level I: Reconnaissance

A certain amount of investigation from orbit is essential prior to ground studies if the Moon is to be explored most efficiently. The orbital studies must provide (1) control for surface geophysical traverses, (2) high resolution views of specific structures, such as outcrops or possible sites of recent activity for later ground study, (3) a general photographic and remote sensing survey completing the task started by the Orbiters, and (4) detection of anomalous areas.

By definition, no emplaced surface science is contemplated as part of this level, but careful orbital study is essential for the successful planning of surface emplaced science in other levels of the program.

3.2 Level II: Sampling of Homogeneous Systems

3.2.1 Usefulness of Apollo Concept

In our review of lunar exploration it became clear that Apollo is ideal for a certain kind of mission - namely, short duration investigation of selected sites where the aim is to make measurements that characterize representative provinces of the Moon. That is, Apollo is most useful as a tool to sample the various kinds of lunar provinces and to make a beginning at interpretation of features, but Apollo is not best suited to studies of major lunar processes, large-scale (> 300 km) structure, or deep-seated structure. This must be taken into account in planning Apollo-deployed surface science.

3.2.2 List of Experiments

As a check for completeness against the master-list, we contrasted the list of experiments generated from the Letters of Intent to Propose solicited by NASA from Apollo experimenters. These letters of intent were provided to us by NASA, October, 1969. The comparison is shown in Table 3.

One difference noted in these two lists of experiments was that the IITRI list tended to be problem-oriented, since it was generated from an ordered program for lunar investigation, while the Apollo proposals tended to be method-oriented, since they were generated by investigators pursuing state-of-the-art experiments in their own respective fields of study. We feel that the Apollo proposals are somewhat heavily weighted toward non-lunar experiments and should be carried out only when lunar surface operations are more routine. Examples of non-lunar experiments are Mars imagers, solar corona and zodiacal light studies, earth cloud motions, etc.

For the purposes of this study of surface science the two lists were combined and the combined list is used henceforth (Table 8 p.24). This list is used as a pool from which to draw lunar experiments.

3.2.3 Relation of Experiments to Sites

Before experiments can be evaluated, it is necessary to review the kinds of sites we want to sample. We prepared a list of 17 type-areas and specific suggested sites which we believe are necessary but sufficient to fulfill the goals and potential of Apollo outlines above. These suggestions are independent of the Site Selection Board's recommendations but closely parallel them; we thus feel that the present Apollo program is close to its optimum potential, though perhaps too limited, especially with the dropping of Apollo 20. The type-areas and sites are given in Table 4.

TABLE 3

COMPARISON OF SURFACE SCIENCE EXPERIMENTS

LUNAR SURFACE SCIENCE

IITRI	APOLLO PROPOSALS
SAMPLE COLLECTION	SAMPLE COLLECTION
CAMERA	CAMERA
STEREO CAMERA	
	GOLD CAMERA (CLOSE-UP STEREO)
GRAVIMETRY	GRAVIMETRY
HEAT FLOW	HEAT FLOW
SEARCH FOR ORGANICS	SEARCH FOR ORGANICS
	SURVIVAL OF MICRO-ORGANISMS
SURFACE DUST TRANSPORT.	HAZARD DUE TO SURFACE EJECTA
	SMALL-SCALE MASS WASTING
SOLAR WIND DEGRADATION & BLEACHING	SOLAR WIND DEGRADATION & BLEACHING
	SOIL CHARACTERISTICS
PENETROMETER	PENETROMETER
HAND CORER	HAND CORER
SHALLOW DRILL (3 m, REGOLITH)	
MEDIUM DRILL (350 m, BEDROCK)	
STRAIN GAUGE	STRAIN GAUGE
	THERMALLY ISOLATED DISKS
	LM ASCENT PLUME EFFECTS
METEOROID ENVIRONMENT	METEOROID ENVIRONMENT
METEORITE IMPACT DETECTOR	
PASSIVE SEISMOMETER	PASSIVE SEISMOMETER
ACTIVE SEISMOMETER	
MASS SPECTROMETER	ATMOSPHERE COMPOSITION
MAGNETOMETER	MAGNETOMETER
CORNER REFLECTOR	CORNER REFLECTOR
RADIO NOISE SURVEY	RADIATION ENVIRONMENT
	BIOMEDICAL TESTS
	LOCOMOTOR ACTIVITY
	SYNTHESIS OF FOOD FROM WASTE
	LUNAR NAVIGATION
	FARSIDE COMMUNICATIONS
TILTMETER	

TABLE 3 (Cont'd)

COMPARISON OF SURFACE SCIENCE EXPERIMENTS

	IITRI	APOLLO PROPOSALS
UTILIZATION	LONG-DISTANCE SURF. COMMUNICATION	
		EARTH-SHINE PHOTOMETER
		STAR-RISE AND -SET EFFECTS
		LUNAR SKY BRIGHTNESS
		PARTICLES AND FIELDS MAGNETOMETER
		PASSIVE COSMIC RAY
		WATER VAPOR ON EARTH
		MARS IMAGER
		SOLAR CORONA AND ZODIACAL LIGHT
		EARTH CLOUD MOTIONS
		X-RAY OBSERVATORY
		MULTISPECTRAL IMAGING
		TELESCOPE PHOTOMETER
		HIGH-RESOLUTION UV PHOTOGRAPHY
		STELLER AND NEBULAR SPECTROGRAPH

Note: This table is based on the combined IITRI and Letters-of-Intent List (see p.8).

TABLE 4: SUGGESTED SITES FOR APOLLO LUNAR SURFACE SCIENCE

(Prior to and Independent of Site Selection Board Recommendations)

	TYPE-AREA	SITE	EST. STAY TIME	MAJOR OBJECTIVES
1	Oldest mare	Mare Tranquillitatis	1d	Dating; origin
2	Youngest mare	Mare Serenitatis	1d	Dating; origin
3	Upland fill	Near Mautolycus	1d	Origin of smooth upland material; dating
4	Diatreme	Dark-halo crater in Alphonsus	3d	Interior samples; dating
5	Basin ejecta blanket	Orientale ejecta (2nd choice: Fra Mauro)	1d	Interior samples; dating morphology
6	Young crater	Censorinus	1d	Proof of origin by impact: dating; structure
7	Upland inter-crater chaos	Near Arzachel	3d	Dating; Lineament origin; nature of ejecta
8	Young crater	Tycho	3d	Applicability of site 6 findings to large crater; dating
9	Volcanics	Possible acidic dome in Marius hills	3d	Evidence of lunar differentiation; moon-peculiar volcanic processes
10	Central peak	Copernicus	3d	Origin (post-impact upwelling?); dating; composition
11	"Ring dike"	Flamsteed ring	3d	Origin (extrusion or ancient flooded crater?); dating; composition
12	Sinuous rilles	Rima Prinz	3d	Nature of flows (lava or water?); dating; attempt Level 3-studies
13	Upland old crater interior	Ptolemaeus	1d	Nature of intra-crater fill in uplands
14	Volcanics	Probable basic dome in Marius hills or Copernicus floor	3d	Possible moon-peculiar volcanic processes
15	Farside uplands	?	3d	Possible systematic difference from front side; composition, etc.
16	Median age mare	Mare Orientale	1d	Rilles & edge effects; dating
17	Farside mare	?	1d	Possible systematic difference from front side

Listed with the sites in Table 4 are the science objectives prompting each selection. It is at this stage that we have first begun to correlate scientific studies with individual sites. Some experiments are site independent, but we will show that many are not. <u>Only by studying the science objectives associated with each site should surface science be selected</u>.

3.2.4 Evaluation of Experiments

After the lists of potential experiments and site-objectives were drawn up, an effort was made to evaluate and recommend scientific experiments for each site. A detailed discussion of the evaluation process will be deferred until Section 4, where surface science from all levels of lunar investigation will be discussed together.

We should point out here, though, a crucial factor affecting science during the Apollo period. With the delay of Apollo 13 for science reasons, we have already seen that the results of early Apollo flights can and must impact on the later flights. Therefore we find <u>it is absolutely essential that the greatest possible flexibility in planning must be maintained to allow early Apollo results to influence surface science deployed in later flights</u>.

3.3 <u>Level III: Determination of Feature Related Processes</u>

3.3.1 Contrast with Apollo Program

There will be a shift in emphasis in lunar surface science at the start of the post-Apollo program. While the early Apollo measures are designed to characterize different sorts of lunar provinces, the post-Apollo program must come to grips with processes. Apollo astronauts will investigate relatively simple sites where the meaning of observations will be unambiguous;

post-Apollo astronauts must visit more complex sites to understand the evolution of the Moon and the interplay of lunar processes.

The following changes must therefore characterize the shift from Apollo to post-Apollo science:

(i) an increase in the ratio of unprogrammed observa- time to instrument deployment time.

(ii) increase in stay-time per site.

(iii) search for "composite sites," or sites which contain within a limited radius (say 200 km) several kinds of features that could be studied by astronauts with modest traverses after a single landing.

(iv) a serious effort to increase the operating lifetime of any emplaced station well beyond the lifetime of current ALSEP-like units; this is necessary to integrate over longer times so as to increase data accuracy and also to change the actual type of phenomenon studied (e.g. in meteorite impact counting where longer times yield impacts of the less frequent, more massive bodies).

3.3.2 Selection of Post-Apollo Experiments

Basically the same list of experiments derived in Section 3.2 can again be used as a pool from which to draw measurement techniques. Again the emphasis is on moon-directed science; non-lunar science is more emphasized in Level IV.

We recognize that as we envision lunar science further and further downstream, our extrapolations of available experiments must be less accurate. Also, we cannot predict the findings of early experiments. These are additional arguments for maintaining flexibility in planning. Further, it is important that the experiments should be related to the sites in a systematic way. The experiments for post-Apollo are discussed in Section 4.

3.3.3 Selection of Post-Apollo Sites

Types of sites that should be studied were selected using the same rationale as in Section 3.2. However, in this case, specific sites are not suggested, since selection may depend on the findings of Apollo as to both science and man's capability.

Table 5 lists the type-sites desired for post-Apollo investigation. This was drawn from a careful review of the scientific objectives, described in Section 2. An estimate of the total effort at each site (man-days) was included and then the sites were divided by type.

It can be seen that there is some overlap with the desired Apollo sites. This is intentional. Again, the Apollo visits are designed to sample these areas and define their parameters which are now quite unknown; the post-Apollo visits are longer and designed for more complete study, operations being based on the earlier Apollo results. If a very limited lunar program is forced upon us, these Level II and Level III operations could be combined in a less efficient operation.

Table 5 lists the estimated number of man-days to be spent at each site for a minimal but complete Level III program. These estimates are based on the author's field experience in volcanic terrain. A total of 764 man-days were found to be required for a minimal program. It is noted that if 600 of these man-days could be fitted into 3-man, 14-day missions, 14 missions would thereby be required. However, some missions will require much longer stay-times, often because of drilling requirements (see Section 4), and others require much less than 14 days. This is why <u>it is important to look for "composite sites", so that the short and long stay-time missions can be combined to define a nominal mission around which surface landings can be designed</u>.

TABLE 5: SUMMARY OF SITES FOR LEVEL III (POST-APOLLO)

COMPOSITE SITES	MAN-DAYS *
Large crater	
Large young crater (as objective)	78
Large crater wall (objective: mass wasting)	4
Fault scarp or large crater wall (objective: dikes and sills)	4
Central peak	60
Dark halo crater	
Dark halo crater (objective: diatreme activity)	10
Diatreme (objective: deep-seated samples)	4
Domes	
Dome field with variety of domes (objective: magma differentiation among domes)	6
Gentle dome	4
Rough "bulbous" dome	6
Confirmed LTP sites (Lunar Transient Phenomena)	
Objective: volcanism	4
Objective: gas emission analysis	9
Basin ejecta blanket	
Objective: ejecta blanket emplacement	48
Objective: sampling deep-seated material	4
Fault scarp	
Concentric faults around basin	24
Objective: mass wasting	4
Objective: sampling deep-seated material	4
TOTAL	273 man-days

* Figure gives total man-days at sites of the kind listed, but not necessarily continuous days at one site.

TABLE 5 (Cont'd.)

SUMMARY OF SITES FOR LEVEL III (POST-APOLLO)

LARGE SITES (Mobility > 200 km)

Mare-upland contact	30	Medium-old crater floor	24
Lineament field	28	Rift areas	12
Mascon-related mare	50	Sinuous rille	18
Linear rille	18	"Exposed" pre-mare ring	24
		TOTAL:	204 man-days

LOCALIZED SITES (Mobility < 200 km)

Lava flow	16	Color-anomalous spot	3
Ash flow	8	Wrinkle ridge	18
Cone	4	"Mantled ring"	30
Rimless crater	12	"Ghost ring"	18
Patterned ground	4	Intermediate-size young craters	60
Contact between blue and red mares	3	Small young crater	54
		TOTAL:	230 man-days

SITES AVAILABLE IN ANY REGION

Any outcrop	2
Dimple crater	8
Anywhere (atm. escape)	24
Gardening	15
Micrometeorite erosion	6
Solar wind & radiation effects	2
TOTAL:	57 man-days

3.3.4 Possible Need for "Semi-permanent Bases"

The need for long stay-times on the order of 100 days for three men to require even first-order understanding of some lunar processes suggests that late in the post-Apollo period, there should be some sort of "semi-permanent bases" as forerunners of the permanent base. These could be used to study the "composite sites," allow the deepest possible drilling and other major experiments, and provide experience for a permanent base.

3.4 Level IV: Comprehensive Regional Exploration and Exploitation

3.4.1 Defining Objectives

An eventual permanent lunar base is a potential national goal. The purposes of this stage of exploration are much broader than those of the Apollo and immediately post-Apollo levels. These include: (1) extending man's domain to the Moon and learning to use natural lunar materials; (2) utilizing the Moon to check our understanding of Earth science and as a platform for astronomical and physical experiments. Beyond these, we see a continued need for lunar science during the future period of permanent occupation of the Moon.

In the very nature of Level II and III exploration lunar astronauts are limited in the three-dimensional range of their operations. Therefore there is a maximum scale of structural features they can investigate by the time the Level III gives way to Level IV. This dimension will be approximately 400 km. Larger features, such as lunar basins and the lunar interior, will have had only cursory study. This fact has a bearing on site selection and is another argument for man's permanent place on the Moon. Almost by definition man must play the crucial role. J. Verhoogen pointed out during the LESA study that the objectives of a lunar base demand "a long-term project...and that the instrument of greatest value in the investigation is man."

3.4.2 Importance of Site Selection for Permanent Bases

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

(i) The scale of accessible structures should be larger than that of those of the Level III studies. Level III 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 IV should be optimized for studying planet-wide features of the Moon.

(ii) 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 III type; full-time pre-occupation with a single crater would waste the potential of the lunar base.

(iii) 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 III. 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.

3.4.3 Example of a Possible Permanent Base Site

The Orientale Region appears in many ways an ideal site (as best we can judge at this early date). The scale of structures is appropriate to Level IV. 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 its east walls 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.

3.4.4 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.

Non-Lunar Science. Forecasting Level IV science is difficult, as noted. Whole areas of non-lunar science such as stellar astronomy, physical 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 be transferred off the Moon. Nonetheless, certain suggestions made in the LESA study, such as simultaneous monitoring of <u>both</u> 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.

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

<u>Lunar Science</u>. Many of these projects will involve continuation of studies begun in Level III. If the earlier levels are correctly performed, Level IV projects can involve refinement of pre-existing concepts. Table 7 gives a summary of probable lunar science activities. We do not propose to go into any further detail on base-science in this document because the lead-time is too long and the LESA study remains as useful a study as we can request at this time.

4. SURFACE EXPERIMENTS AND EMPLACED STATIONS

In sections 2 and 3, a master list of experiments was described and sites and objectives for lunar science were presented. It remains to discuss how experiments should be selected for individual sites and then to present the selections, to rank the experiments by some measure of their importance, and to choose

TABLE 6: SELECTED NON-LUNAR SCIENCE FOR THE PERMANENT LUNAR SURFACE BASE*

Area	Program	Advantage of Moon over Near-earth Orbit
Geophysics	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 nonearth environment.	Availability of sub-surface rock layers to provide shielding and simulate early planetary bodies.

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

TABLE 7: 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 I-III physical and selenodetic data.
Origin of craters, sinuous rilles, linear rilles, crater chains, etc.	Refinement of level I-III data. Base site must be chosen to facilitate access to these features.

from the experiments the ones that should be deployed as part of automated emplaced stations.

4.1 Criteria for Experiment Selection

A list of criteria was drawn up against which experiments could be checked for suitability. In Table 8 these selection criteria are listed in a matrix against the Apollo experiment list derived above in section 3. Such a table can be used either to select experiments for a particular mission or to evaluate importance of experiments in the long-term lunar program. The selection criteria, listed at the top of the table, are:

Physical coupling: Interface restrictions due to mechanical or field effects. Example: Magnetometer must be removed from other instrumental fields.

Scientific coupling: Inter-relationships among experiments. Example: Heat flow measurements are naturally coupled with the drill.

Freedom from support capability. Example: Active seismometry requires either use of explosives on surface or impacting of spent stages such as the LM. Tests on astronaut performance and condition may consume their time and to this extent detract from lunar surface science.

Best site locations: In addition to specified sites, the term "variety" indicates that the experiment must be deployed in various areas in order to gain discriminatory information. The term "any" indicates that results are expected to be similar in various areas of the Moon (usually because of the structural uniformity of the regolith); any site would do.

Experiment location within site: Example: The dust transport and mass wasting experiments should be deployed on slopes (such as small crater interiors) as well as on level ground.

Lunar time of day: (Can also be defined by lunar phase). This is in general not critical, though some experiments may have to be performed at night or at least in areas of long shadow.

Key requirements: A few general comments are inserted here. In view of the limited mobility of Apollo astronauts and the coverage of soil characteristics by Apollo 11 and in the future by the Gold camera, it is recommended that the available lunar landscape be photographed in stereo in the future. Experiments such as "Synthesis of food from waste," proposed to NASA for the lunar program, would appear demonstrable in earth-orbit and have no place as experiments of lunar science.

Ease of emplacement and servicing: Important in assessing grouping of experiments, since stay time is limited.

Significance of unexpected result: Of course, the expected result depends on one's hypotheses. The listings are estimates of the importance of anomalous results without regard to probability. Examples: Discovery of life forms (unexpected) would be extra-ordinarily important. Discovery of large variations in heat flow (unexpected) would be important in indicating areas of thermal activity. Some experiments with seemingly low probability of positive result (such as the search for life) must be given high weight because of this criterion.

Maintenance of value after several missions: The figure given is the number of missions after which the value of returned data is expected to drop to ½ the initial value. We regard this as a very important criterion. The point is that some measures are needed early in the program to typify the Moon, but (e.g. because of the regolith uniformity) after two or three missions may be relatively pointless and should give way to other experiments. Example: The meteoroid environment, once determined, is an exogenic constant of lunar science.

Impact on later lunar program: This is another very important criterion. It is a measure of potential that an experiment has in requiring a change in emphasis of later lunar exploration. Many experiments are of "go/no go" significance. For example, if seismic studies show that the Moon is quite "dead," further seismic studies are pointless; on the other hand if the moon is quite active, passive seismometers must increase in sophistication.

Number of sites wanted: This is in the nature of a summary of the preceding columns and is based on all of them. This represents the overall relative importance of the experiments and is given in terms of the number of our proposed Level II sites where the experiment should be deployed.

4.2 Listing of Experiments by Sites

Table 9 shows our selection of experiments for Apollo sites, and Table 10 shows a similar list for the post-Apollo program. In each table, the experiments selected for emplaced stations has been identified. The tables are based on the criteria given in Table 8, although we recognize that in the post-Apollo program it is difficult to foresee the actual conditions of deployment. We recognize, too, that this cannot be described as an exhaustive study of all possible experiments; certainly these tables should be compared with what is actually proposed by experimenters and available when the time comes. Yet we do believe that all these experiments will be required in any comprehensive lunar exploration.

4.3 Listing of Experiments by Importance

In Tables 9 and 10, each site was considered independently. Thus it is possible to rank the experiments as to importance by reviewing their number of entries. The result is shown in Tables 11 and 12. For Apollo experiments (Tables 11 and 12) the ranking is by number of sites; for post-Apollo experiments (Table 13) it is by number of man-hours at the site as well as by number of sites (the two numbers were combined to make the final listing). The total number of man-hours at the site represents the total

TABLE 9: PROPOSED GROUPING OF EXPERIMENTS AT APOLLO SITES

The following list reviews the first ten Apollo sites and a proposed set of experiments (based on the IITRI criteria study) grouped for each site on the basis of Table 8 with regard for reasonable total weight and deployment time.

Site	Site-dependent Experiments*	Site-independent Experiments*	Emplaced Station Experiments
1. Mare Tranquillitatis (Oldest Mare)	Sample collection Cameras Seismometer (Passive) Core-sampling drill Close-up stereo camera Hand corer Soil characteristics Penetrometer Magnetometer	Biomedical tests Retro-reflector Locomotor activity	Seismometer (Passive) Magnetometer
2. Mare Imbrium (Intermediate Mare)	Biomedical tests Hazard due to soil ejecta	Sample collection Cameras Seismometer (passive) Core-sampling drill Seismometer (active) Close-up stereo camera Hand corer Heat flow measurer Soil characteristics Gravity meter Magnetometer	Seismometer (passive) Seismometer (active) Retro-reflector Magnetometer Heat Flow Probe
3. Fra Mauro (Imbrium ejecta, modified uplands)	Solar wind degradation and bleaching measurement Fluorescence detector Survival of micro-organisms on surface and in drill hole	Sample collection equipment Cameras Seismometer (passive) Core-sampling drill Seismometer (active) Close-up stereo camera Hand corer Heat flow measurement	Seismometer (passive) Seismometer (active) Solar wind degradation and bleaching measurement Survival of micro-organisms on surface and in drill hole Heat Flow Probe

* Site dependent = definitely want measurement at indicated site.
Site independent = measure is as acceptable at any other site.

Table 9 (Cont'd)

Site	Site-dependent Experiments*	Site-independent Experiments*	Emplaced Station Experiments
	LM ascent plume effects Magnetometer	Soil characteristics Gravity meter Penetrometer	LM ascent plume effects Magnetometer
4. Rima Bode II (Rille) or Littrow Area (Wrinkle ridge)	Solar wind degradation and bleaching measurement Search for organics with detector on surface Survival of micro-organisms on surface and in drill hole Surface dust transport and small-scale mass wasting Meteoroid environment	Sample collection equipment Cameras Seismometer (passive) Core-sampling drill Seismometer (active) Close-up stereo camera Hand corer Heat flow measurement Soil characteristics Gravity meter Strain gauge Penetrometer	Seismometer (passive) Seismometer (active) Strain gauge Solar wind degradation and bleaching measurement Survival of micro-organisms on surface and in drill hole Surface dust transport and small-scale mass wasting Meteoroid environment Heat Flow Probe
5. Censorinus (Fresh impact crater)	Surface dust transport and small-scale wasting Temperature-density probe Thermally isolated disks Meteorite impact detector Hazard due to soil ejecta	Sample collection equipment Cameras Seismometer (passive) Core-sampling drill Seismometer (active) Close-up stereo camera Hand corer Heat flow measurement Soil characteristics Strain gauge Penetrometer	Seismometer (passive) Seismometer (active) Strain gauge Surface dust transport and small-scale wasting Thermally isolated disks Meteorite impact detector Hazard due to soil ejecta Heat Flow Probe
6. Tycho Rim (Large fresh impact crater)	Solar wind degradation and bleaching measurement LM ascent plume effects Magnetometer	Sample collection equipment Cameras Seismometer (passive) Core-sampling drill	Seismometer (passive) Seismometer (active) Strain gauge Solar wind degradation and bleaching measurement

Table 9 (Cont'd)

Site	Site-dependent Experiments*	Site-independent Experiments*	Emplaced Station Experiments
		Seismometer (active) Close-up stereo camera Hand corer Heat flow measurement Soil characteristics Gravity meter Strain gauge	LM ascent plume effects Magnetometer Heat Flow Probe
7. Copernicus Interior (Central peak)	Fluorescence Search for organics with detector on surface Meteoroid environment Lunar navigation system Radiation environment Earth-shine photometer Backside and long distance surface communications Star-rise and set effects	Sample collection equipment Cameras Seismometer (passive) Core-sampling drill Seismometer (active) Close-up stereo camera Hand corer Heat flow measurement Soil characteristics Gravity meter Strain gauge	Seismometer (passive) Seismometer (active) Strain gauge Meteoroid environment
8. Descartes (Upland chaos and possible volcanics)		Sample collection equipment Cameras Seismometer (passive) Core-sampling drill Seismometer (active) Close-up stereo camera Hand corer Heat flow measurement Soil characteristics	Seismometer (passive) Seismometer (active) Thermally isolated disks Meteorite impact detector Lunar sky brightness Heat Flow Probe
9. Marius Hills (Volcanics)	Fluorescence detector	Sample collection equipment Cameras Seismometer (passive)	Seismometer (passive) Seismometer (active) Heat Flow Probe

Table 9 (Cont'd)

Site	Site-dependent Experiments*	Site-independent Experiments*	Emplaced Station Experiments
		Core-sampling drill Seismometer (active) Close-up stereo camera Hand corer Heat flow measurement Soil characteristics	
10. Hadley/Apennines (Simmons rille; fault scarp)		Sample collection equipment Cameras Seismometer (passive) Core-sampling drill Seismometer (active) Heat flow measurement	Seismometer (passive) Seismometer (active) Heat Flow Probe

Note: This table is based on the combined IITRI and Letters-of-Intent List (see p. 8)

TABLE 10: PROPOSED GROUPING OF EXPERIMENTS AT LEVEL III SITES

GENERAL PROCESS	SPECIFIC PROCESS	TYPE SITE	OBSERVATIONS TO MAKE OR HYPOTHESES TO TEST	EXPERIMENTS	EST. MAN-DAYS EACH SITE MOBILITY	EST. NO. VISITS	EMPLACED SCIENCE
VOLCANISM	Lava flow emplacement	Lava flow	Was it fluid basalt? Was it highly frothed? Look for source. Differences from earth? Subsurface cavities? Subsurface flow units?	Sampling Cameras Drill (20m) "Gold camera" Active seismic Gravity traverse Observing and mapping traverse	8 200 km	2	None
	Ash deposition	Ash flow	Vertical fall or horizontally moving fluidized system?	Sampling Cameras "Gold camera" Drill (3m) Active seismic Gravity traverse Trenching	8 30 km	1	None
	Diatreme activity	Dark halo crater	Nature of particles in halo - is it ash? Collapse or entirely gas coring?	Sampling Cameras "Gold camera" Drill (100m) Active seismic Gravity traverse Trenching	10 30 km	1	None
	Dome formation	Cone	Exact analog of terrestrial cinder cone?	Sampling Cameras Drill (100m) Active seismic? Trenching	4 40 km	1	
		Gentle dome	Basaltic? Exact analog of terrestrial shield volcano?	Sampling Cameras Drill (100m) Active seismic Trenching	4 50 km	1	None
		Rough "bulbous" dome	More andesitic than rough dome? Resurgent?	Sampling Cameras Drill (100m) Active seismic Trenching	6 60 km	1	

TABLE 10 (Cont.)

GENERAL PROCESS	SPECIFIC PROCESS	TYPE SITE	OBSERVATIONS TO MAKE OR HYPOTHESES TO TEST	EXPERIMENTS	EST. MAN-DAYS EACH SITE MOBILITY	EST. NO. VISITS	EMPLACED SCIENCE
VOLCANISM	Recent volcanism	Confirmed LTP sites	Nature of activity: Flows? Gas eruptions?	Sampling Cameras Heat flow Gas analysis Passive seismic Tiltmeter "Gold camera" Neutron-gamma traverse Thermal probe Trenching	2 50 km	2	Passive seismom. Gas analysis Tiltmeter Thermal probe Heat flow probe
	Active volcanism	Active site (if found)	Nature of eruption Temperature of effluents Gas content	Sampling Cameras Gas analysis Visual & IR spectrometer Thermal probes "Gold camera" Trenching	3? 50 km	1	Passive seismic Tiltmeter Gas analysis Thermal probes
	Volcanic assimilation	Mare-upland contacts (at damaged structures)	Melting at contacts? Metamorphism? Cause of destruction	Sampling Cameras Drill (300m) Gravity traverse "Gold camera" Active seismic Observing & mapping traverse Trenching	30 200 km	1	None
	Dike & sill emplacement	Fault scarp or fresh crater wall	Search for examples of dikes & sills	Sampling Cameras Drill (300m) "Gold camera" Active seismic Gravimetry Observing & mapping traverse Trenching	4 100 km	1	None
TECTONICS	Collapse	Rimless crater	Can crater be identified as collapse feature? What is nature of subsurface cavity?	Sampling Cameras Drill (300m) Gravity traverse Active seismic	6 40 km	2	Passive seismom. Tiltmeter

Table 10 (Cont.)

GENERAL PROCESS	SPECIFIC PROCESS	TYPE SITE	OBSERVATIONS TO MAKE OR HYPOTHESES TO TEST	EXPERIMENTS	EST. MAN-DAYS EACH SITE MOBILITY	EST. NO. VISITS	EMPLACED SCIENCE
TECTONICS				Passive seismic Tiltmeter Observing & mapping traverse			
	Radial lineament formation	Lineament field outside young basin	Sources of lineaments Look for exposed fault scarps Map jointing Separate tectonic lineaments from exogenic striations (e.g. gouges from flying fragments)	Sampling Trenching Cameras Observing & mapping traverse Gravity traverse Drill (300m) Active seismic Passive seismic Tiltmeter Heat flow Strain gauge	28 400 km	1	Passive seismom. Tiltmeter Strain gauge Heat flow probe
	Concentric-Faulting	Concentric scarps around basins	Confirm normal faults Look for exposed outcrops Look for dikes, sills Look for flows Is bedding upturned? Extent of talus slopes at bases Due to sagging as basin filled with extruded lava?	Sampling Cameras "Gold camera" Drill (300m) Heat flow Passive seismic Active seismic Tiltmeter Strain gauge Gravity traverse Observing & mapping traverse	24 400 km	1	Passive seismic Tiltmeter Strain gauge Heat flow probe
	Graben & horst formation	Linear rille	Evidence for doming? Direction of stresses Nature of floor structure (uplifts) Look for dikes, sills in walls Look for flows in walls Are wall beds upturned?	Sampling Cameras "Gold camera" Drill (300 m) Passive seismic Active seismic Tiltmeter Strain gauge Gravity traverse Observing & mapping traverse	18 250 km	1	Passive seismic Tiltmeter Strain gauge

Table 10 (Cont.)

GENERAL PROCESS	SPECIFIC PROCESS	TYPE SITE	OBSERVATIONS TO MAKE OR HYPOTHESES TO TEST	EXPERIMENTS	EST. MAN-DAYS EACH SITE	MOBILITY	EST. NO. VISITS	EMPLACED SCIENCE
TECTONICS	Isostasy	Medium old crater floor	Has there been isostatic adjustment? Determine effective viscosity Relation of isotasy to central peak	Sampling Drill (300m) Active seismic Passive seismic Gravity traverse Strain gauge Tiltmeter	12	300 km	2	Passive seismic Tiltmeter
GRADATION	Thermal exfoliation	Any outcrop	Has diurnal thermal cycle caused exfoliation? Any evidence for action of water/ice or other volatiles?	Sampling Cameras "Gold camera"	1	10 km	2	
	Mass wasting	Large crater walls	Interplay of slumping & faulting Extent of downslope motions Effect in smoothing craters	Cameras Trenching "Gold camera" Drill (100m) Mass transport & dust mobility measure Passive seismic	2	10 km	2	Mass transport & dust mobility measure Passive seismic
		Patterned ground	Extent of downslope motions Relation of motion to patterning Identification of talus at base?	Cameras Trenching "Gold camera" Drill (60m) Mass transport & dust mobility measure Passive seismic Observation & mapping traverse	2	10 km	2	

TABLE 10 (Cont.)

GENERAL PROCESS	SPECIFIC PROCESS	TYPE SITE	OBSERVATIONS TO MAKE OR HYPOTHESES TO TEST	EXPERIMENTS	EST. MAN-DAYS EACH SITE MOBILITY	EST. NO. VISITS	EMPLACED SCIENCE
DENUDATION	Isostasy	Fault scarp	Extent of downslope motion Extent of covering or baring of bedrock Identification of talus at base?	Cameras Trenching "Gold camera" Drill (100m) Mass transport & dust mobility measure Passive seismic	2 20 km	2	Mass transport & dust mobility measure Passive seismic
	Drainage	"Dimple crater"	Evidence for cavity underneath	Cameras Trenching Drill (60m) (4 holes) Gravity traverse Active seismic Mass transport & dust mobility measure	4 10 km	2	None
	Deposition processes in ejecta	Ejecta blanket (basin & large crater)	Evidence for base surge Evidence for turbulent motion Estimate of density & mass transport rate in ejecta "cloud"	Cameras Trenching Samples "Gold camera" Hand corer Drill (3 m) (10 holes) Drill (300m) (2 holes) Observation & mapping traverse Gravity traverse Active seismic	24 400 km	2	None
LITHOLOGIC DIFFERENTIATION	Differentiation in magma	Variety of dome morphologies	Are different dome forms of dome different rock types? Are more craggy domes more acidic?	Sampling Trenching Cameras Drill (100m)	6 400 km	1	None

TABLE 10 (Cont.)

GENERAL PROCESS	SPECIFIC PROCESS	TYPE SITE	OBSERVATIONS TO MAKE OR HYPOTHESES TO TEST	EXPERIMENTS	EST. MAN-DAYS EACH SITE MOBILITY	EST. NO. VISITS	EMPLACED SCIENCE
LITHOLOGIC DIFFEREN-TIATION		Vicin-ity of contact between "blue" & "red" maria "Wood's spot" or similar color anomaly	What are differences in lava composition to account for change in color?	Sampling Trenching Cameras Gravity traverse Active seismic Drill (300m) Observation traverse	3 60 km	1	None
			Is colorimetric anomaly related to differentiation?	Sampling Cameras Gravity traverse Active seismic Drill (300m)	3 100 km	1	
INTERIOR PROCESSES	Differen-tiation	Lowest exposure in large scarp	Any evidence for ver-tical gradients in composition?	Sampling Cameras Drill (300m)	4 60 km	1	Passive seismom.
		Diatreme	Evidence for ultra-basics from depth?	Sampling traverse Cameras Drill (300m)	4 100 km	1	
		Ejecta from young basin	Evidence for ultra-basics from depth? Correlation of radial range from basin with depth variations	Sampling traverse Cameras	4 100 km	1	
		Any site for sel-enophy-sical measures	Detect structure deep within moon & indicat-ing presence or ab-sence of differentation	Active seismic network based on passive seismometers Heat flow network	- -	-	

TABLE 10 (Cont.)

GENERAL PROCESS	SPECIFIC PROCESS	TYPE SITE	OBSERVATIONS TO MAKE OR HYPOTHESES TO TEST	EXPERIMENTS	EST.MAN-DAYS EACH SITE MOBILITY	EST.NO. VISITS	EMPLACED SCIENCE
INTERIOR PROCESSES	Convection	Possible rift or spreading areas	Possible connection between wrinkle ridges and midocean ridges	Sampling Cameras Gravity traverse Drill (300m) Heat flow traverse Active seismic Passive seismic Tiltmeter Strain gauge	12 400 km	1	Passive seismic Tiltmeter Strain gauge Heat flow probe
FORMATION OF UNIQUE LUNAR STRUCTURES	Sinuous rille formation	Sinuous rille	Confirmation of erosion & transport by flow Nature of flowing material Possible relation to water or volatiles? Possible relation to lava? Nature of crater at "head" of rille	Sampling Cameras "Gold camera" Observation & mapping traverse Gravity traverse Drill (100m) (4 holes) Active seismic Neutron gamma traverse	18 400 km	1	None
	Wrinkle ridge formation	Wrinkle ridge	Confirmation of lava flow sources at ridges Identification of compression or rifting Search for folding	Sampling Cameras "Gold camera" Observation & mapping traverse Gravity traverse Drill (300m) (4 holes) Active seismic	18 200 km	1	None

TABLE 10 (Cont.)

GENERAL PROCESS	SPECIFIC PROCESS	TYPE SITE	OBSERVATIONS TO MAKE OR HYPOTHESES TO TEST	EXPERIMENTS	EST.MAN-DAYS EACH SITE MOBILITY	EST.NO. VISITS	EMPLACED SCIENCE
UNIQUE STRUCTURES	Mascon formation	Mascon related mare	Are mascons due to layers of dense lava on surface? Or buried bolides? Or other anomalies? Is nickel-iron involved?	Sampling traverse Gravity traverse Drill (5 km) Active seismic Passive seismic Magnetic traverse	50 600 km	1	Passive seismic
	Formation of "exposed" pre-mare rings (e.g. Flamsteed ring)	"Exposed" pre-mare ring	Are they the tops of pre-mare craters exposed above lava? Are they ring-dikes? Evidence for assimilation	Sampling Cameras "Gold camera" Gravity traverse Active seismic Drill (300m)	24 350 km	1	None
	Formation of "mantled ring" (e.g. Ptolemaeus B)	"Mantled ring"	Cause of relief Are they buried impact craters? Has original structure been completely assimilated or just buried? Is regolith different than in surroundings	Sampling Cameras "Gold cameras" Gravity traverse Active seismic Drill (2 km)	30 60 km	1	None
	Formation of "ghost rings" (e.g. in Orbiter mare photos)	"Ghost ring"	Cause & extent of relief Are they buried craters? Are they melted or isostatically destroyed craters that formed in molten flows?	Sampling Cameras "Gold cameras" Gravity traverse Active seismic Drill (1 Km)	18 30 km	1	None

TABLE 10 (Cont.)

GENERAL PROCESS	SPECIFIC PROCESS	TYPE SITE	OBSERVATIONS TO MAKE OR HYPOTHESES TO TEST	EXPERIMENTS	EST.MAN-DAYS EACH SITE MOBILITY	EST.NO. VISITS	EMPLACED SCIENCE
UNIQUE STRUCTURE	Formation of central peaks	Central peak (young crater)	Are they igneous extrusive features? Are they rebound structures? Relation to wall slumping? Relation to crater formation?	Sampling Cameras "Gold cameras: Gravity traverse Active seismic Drill (5 km)	60 100 km	1	None
ATMOSPHERE PROCESSES	Gas emission	Confirmed LTP site (or active site if found)	Composition of gases Association with heat anomalies Association with volcanism Search for sublimates and surface deposits	Samples Cameras (if "Gold cameras": Total gas pressure gauge Gas analysis Heat flow Gas detector Passive seismic Strain gauge Tiltmeter	3 available) 50 km	3	Gas detector Passive seismic Strain gauge Tiltmeter Total pressure gauge Heat flow probe
	Escape of atmosphere	Anywhere on surface and in orbit	Test time rate of change of composition as correlated with known inputs from rocket exhausts and other man-made sources Test rate of lost against atomic mass Test mobility and transport from light to dark side	Gas analysis (mass spectrometer) Total pressure gauge	6 0	4	Gas analysis Total pressure gauge

TABLE 10 (Cont.)

GENERAL PROCESS	SPECIFIC PROCESS	TYPE SITE	OBSERVATIONS TO MAKE OR HYPOTHESES TO TEST	EXPERIMENTS	EST.MAN-DAYS EACH SITE MOBILITY	EST.NO. VISITS	EMPLACED SCIENCE
IMPACT CRATERING	Primary cratering	Large (D>50 km) young crater	Confirm primary impact origin Nature of bolide (Ni-Fe? Chondrite? Cometary?) Modification processes	Sampling Cameras "Gold camera" Active seismic Gravity traverse Magnetic traverse Drill (5 km) Drill (300m 5 holes)	78 600 km	1	None
		Intermediate (D~10 km) young crater	Confirm primary impact origin Nature of bolide (Ni-Fe? Chondrite? Cometary?) Modification processes	Sampling Cameras "Gold camera" Active seismic Gravity traverse Magnetic traverse Drill (300m 4 holes)	60 200 km	1	
		Small (D~1 km) young crater	Confirm primary impact origin Nature of bolide (Ni-Fe? Chondrite? Cometary?) Modification processes Origin of inner ring-bench in some craters due to thin regolith? Diagnostic features	Sampling Cameras "Gold camera" Active seismic Gravity traverse Magnetic traverse Drill (300m)	18 50 km	3	

TABLE 10 (Cont.)

GENERAL PROCESS	SPECIFIC PROCESS	TYPE SITE	OBSERVATIONS TO MAKE OR HYPOTHESIS TO TEST	EXPERIMENTS	EST. MAN-DAYS EACH SITE MOBILITY	EST. NO. VISITS	EMPLACED SCIENCE
IMPACT CRATERING	Gardening	Any surface on regolith (pick sites of different aged regolith)	Rate of turnover Admixture of cosmic material Rate of deepening Net mass loss or mass gain?	Sampling Cameras "Gold camera" Sampling of meteoritic mass-dependent flux Drill (300m)	3 2 km	5	Meteorite flux determination (mass-dependence
	Micro-meteorite erosion	Any surface site	Rate of microerosion and turnover Mass loss or mass gain? Admixture of cosmic material	Sampling Cameras "Gold camera" Sampling of micro-meteoritic mass-dependent flux (Drill (3 m)	3 1 km	2	Micro meteorite flux determination (mass dependence)
SOLAR WIND AND RADIATION EFFECTS	Bleaching darkening, sputtering	Any surface site	Effects of surface exposure	Sample surfaces explosed	2	1	Sample surfaces exposed

TABLE 11: APOLLO LUNAR SURFACE SCIENCE EXPERIMENTS IN ORDER OF IMPORTANCE

Experiment	No. sites
Sample collection equipment	17
Cameras (stereo better than non-stereo)	17
Passive seismometer	17
Core-sampling drill (to 3 meters)	17
Active seismometer	12
Close-up stereo camera	10
Hand corer	9
Heat flow probes	9
Soil characteristics	9
Gravity meter	5
Strain gauge	4
Penetrometer	4
Solar wind degradation and bleaching monitor	3
Fluorescence detector	3
Search for organics with detector on surface	2
Survival of micro-organisms	2
Surface dust transport and small scale mass wasting	2
Temperature-density probe	2
Thermally isolated disks	2
LM ascent plume effects	2
Meteoroid environment detector	2
Meteorite impact detector	2
Magnetometer	2
Biomedical tests	2
Hazard due to soil ejecta	2
Retro-reflector	2
Locomotor activity	1
Lunar navigation system	1
Radiation environment	1
Earth-shine photometer	1
Backside communications & long distance surface comm.	1
Star-rise and -set effects	1
Lunar sky brightness	1
Synthesis of food from wastes	1

Note: This table is based on the combined IITRI and Letters-of-Intent List (see p.8).

TABLE 12: APOLLO SCIENCE EXPERIMENTS: A COMPARISON

Experiment	NASA Sites Max.	NASA Sites (Min.)	IITRI Sites (Scaled to 9)	Candidates for Deletion
Sample Collection	9		9	
Cameras	9		9	
Passive seismic	9	(8)	9	
Core Sampling Drill (to 3m)	3	(2)	9	
Active Seismic	5		7	
Close-up Stereo	9	(5)	6	
Hand Corer	9		5	
Heat Flow	4	(3)	5	
Soil Characteristics	9	(7)	5	
Dust Detector (Transport?)	9	(7)	1	X
Gravity Meter	4		3	
Magnetometer	4		1	
Retroreflector	4	(3)	1	
Meteoroid Environment	2	(0)	1	
Strain Gauge	0		2	
Penetrometer	9(?)		2	X
Solar Wind Degradation and Bleaching	0		2	
(Others)	0		1-2	
Solar Wind Composition	8		0	X
Cold Cathode Gauge	4		0	X
Electrical Properties	4		0	X
Suprathermal Ions	3		0	
Solar Wind Spectrum	2		0	
(Others)	2-1		0	

Note: This table is based on the combined IITRI and Letters-of-Intent List (see p.8).

TABLE 13: LEVEL - III LUNAR SURFACE SCIENCE EXPERIMENTS IN ORDER OF IMPORTANCE

Experiment	No. man-hours at sites	No. Sites
Sample collection equipment	739	55
Cameras (stereo better than non-stereo)	648	54
Active seismometer	702	36
Gravity traverse	685	31
Close-up stereo (Gold) camera	545	40
Drill (100-300m)	465	39
Observing and mapping traverse	223	16
Trenching for stratigraphic study	194	24
Passive seismometry	193	19
Drill (1-5km)	296	6
Drill (3-20m)	148	11
Tiltmeter	131	13
Stain gauge	115	9
Magnetometer traverse	182	5
Heat flow	89	10
Gas analysis	40	10
Total gas pressure gauge	33	7
Mass transport measurement	20	8
Hand corer	48	2
Meteoroid environment detector	21	7
Neutron-gamma traverse	22	3
Gas detector	9	2
Thermal probe	7	3
Visual & IR spectrometer	3	1

time spent on all experiments at that site; it is thus a weighing factor for the importance of the site.

Finally, in Table 14, a similar listing is given of the importance of various experiments for emplaced science. Here the listings for both Apollo and post-Apollo are given by number of sites only, not by number of man-hours (since this is irrelevant for ALSEP-like packages).

4.4 Need for Long-Lived Emplaced Stations

The need for emplaced stations comes about either through the need for long integration-time or to monitor infrequent lunar events. Examples of the first case are measurement of the turnover rate and degradation rate of the regolith or measurement of the meteorite flux. In these cases, the measurables are small but increase with time; further, the longer the integration time, the higher the mass of the largest impacting bodies measured in the flux experiment. Examples of infrequent lunar events are seismic phenomena and possible lunar transient events, which may be volcanic eruptions.

Emplaced stations should be thought of as a network of instruments sampling the Moon. It is conceivable that early Apollo or post-Apollo measurements could demonstrate a need for radical redesign of the emplaced station network. For example, highly unexpected and anomalous heat flow measurements could instigate a series of heat-flow emplacements. More probable is a situation requiring simultaneous use of emplaced stations (similar to ALSEP) as a network. Examples would be simultaneous use of at least three seismographs in passive or possible active seismometry, which is required to triangulate positions of moonquake epicenters. To make this more feasible, we require extended lifetime of emplaced stations.

Extension of lifetime of emplaced stations is perhaps the cheapest single major advance in lunar surface science. The potential value of at least four experiments rises directly with

TABLE 14: AUTOMATED EMPLACED EXPERIMENTS LISTED BY IMPORTANCE

Experiment	Recommended No. Sites	
	Apollo	Post-Apollo
* Passive seismometer	10	21
* Tiltmeter		13
Heat flow	8	8
* Strain gauge	4	8
* Meteoroid environment (mass dependence)	2	7
* Gas analysis		7
* Total gas pressure		7
* Surface dust transport & mass wasting	2	6
* Solar wind degradation & bleaching	3	1
Thermal probe		3
* Gas detector		3
Retro-reflector	2	
* Survival of micro-organisms	2	
LM ascent plume effects	2	
* Magnetometer	2	
* Meteorite impact detector	2	
Thermally isolated disks	2	
Hazard due to soil ejecta	1	

* Indicates experiments where long operating lifetime (~ 2 years) is critically important either because of necessary integration time or infrequency of events monitored by instrument.

their lifetime: strain gauge measures, passive seismometry, micrometeorite flux measurement, and search for major impacts. In the case of the two meteorite-related experiments, the nature of the meteoroid mass distribution is such that the longer the integration time, the larger the mass of the largest particles that will be seen. Therefore, all these experiments are in the nature of waiting for the desired event (the largest possible disturbance), and the information increases with experiment lifetime.

5. REMOTE UNMANNED LANDERS, UNMANNED/MANNED ROVERS AND FLYING UNITS FOR SURFACE SCIENCE

5.1 Limited Need for Remote Landers

We have considered the possibility that some emplaced stations should be delivered to spots where manned landings are not desired, hazardous, or ruled out by energy requirements. It appears that this situation would most likely arise during the Apollo program; unmanned landers are not likely to be available in any case.

In our review of lunar science we see no pressing need for unmanned landers, either in Apollo or post-Apollo time periods; Apollo is designed to sample all important areas. Post-Apollo will sample many more and have roving vehicles in addition. The principal need for unmanned landers (Surveyor-type vehicles) would be to deploy a network of emplaced stations aroung the Moon, but this should be done in any case by the manned landings if care is taken to include the necessary instruments in the packages from the start of their design. That is, <u>emplaced stations should be viewed as constituting a global network, achieved by suitable choice of manned landing sites</u>.

This makes it crucial that emplaced stations should have the longest possible lifetime, so that when the landing series is complete, a large fraction of the stations will still be simultaneously working.

5.2 Importance of Unmanned Rovers

We have found in current NASA planning a requirement for regional reconnaissance for which it is proposed that an unmanned rover be considered. (Santa Cruz 1967, Space Science Board 1969). We agree with the need for a combined set of gravimetric, seismic, electromagnetic and compositional measurements over much larger areas than will be covered by the Apollo sites. The overall usefulness of an automated rover can be considered in the context of the four levels of exploration.

Level I reconnaissance could benefit from a long-range automated rover, if it can provide the combination of measurements identified above. The functions that a rover can perform uniquely, compared to an orbiter, are sample collection and seismometry. We are not convinced that an automated rover can add sufficiently to orbital data to warrant its development for lunar reconnaissance.

Level II science is restricted to local areas which are typical of provinces or features. The long range automated rover is not suited to, nor necessary for, this exploration.

In Level III the emphasis is on analysis of structurally complex, non-homogeneous sites. We feel a man will be required to discriminate and choose locales for examination, determine ways of reaching these locales which may require clever utilization of the terrain or existing facilities, and choose samples and structures to analyze, which may depend on a variety of sensory inputs. We question whether we will really need remote TV, etc. at this stage of lunar exploration, unless it can be made available considerably before manned exploration at this level, or if intensive manned lunar exploration is postponed significantly.

In Level IV we are utilizing the Moon. This corresponds most closely with present-day geophysics, with permanent habitation of the Moon probably involved. It is too early to evaluate the role of an unmanned rover at this stage, but we point out that such rovers are not in use in terrestrial exploration even in the most difficult areas.

5.3 Need for Manned Rovers

Astronaut mobility will become increasingly important toward late Apollo and early post-Apollo flights, because the sites visited will be increasingly complex, geologically. In the sites anticipated in the Apollo program, the total travel requirement ranges up to about 200 km. In the post-Apollo program we list two sites requiring 600 km total travel (Table 10).

Manned rovers will be important in deploying emplaced stations as well as in traverses, sample collecting, and field observation. Emplaced stations will not always be put down at some arbitrary spot near the LM. In regions of suspected tectonic activity, for example, strain gauge, tiltmeters, and seismometers should be installed on or near possible faults. In suspected volcanic regions, gas detectors, tiltmeters, etc. should be placed with considerable attention to surrounding structure.

5.4 Need for Flying Units

Rovers are only part of the system required to install the emplaced stations and facilitate other observations. The lunar flying units should be capable of carrying not only a man but also at least an ALSEP-size package over total vertical distances of 25,000 feet. This would permit:

(i) investigations on the face of major faults

(ii) investigation of central peak complexes,

(iii) descent into major craters such as Copernicus or Tycho from their rims

(iv) investigations on the walls of such major craters.

It should be noted that very young large craters, such as Tycho, are extremely rough not only by lunar but by terrestrial standards. The flying unit may be the only means of reaching and emplacing stations in the floors of Tycho-like craters which may be too rough for either LM landings or rover mobility.

6. RECOMMENDATIONS

The following recommendations on various aspects of the lunar exploration program were derived from different parts of this study.

1. Flexibility is of crucial importance in planning, especially in the Apollo phase. Early experimental results must impact on and modify later experiments. Sufficient time must be allowed between flights to absorb the significance of results; the delay of Apollo 13 is a proper step.

2. Separate Apollo missions and their landing sites conceptually from post-Apollo missions and their sites. Do not attempt to force the Apollo astronauts to perform field studies of geologically complex sites before the range of basic lunar parameters has been defined. Early Apollo sites should be the clearest possible examples of uncontaminated lunar structures.

3. Present single-frame photography on Apollo missions should be replaced with stereo photography, even at the cost of reducing the total number of scenes. Variable baselines (lens separations) should be used, so that distant scenery can be scaled and interpreted in stereo. Absence of distance-indicating haze on the Moon makes stereo photography essential in indicating distance. For distant (a mile or so) details such as ridges, separations on the order of hundreds of yards are needed, implying two shots with the same camera from different positions, rather than an ordinary stereo camera.

4. The ratio of instrument deployment time to simple observation time (photography, visual observing, sample collection) should decrease as more complex sites are visited late in Apollo.

5. It is crucial to obtain the maximum possible lifetime of emplaced instruments. This is the cheapest way to increase lunar data. An example comes from seismometers: three must be operating simultaneously to get a "fix" on any seismic event. With only two landings a year, a minimum lifetime of 1½ years is needed to get any overlap at all.

6. 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.

7. In the mid 70's, studies should begin to review which non-lunar (astronomical, physical, biological, etc.) experiments should be performed on the lunar surface and which in earth orbit or lunar orbit.

8. Site selection for a permanent base or bases should be deferred to the late 70's to utilize experience with lunar science gained by post-Apollo exploration.

9. There is an apparent need for lunar reconnaissance which can utilize a long range automated rover. We are not convinced that the added contribution that an automated rover provides over orbital missions is worth its development.

10. Experiments in Apollo and early post-Apollo programs should emphasize Moon-directed science in preference to experiments in areas such as space science, interplanetary particles and fields, observations of other planets, astronomy, pure physics, etc. In brief, non-lunar experiments should not be hauled all the way to the Moon unless there is a compelling reason.

11. Emplaced stations will be required on all Apollo missions but will not be required on all post-Apollo missions.

12. No need is found for unmanned landers (Surveyor-type vehicles) during Apollo or post-Apollo exploration if manned-landings are continued.

13. Flying units with total vertical range of 25,000 ft. are needed for observing and deploying emplaced stations.

14. Further mission planning should be based on "repeated iteration" with feedback among scientific objectives, landing sites, vehicle constraints, and experiment choices; rather than by fixing one group of parameters before proceeding to the next.