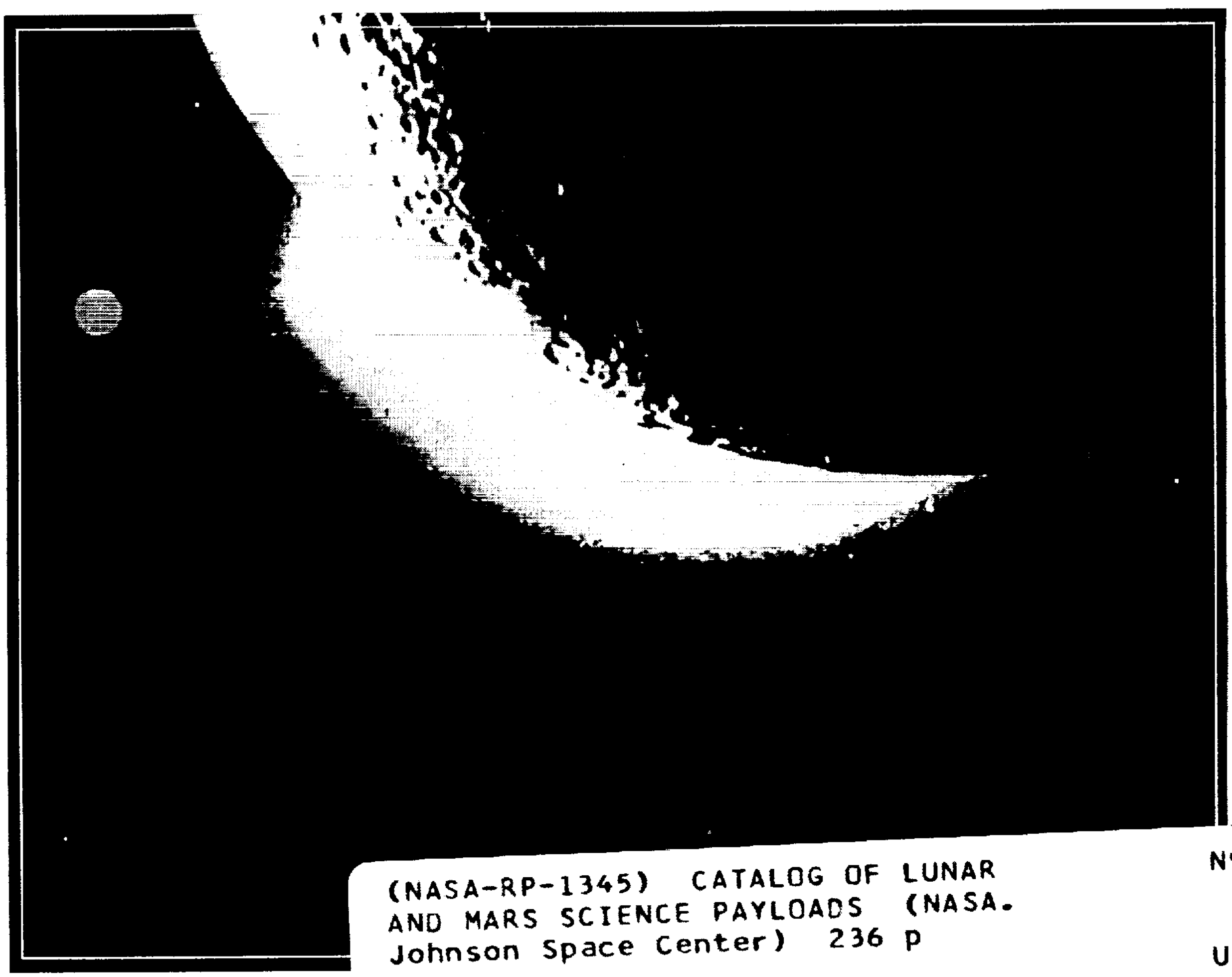
NASA Reference Publication 1345

Catalog of Lunar and Mars Science Payloads

Nancy Ann Budden, Editor



August 1994

Taken during the Clementine mission, the cover photograph shows the Moon oriented with the south pole at the bottom of the image. The far side is on the right, shrouded in darkness, with the near side on the left, lit by earthshine. The Sun is about 5 degrees below the Moon's horizon, causing a glow which is a combination of the solar corona and zodiacal light. The bright star to the left of the Moon is Venus.

Clementine image courtesy of the Clementine Program Office, BMDO, Department of Defense.

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Preface

Within our lifetimes we will return to the Moon and see humans explore Mars. When that happens, it will be the result of years of mission planning that were derived initially from dreams as well as data. This catalog describes science payloads for lunar and Mars missions that fall into both the dream and data category, ranging from space-proven hardware to experiments that are no more than a ripe concept in our imagination.

The need for an instrument catalog describing the physical characteristics of lunar and Mars science instruments was identified in 1989 during the early days of the NASA Lunar and Mars Exploration Program Office (LMEPO) at the Johnson Space Center (JSC). Mission engineers and scientists in the LMEPO began to seriously map our path back to the Moon and on to Mars. To do this, LMEPO developed reference missions and architectures describing in detail how a mission would be organized. Such advanced planning requires a moderate level of understanding of all the various interrelated systems, including surface, transportation, and human support systems. One critical mission element to integrate into these systems is the science program. We need to answer a number of questions in advance. The most important step is to establish which scientific questions will be addressed as we explore the planetary surfaces. Then we can determine what type of observations and equipment will ensure a successful science program. Specifically, what science instruments will we transport and how will these payloads affect the mission? What mission infrastructure (or subsystems) will be necessary to deliver, operate and sustain the instruments? How much will the science payloads weigh, and how much volume will be needed to transport them to the planet's surface? Can they be deployed robotically or are humans needed to place or operate them on the surface? How much power is needed to drive the instruments, and is this power requirement constant or intermittent? Are there specialized skill requirements for the crew, such as experience in astronomy, field geology, or geochemistry? What information and communication links are necessary to operate and relay messages to the experiments as well as off load and return data to Earth?

This handbook tabulates data for all these questions and offers the best available descriptions of the scientific instruments that have been considered for lunar and Mars missions. In 1992 our office at JSC changed its name to the Exploration Programs Office (ExPO) and in 1993 to the Planetary Programs Office. Today in the Planetary Programs Office, the quest for human exploration beyond Earth orbit continues, fostering the persistent need for this catalog.

This document is a compilation of science payload descriptions originally generated by Jet Propulsion Laboratory (JPL) and JSC from 1989 through 1992. Payloads were described for human and robotic lunar and Mars missions to support LMEPO at JSC. This work was funded first by NASA Headquarter's Office of Space Science and Applications and later by LMEPO. JPL generated a series of documents titled "SEI Science Payloads," informally referred to in house as the green book, under the project management of Richard Wallace. The final edition of the green book was published in May 1991 as JPL Report D-7955 Revision A, "FY91 Final SEI Science Payloads: Description and Delivery Requirements."

Two years of subsequent work on space exploration science payloads was carried out during 1991 and 1992 within the LMEPO and later ExPO Science Integration Office under my project management. Existing payload descriptions were updated, and additional payloads were added. In addition, specialized science payload complements are included for three missions studied in 1991-1992: the Scout, Artemis (Common Lunar Lander) and First Lunar Outpost (FLO) missions.

Be aware that the payloads collected here are in varying stages of concept and maturity. Payloads from Apollo actually existed and can be characterized in greater detail, whereas other instruments are concepts only and have never been formally finalized or designed. For example, well-documented Apollo fielo geology tools already exist and can be described in detail, whereas lunar observatories or martian meteorological stations have never been built or deployed and in some cases, only exist in our imaginations. The level of maturity has been noted for each instrument and should be kept in mind when using the payload data.

This catalog gathers science payload data in a format that is easy to use. The information is intended for engineers and scientists alike. I have compiled what we know to date with the hope that this document will be updated annually or as resources permit. It is my desire that this document will continue to support mission studies that will ultimately come to fruition with a return to the Moon and the inevitable journey to Mars.

Nancy Ann Budden
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Acknowledgments

This document would not be possible without the original contribution by Richard Wallace and his team at JPL from 1989 to 1991. Their approach and data forms the bulk of this effort.

Dean Eppler, a lunar geologist on contract to our office from SAIC, spent a portion of the next two years (1991-1992) compiling and generating new science payloads and updating some of the payloads from the final 1991 JPL document. Dr. Eppler also developed a more user-friendly format and put all existing payloads into this format. He worked the science payloads for the First Lunar Outpost (FLO) for this document.

In 1992, under a short-lived contract to our office from McDonnell Douglas, Nadine Barlow as a Mars scientist continued to reformat and update some of the Mars science payload descriptions. Dr. Barlow also compiled the Scout and Artemis (Common Lunar Lander) payloads for the catalog. The efforts of these two individuals added much to this document and are greatly appreciated.

I would also like to thank all of the principal investigators who contributed designs, data, concepts, parameters, ideas, and imagination to this effort. Without them and their voluntary contributions, there would be no catalog. They are listed individually in their respective chapters.

Finally, I would like to thank Bret Drake, Kent Joosten, David Weaver, and Dean Eppler for reviewing drafts of the document.

CONTENTS

Acronyms

ALSEP	Apollo Lunar Surface Experiment Package
BAMS/XRF	Backscatter Mossbauer Spectrometer and X-Ray Fluorescence Analyzer
CCD	Charge Coupled Device
CT	Cathode Luminescence
CTI	CCD/Transmit Instrument
DC	Direct Current
DASI	Digital Array Scanned Interferometer
DOD	Department of Defense
DOE	Department of Energy
DSC	Differential Scanning Calorimeter
DT	Diffraction Tomography
EM	Electromagnetic
EOS	Earth Observing System
EUV	Extreme Ultraviolet
EVA	Extravehicular Activity
ExPO	Exploration Programs Office
FFT	Fast Fourier Transform
FLO	First Lunar Outpost
GCMS	Gas Chromatograph Mass Spectrometer
GR/NS	Gamma Ray/Neutron Spectrometer
ILRA	Integrated Lunar Regolith Analyzer
IR	Infrared
ISMU	In Situ Materials Utilization
IVA	Internal Vehicular Activity
JSC	Johnson Space Center
JPL	Jet Propulsion Laboratory
KREEP	Potassium, Rare Earth Elements, Phosphorus
LIBS	Laser Induced Breakdown Spectrometer
LIDAR	Laser Image Detection and Ranging
LLDEF	Lunar Long Duration Exposure Facility
LMEPO	Lunar and Mars Exploration Program Office
LOLA	Lunar Observer Laser Altimeter
LPI	Lunar Planetary Institute
LRV	Lunar Roving Vehicle
LTT	Lunar Transit Telescope
LUMIS	Lunar Ultraviolet Mapping Interferometric Spectrometer

Acronyms (concluded)

MACE	Mars Aqueous Chemistry Experiment
MEV-GEV	Magnetics-Environment-Volatiles/Gravity-Environment-Volatiles
MHD	Magnetohydrodynamics
MIT	Massachusetts Institute of Technology
PI	Principal Investigator
PPO	Planetary Projects Office
RADAR	Radio Detection and Ranging
RFI	Radio Frequency Interference
RHU	Radioisotope Heater Unit
RTG	Radioisotope Thermal Generator
SAIC	Science Applications International Corporation
SALUTE	Steerable Automatic Lunar Ultraviolet Telescope Explorer
SAR	Synthetic Aperture Radar
SBCA	Siderostat/Beam Compressor Assembly
SEI	Space Exploration Intitiative
SERC	Space Engineering Research Center
SIMS	Secondary Ion Mass Spectrometer
SLIM	Small Lunar Information Mission
SWUAAT	Southwest Ultraviolet Astronomical/Atmospheric Telescope
TAPS	Thermal Analyzer for Planetary Soils
TBD	To Be Determined
TBS	To Be Supplied
TES	Thermal Emission Spectrometer
TSU	Thermal Storage Unit
UHF	Ultra High Frequency
UV	Ultraviolet
VIRIS-PIDDP	Visible Infrared Imaging Spectrometer-Planetary Instrument Definition and Development Program
VLF	Very Low Frequency
WIMP	Weakly Interactive Massive Particle
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence
XRFI	X-Ray Fluorescence Imager

Introduction

This catalog is organized into three parts. Part I, which contains payload descriptions for the moon, divides lunar payloads into three sections. The first section, Lunar Science Payloads, is a general collection of lunar payloads grouped according to scientific discipline. These can be used for any appropriate lunar mission and represent the core of lunar payload data. The next two sections list specialized science payloads for a lunar orbiting mission, the Lunar Scout, and a robotic mission using a common lunar lander, the Artemis Mission. A brief mission description is included for both these unmanned lunar missions, which were proposed and studied by NASA.

Part II contains payload descriptions for Mars. Its one section, Mars Science Payloads, is a general collection of martian science payloads grouped according to scientific discipline. There are fewer payloads in this section than in the lunar section because the early focus in the ExPO office was on lunar missions. More Mars payloads are expected to be added in time.

Part III, entitled "Applications of the Catalog of Lunar and Mars Science Payloads," shows how this catalog contributed to a human lunar mission, First Lunar Outpost (FLO), and a human Mars mission, Mars Exploration Program Study. Both of these missions have been studied by NASA over the last two years. Brief mission descriptions are included for each study.

The payload descriptions from the final JPL document are not repeated unless there has been an update or change to the JPL data. If the reader wants to consult this earlier data, do so in the JPL "FY91 Final SEI Science Payloads: Description and Delivery Requirements."

Technology Readiness Scale

Technology readiness is noted for each science payload in this catalog. Technology readiness is evaluated qualitatively using a scale developed by NASA's Office of Aeronautic and Space Technology. Levels 1-13 are defined as follows:

Level 1: Basic principles observed and reported
Level 2: Technology concept and/or application formulated
Level 3: Analytical and experimental critical function and/or characteristic proof-of-concept
Level 4: Component and/or breadboard validation in the laboratory
Level 5: Component and/or breadboard demonstration in the relevant/simulated environment
Level 6: System validation model demonstrated in a relevant/simulated environment
Level 7: System validation model demonstrated in an actual environment
Level 8: Technology applied to construction of component and/or breadboard of expected flight hardware configuration
Level 9: Capability of full scale subsystem prototype demonstrated in ground tests
Level 10: Capability of full scale subsystem prototype demonstrated in actual environment
Level 11: Full scale system prototype
Level 12: Capability demonstrated in flight test of flight hardware
Level 13: Capability demonstrated by operational flight experience

The readiness levels applied to payloads in this document have been applied without a significant level of analysis. Preliminary, phase-A level studies of each payload should be conducted in the future to refine these evaluations to get an accurate determination of the level of development that will be required for each instrument or each instrument package.

Part I: *The Moon*

A. *Lunar Science Payloads*

1. Geoscience Payloads

LUNAR GEOLOGIC FIELD EQUIPMENT PACKAGE

Date: 8/10/92

PAYLOAD SUMMARY	
Estimated Mass:	**336 kg**
Estimated Volume:	**1.8 m^3**
Estimated Power:	**500 W; supplied by rechargeable batteries in applicable instruments**
Estimated Data Rate:	**all data stored internally in applicable instruments**

Rationale

Proper geologic field work will require hand tools to tackle a variety of tasks, such as removal of samples from larger rocks, emplacing probes in the lunar regolith, recovering drive-type core tubes and properly documenting sample environment. This equipment allows the astronauts to properly carry out the necessary tasks to ensure that good samples are taken, properly documented, and stored.

Description

Geologic field tools are the suite of basic tools that will be delivered to the lunar surface for use in collecting, documenting, storing, and transporting rock, soil, and drive-tube samples. Similar sets of field tools were developed for the Apollo program, and in many cases, identical tools will be used for SEI field activities. Where appropriate, estimates for the mass, volume, etc. were taken from the corresponding Apollo equipment. Each equipment package contains the necessary tools, collection bags, and storage containers to outfit a team of 2 astronauts.

A brief description and the purpose of each component is listed below:

TOOLS	PURPOSE
Regolith drill	Collect up to 3 meter cores of soil samples; drill holes for emplacement of heat flow and other geophysical experiment probes
Rock drill	Collect ~2 cm diameter rock cores up to 15 cm deep from surface samples; includes bits.
Rock Hammer	Remove samples off of boulders; emplace drive tubes.
Chisel	Remove samples off of boulders; trim samples
Rake	Collect representative populations of samples >1 cm in size from the lunar regolith.
Rover soil sampler	Allows an astronaut to collect a soil sample without getting off an unpressurized rover.
Adjustable angle scoops	Collect soil samples, trench.
Tongs	Pick up rock samples without bending over.

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Long extension handle	Handle which will fit on any of the above tools through use of a universal fitting. Allows extension of the astronauts reach, and can provide a limited increase in leverage if needed.
Drive tube	Collect 4-cm by 40-cm long soil sample; can be mated to produce longer cores. Physically driven in to the soil using the rock hammer to obtain sample.
Gnomon	Small folding device used for photodocumentation of sample environment. Allows determination of the local vertical, and also provides a color/grey scale for calibration of photographic images.
Orientation/inclonometry tool	Similar to a Brunton compass, this tool will allow determination of orientation of rock units.
Sample scale	Allows weighing of samples prior to storage.
Tool carrier	Rack for carrying tools on unpressurized rover.
Camera equipment	Includes all camera bodies, backs and lenses for adequate photo-documentation of sample environment
CONTAINERS	
Sample collection bag	Soft-sided, non-sealing bag for storing samples that will not be kept in the lunar ambient environment.
Sample return container	Aluminum case which has provisions for sealing in the lunar environment; used for samples where it is important to maintain lunar ambient conditions.
CONSUMABLES	
Documented sample collection bags	A variety of plastic bags for collecting samples in prior to storage in containers.
Photographic film	A variety of formats and types of photographic film to be used to document EVA activities.

Power Consumption

Most equipment will not require any electrical power to operate. The following tools will require battery power:

Regolith drill	2150 W-hr @ 430 W
Rock drill	2000 W-hr @ 500 W
Multispectral imager	2000 W-hr @ 500 W

Payload Breakdown

	Mass (kg)	Volume (cm^3)	Number/package	Total Mass (kg)	Total Volume (cm^3)
TOOLS					
Regolith Drill (includes bits)†	13.9	16704	1	13.9	16704
Rock Drill (includes bits)	6	4000	1	6	4000
Geologic Hammer	1.3	1200	2	2.6	2400
Chisel	0.2	100	2	0.4	200
Rake	1.5	9100	2	3	18200
Rover soil sampler	0.1	500	1	0.1	500
Small adjustable angle scoop	0.5	1100	2	1	2200
Large adjustable angle scoop	0.6	1200	2	1.2	2400
32-inch tongs	0.2	1600	2	0.4	3200
Long extension handle	0.8	150	2	1.6	300
4-cm drive tube	0.5	11000	45	22.5	495000
Gnomom	0.3	5300	1	0.3	5300
Orientation/inclonometry tool	2	1000	1	2	1000
Sample scale	0.2	900	1	0.2	900
Large tool carrier	5.9	72600	1	5.9	72600
Camera Equipment	25	10000	1	25	10000
Multispectral imager	35	160000	1	35	160000
TOOLS SUBTOTAL				121	0.79 m^3
CONTAINERS					
Sample collection bag	0.8	3300	25	20	82500
Lunar sample return container	6.6	28000	10	66	280000
Regolith drill stems (per 3-meter hole)	1.2	1267	10	12	12670
CONTAINERS SUBTOTAL				98	0.38 m^3
CONSUMABLES					
Documented sample collection bags*	25		1	25	
Photographic film	25	300000	1	25	300000
CONSUMABLES SUBTOTAL				50	0.30 m^3
COMBINED SUBTOTALS				269 kg	1.47 m^3
25% MARGIN				67	0.37
TOTAL				336 kg	1.84 m^3

†Tool kit includes sufficient bits and stems to drill ten 3-meter holes.
*Stored in sample return containers during transport to the surface.

Data Rate
Most data will not require any data storage/transmittal capability. The multispectral imager will store all data internally; consequently, no linking with the communications infrastructure is needed.

Data Management Strategy
TBD

Operational Constraints
None.

Crew Interaction
Operated by EVA crew. Training and experience as a field geologist will be necessary pre-requisite.

Payload Delivery Options
This payload comes as a single packaged unit, and should not be broken down into smaller components.

Estimated Set-up Time
1 IVA hour, 1 EVA hour.

Maintenance Needs
Inspection, cleaning, repair and replenishment of consumables as needed between EVAs. Battery recharge for rock drill and multispectral imagers. Estimate <1 hour IVA between EVAs.

Technology Assessment
Most tools were developed for Apollo; a review of designs and operational experience with subsequent changes in design to correct design faults may be necessary. Otherwise, most tools may be considered at Level 13 in NASA's technological readiness scale (see Appendix 1). The orientation/inclonometry tool was not developed for Apollo; development should be considered at technology readiness level 1. Multispectal imager will need development, and should be considered at a technology readiness level 1.

Infrastructure Interface Requirements
Rover designs should accomodate tool carriers.
Astronaut support during EVA will require voice, video data links to communications infrastructure.
Rechargeable batteries will require power off of lander/base power infrastructure.

Resupply Needs
Consumables and replacement batteries as needed on a yearly basis.

Science/Exploration Community Contact
TBD

References
Allton, J. H., 1989, Catalog of Apollo Lunar Surface Geological Sampling Tools and Containers: Johnson Space Center Publication JSC-23454.
Budney, C. J., Ionasescu, R., Snyder, G. C. and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

LUNAR GEOPHYSICAL MONITORING PACKAGE

Date: 8/12/92

PAYLOAD SUMMARY	
Estimated Mass:	**216 kg**
Estimated Volume:	**0.5 m^3**
Estimated Power:	**96 W**
Estimated Data Rate:	**data rates for individual instruments range from 0.04 kbps to 1 kbps**

Rationale
Numerous questions about the structure, composition, and evolution of the lunar interior remain. The Lunar Geophysical Monitoring Package contains instruments designed to address these questions by measurements of time variant values of selected geophysical parameters. Among the data provided by these instruments is information on the variation of the Moon's magnetic field strength, seismic activity, heat flow, micrometeorite and impact ejecta flux, and the distance between the experiment site and observatories on the Earth.

Description
The Lunar Geophysical Monitoring Package is a collection of geophysical instruments designed to measure the variation over time of selected geophysical parameters. The package has a pedigree that extends back to the Apollo Lunar Scientific Experiments Package (ALSEP) and the preliminary concept of the instruments is based on ALSEP designs.

The set of instruments contained in the package will be deployed at a variety of locations across the lunar surface. Widespread deployment of these packages will allow geophysicists to characterize the interior of the Moon in detail and standardization of the instrument sets will insure that the same data set is collected at each location. As in the Apollo program, however, there may be additional instruments that can be deployed on a one-time basis to answer specific geophysical questions. To that end, a placeholder allows mass-volume-power planning for the package to be sufficiently robust that additional instrumentation can be added later without perturbing related surface accommodation planning.

As with ALSEP, it is likely that many of these packages will be deployed in locations where regular return for maintenance or component change-out is unlikely. Therefore, package and instrument designs will need to be robust, long lasting, and self contained with respect to power and communications capability.

The purpose of each of the instruments is as follows:

Central Station	Controls power conditioning and distribution, processing of all commands controlling experiments, and transmittal of data back to Earth.

Magnetometer	Measures the field strength and direction of the lunar magnetic field with a range of ~0 – ±200 γ and a sensitivity of 0.1 γ (based on designs in NASA SP-289, pg. 9-4).
Passive Seismometer	Measures the magnitude and direction to lunar seismic events with a sensitivity of ~10^{-3} to 10^{2} Hz with amplitudes on the order of 10^{-1} nm (based on designs in NASA SP-289, pg.8-3).
Heat Flow Probes	Measures the rate of heat flow from the lunar interior by temperature and thermal-property measurements in the lunar subsurface; sensitivity ranges from ~10^{-5} to 10^{-3} W/cm-°K and ±0.05 °K (based on designs in NASA SP-289, pp. 11-2–11-3).
Ejecta and Meteorites Experiment	Measures the impact of primary cosmic dust particles and lunar ejecta emanating from meteorite impact sites on the Moon; sensitivity includes particles with masses ≥10^{-14} g, diameters ≥2 x 10^{-5} cm, and speeds ≤75 km/sec (based on designs in NASA SP-330, pg. 16-3).
Laser Ranging Retroreflector	Measures the distance from the Earth to the deployment site on the moon with centimeter accuracy.
Discretionary PI Science	Placeholder to allow augmentation with additional instruments, based on future experiment designs.

Power Consumption

Power will be supplied to each instrument after conditioning and distribution by the central station. ALSEP stations successfully used radioisotope thermal generators for power, although some form of advanced solar cell/battery technology may be available for this package. Because geophysical packages may be deployed in areas remote from a lunar outpost, the power source selected will have to be maintenance free and provide reliable power for a period of several years without human interaction. Conventional batteries are therefore unlikely to be used.

Planned power consumption on each instrument is as follows:

Central Station	25 W
Magnetometer	10 W
Passive Seismometer	10 W
Heat Flow Experiment	5 W
Ejecta and Meteorites Experiment	2 W
Discretionary PI Science	25 W

Data Rate

Each instrument will have its own data rate; present maximum is planned at 1 kbps.

Data Management Strategy
The present configuration calls for data to be processed through a central station, similar to ALSEP designs. Alternatively, it may be possible to provide each instrument with its own data handling and transmission capability. Preliminary design studies should determine the most efficient and feasible method of data handling. Deployment of stations on the lunar farside will require additional communications infrastructure to transmit data to terrestrial ground stations.

Payload Breakdown

Component	Mass (kg)	Volume (m^3)	Power (W)	Data Rate (Kb/s)
Central Station	25	TBD	25	
Magnetometer	10	0.1	10	0.04
Passive Seismometer	15	TBD	10	1
Heat Flow Experiment	10	TBD	5	0.02
Ejecta and Meteorite Exp.	3	0.1	2	0.5
Laser Ranging Retroreflector	10	0.1	0	0
Discretionary PI Science	100	0.1	25	TBS
SUBTOTAL	173	0.4	77	1.56
25% MARGIN	43	0.1	19	0.39
TOTAL	216	0.5	96	1.95

Operational Constraints
None.

Crew Interaction
Initial deployment and start-up. Maintenance on those stations close to outposts. Stations deployed at considerable distance may have to be serviced robotically in the event of unscheduled maintenance or repair.

Payload Delivery Options
The payload should be packaged and delivered as a single payload.

Estimated Set-up Time
8 EVA hours.

Maintenance Needs
These instruments should be designed to operate autonomously, without requirements for regular maintenance.

Technology Assessment
Instruments to measure these parameters have been in extensive use both terrestrially and as ALSEP payloads for a significant period of time, suggesting technology readiness level 13. Some development work may be required on power systems if an advanced solar cell/battery power source is desired over the existing radioisotope thermal generators. This suggests a technology readiness level 2 for power systems.

Infrastructure Interface Requirements
Communications/data links to transmit data to terrestrial stations.

Resupply Needs

ALSEP stations were considered expendable; that is, no provision was made for replacement or repair of malfunctioning instruments. Whether these stations are considered expendable as well will depend on the cost of production, deployment location and philosophy, and the level of transportation infrastructure on the lunar surface.

Science/Exploration Community Contact
TBD

References

Budney, C. J., Ionasescu, R., Snyder, G. C. and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

Natl. Aeron. Space Admin. (1972), Apollo 15 Preliminary Science Report: NASA SP-289, U. S. Govt. Print. Off., Wash. D.C.

Natl. Aeron. Space Admin. (1973), Apollo 17 Preliminary Science Report: NASA SP-330, U. S. Govt. Print. Off., Wash. D.C.

LUNAR TRAVERSE GEOPHYSICAL PACKAGE

Date: 8/13/92

PAYLOAD SUMMARY	
Estimated Mass:	**401 kg**
Estimated Volume:	**TBD (>0.1 m^3)**
Estimated Power:	**100 W**
Estimated Data Rate:	**data rates for individual experiments range up to 1.6 Mbps**

Rationale
The Lunar Traverse Geophysical Package contains a variety of experiment packages that will be used by an astronaut crew to determine the subsurface structure of the Moon. These instruments will be deployed as part of normal traverse operations and will provide successive profiles of the lunar subsurface using a variety of measurement parameters.

Description
The Lunar Traverse Geophysical Package is a collection of geophysical instruments that are designed to profile the subsurface structure of the Moon at a range of scales and using a variety of measurement parameters. The package has a pedigree that extends back to many of the experiments deployed during the Apollo Program.

The set of instruments contained in this package will be deployed at various locations on the lunar surface during geologic traverses. Routine use of these instruments will allow the progressive development of a picture of the subsurface structure in the vicinity of the outpost. Although the complement of instruments planned should cover a variety of potential geophysical techniques, there may be additional instruments that can be deployed to answer specific geophysical questions. To that end, a placeholder for discretionary principal investigator science is included in the package. This placeholder allows mass-volume-power planning for the package to be sufficiently robust that additional instrumentation can be added later without perturbing related surface accommodation planning.

The purpose and sensitivity of each of the instruments is as follows:

Electromagnetic Sounder	Determine local structure at various scales; direct detection of water and volatiles; determine the changes in the dielectric constant and bulk densities of lunar materials; sounding frequencies from 1 to 1,000 MHz.
Active Seismic Experiment	Determine the structure of the subsurface using a combination of geophones and detonation of explosive packages to generate seismic waves in the upper few kilometers of the lunar crust
Traverse Gravimeter	Determine variations in the Moon's gravity at selected locations on the lunar surface; sensitivity to variations of 0.1 gal

Electrical Properties Experiment	Determine subsurface structure by detecting variations in electrical current transmitted into the lunar crust; direct detection of subsurface water to a depth of 1-2 km
Profiling Magnetometer	Measure the local variation in the moon's magnetic field to 0.5 γ
Discretionary PI Science	Placeholder to allow augmentation with additional instruments, based on future experiment designs.

Payload Breakdown

Component	Mass (kg)	Volume (m^3)	Power (W)	Data Rate (Mb/s)
Electromagnetic Sounder	10	0.02	10	1.6
Active Seismic Experiment*	175	0.01	10	1
Traverse Gravimeter	15	0.01	10	
Electrical Properties Experiment	16	0.04	10	
Profiling Magnetometer	5	TBS	10	
Discretionary PI Science	100	0.1	25	TBS
SUBTOTAL	321	0.18	75	2.6
25% MARGIN	80	0.05	19	0.7
TOTAL	401	0.23	94	3.3

*includes explosive packages for seismic energy source.

Power Consumption

Power will be supplied internally to each instrument by means of rechargable batteries. Instruments should be able to go at least 1 month of normal use between charge, which should allow the instrument package to be used on a long pressurized rover traverse without drawing off the internal power of the rover.

Preliminary estimates for power consumption on each instrument is as follows:

Electromagnetic Sounder	10 W
Active Seismic Experiment	10 W
Traverse Gravimeter	10 W
Electrical Properties Experiment	10 W
Profiling Magnetometer	10 W
Discretionary PI Science	25 W

Data Rate

Data rate on each instrument will be variable, based on instrument design and the complexity of the signals returned.

Data Management Strategy

Each instrument should store data internally in either a tape cassette or on a digital disk for retrieval later for data reduction.

Operational Constraints

None.

Crew Interaction

Deployment and operation; normal maintenance and repair as necessary.

Payload Delivery Options
The payload should be packaged and delivered as a single payload.

Estimated Set-up Time
These instruments should be operated routinely as part of geology and/or geophysics traverses. Estimates for individual instruments vary. The most labor intensive will be the active seismic experiment, which may take up to several hours to set up a geophone line. Other packages, such as the traverse gravimeter, should be able to be deployed, operated, and then stowed within several minutes. As experiment designs become more mature, time estimates should be determined in order to refine EVA operation planning time.

Maintenance Needs
Routine maintenance as required.

Technology Assessment
Instruments to measure these parameters have been in extensive use both terrestrially and, in some cases, as part of the Apollo Program, suggesting technology readiness level ranging from level 5 to level 13.

Infrastructure Interface Requirements
Data recording should be built into each instrument, so no interface requirements are anticipated.

Resupply Needs
Explosives packages will need to be resupplied on a regular basis. Also, the data recording medium in each experiment may need resupply depending on the data volume recorded.

Science/Exploration Community Contact
TBD

References
Budney, C. J., Ionasescu, R., Snyder, G. C. and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

Natl. Aeron. Space Admin. (1972), Apollo 15 Preliminary Science Report: NASA SP-289, U. S. Govt. Print. Off., Wash. D.C.

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GEOSCIENCE LABORATORY INSTRUMENTS

Date: 1/17/92

PAYLOAD SUMMARY

LANDER GEOSCIENCE LABORATORY

Estimated Mass:	**46 kg**
Estimated Volume:	**0.1 m^3**
Estimated Power:	**181 W**
Estimated Data Rates:	**all data stored in lander on appropriate magnetic or optical storage medium; returned to earth as stored data**

HABITAT GEOSCIENCE LABORATORY

Estimated Mass:	**123 kg**
Estimated Volume:	**0.2 m^3**
Estimated Power:	**396 W**
Estimated Data Rates:	**all data stored in habitat on appropriate magnetic or optical storage medium; returned to earth as stored data**

Rationale
The volume and mass of samples that will be collected during an extended lander stay on the lunar surface, or during establishment of an outpost on either the lunar or Martian surface, is likely to be too great to return to Earth. Inclusion of basic laboratory tools for sample analysis allows preliminary investigations of collected samples to take place, allows"high-grading" of samples and development of suites of samples from a particular traverse, reducing the number of samples to be returned. In addition, sample analysis capability will allow real-time analysis of samples in as close to pristine lunar or Martian conditions as possible.

Description
The instruments for each laboratory set will be built into either the lander or habitat prior to delivery on either the lunar or Martian surface. Each instrument has a specific analysis capability, summarized below:

Instrument	Function
Binocular Microscope	Preliminary, magnified examination of rock and soil samples
Mössbauer Spectrometer	Iron mineralogy (metal and Fe-bearing minerals; soil maturity)
Paleomagnetics magnetometer	Determination of residual rock magnetism
Sample preparation/preservation equipment	Prepare samples for return to Earth
Optical sizing equipment	Grain size analysis
X-ray Fluorescence	Chemical composition
Proton, α-, X-ray spectrometer	Chemical composition
γ-ray spectrometer	Chemical composition
Scanning electron microscope with energy dispersive x-ray analysis	High magnification imaging and chemical composition
Gas chromatograph	Gas analysis
Ferromagnetic resonance spectrometer	Iron metal analysis

PAYLOAD BREAKDOWN

INSTRUMENT	MASS (kg)	POWER (W)	VOLUME (m^3)	BITS/ANALYSIS*
LANDER GEOSCIENCE LABORATORY				
Binocular microscope	5	20	0.01	10 Mb
Mössbauer spectrometer	2	4	0.003	60 kb
Paleomagnetics Magnetometer	10	20	0.02	1 kb
Sample preparation and preservation equipment	20	100	0.05	
SUBTOTAL	37	144	0.08	
25% MARGIN	9	36	0.02	
TOTAL	46	180	0.10	
HABITAT GEOSCIENCE LABORATORY				
Binocular microscope	5	20	0.01	10 Mb
Mössbauer spectrometer	2	4	0.003	60 kb
Paleomagnetics Magnetometer	10	20	0.02	1 kb
Sample preparation and preservation equipment	20	100	0.05	
Optical sizing equipment	2	2	0.002	1 kb
X-ray fluorescence	3	5	0.002	20 kb
Alpha, Proton, X-ray spectrometer	5	30	0.004	320 kb
Scanning electron microscope w/ energy dispersive x-ray analysis capability	12	25	0.042	10 Mb
Gas analysis (GCMS)	19	60	0.028	800 kb
Ferromagnetic Reson. Spectrom.	20	50	0.03	50 kb
SUBTOTAL	98	316	0.191	
25% MARGIN	25	79	0.05	
TOTAL	123	395	0.24	

*total data output from each instrument in a single analysis operation.

Power Consumption

Lander geoscience laboratory: 181 W discontinuous
Habitat geoscience laboratory: 396 W discontinuous
All analytical instruments will draw some power in a continuous standby mode; the amount will depend on final instrument design.

Data Rate

The total data output from these instruments depends on the number of samples collected and the number of analyses run per sample. Each instrument should be designed with either an internal data storage capability or the ability to interface with an appropriate data storage device. Although optical storage disks are preferred, due to the large volume of data generated by each analysis, magnetic media can be used as well. It is unlikely that continuous transmission of data to an Earth location would be required; however, it is estimated that data rates of ~100 kbits per second would need to be accommodated. Transmission of processed data would require lower rates.

Operational Constraints
Both sets of instruments operate in a pressurized lander/habitat environment. A vacuum source is required to operate the scanning electron microscope and all spectrometers.

Crew Interactions
These instruments will require a trained crewmember to operate, preferably one with a background in geology/geochemistry. Real-time, terrestrially-based assistance is feasible if a communications infrastructure exists to transmit data, but it is not required for normal operations. In addition, at least one crewmember should be trained in maintenance and troubleshooting.

Payload Delivery Options
Each set of instruments will be pre-packaged in a laboratory module or lander prior to launch for the lunar surface. Consequently, payloads may not be broken down into smaller packages.

Estimated Set-up Times
Built into habitat or lander prior to launch.

Maintenance Requirements
Periodic maintenance (schedule dependent on instrument design).

Technology Assessment
Working models of all instruments have been constructed, suggesting technology readiness level 4. Some development work adapting the instruments to a lander or habitat will be necessary, based on lander/habitat design.

Infrastructure Interface Requirements
Power to run instrument packages.
Comm/data links if it is necessary to transmit data back to Earth.
Lander laboratory instruments will be an integral part of the lander; therefore, they need to be included in lander design at the beginning of the design process.

Resupply Needs
Optical disks or magnetic media, depending on data storage design.

References

Budney, C. J., Ionasescu, R., Snyder, G. C. and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

Morris, R. V., 1992, personal communication.

10-METER DRILL

Date: 8/13/92

PAYLOAD SUMMARY	
Estimated Mass:	**263 kg**
Estimated Volume:	**0.1 m^3**
Estimated Power:	**6120 W (discontinuous)**
Estimated Data Rate:	**NA**

Rationale
A drill of this capability will be a basic research tool for any geologic and geotechnical research activities at a lunar or Mars outpost. The 10-meter depth capability should be sufficient to collect a soil core from the surface to the base of the regolith or from crystalline rock units, drill emplacement holes for heat flow or neutron probes, and to recover cores that may answer questions on the origin and quantity of volatiles on both planets.

Description
This drill owes its initial pedigree to the Apollo Drill, which was limited to drilling in the lunar regolith. The drive unit will be similar to the Apollo drill motor, but has higher power, more torque and improved heat rejection to permit longer operating periods and drilling in consolidated rock units as well as regolith. The unit is designed with a concentric drive so that sections of the drill string can be added and sections of collected core removed from the top of the drill. Bit and string assemblies for two kinds of operations are included: a hollow soil auger capability to take cores of the regolith, and a hardened bit that can take cores through crystalline rock. In each case, the drill should be able to return 10 meters of 2-cm diameter core. Individual drill string segments should be 50-cm long. The drill should be used attached to the back of the rover so as to apply sufficient force (estimated to be ~800 N) to the drill bit during operation. Removal of the drill string and core also may require a significant force. Consequently, a system for removal of the drill string should be developed as part of the drill package.

Payload Breakdown

Component	Mass (kg)	Volume (m^3)	Power (W)
Drill string	4.0	0.2	NA
Sample sleeve	0.1	0.01	0
Drive head	70	0.02	6000
Mount	100	0.03	0
Sample Rack	35	0.03	20
SUBTOTAL	210	0.26	6020
25% MARGIN	53	0.07	1565
TOTAL	263	0.33	7585

Power Consumption
6120 W discontinuous; to reduce the mass of the drill, power should be drawn from the rover power source rather than from integral batteries.

Data Rate
None.

Data Management Strategy
None.

Operational Constraints
None.

Crew Interaction
Unpacking, set-up and operation.

Payload Delivery Options
Delivered as a single package; delivery should include drill bits and string as well as drill.

Estimated Set-up Time
10 EVA hours.

Maintenance Needs
Drill bit exchange and replacement; drive unit lubrication as needed.

Technology Assessment
Methods of heat rejection, cuttings removal, soil core retention and basic drill design need to be developed. Estimate Technology Readiness Level 3.

Infrastructure Interface Requirements
Mating and interface with rover designs to provide adequate power and anchoring for drilling and core removal.

Resupply Needs
Drill bits and drill string; initial package includes sufficient drill string to drill ten 10-meter cores.

Science/Exploration Community Contact:
TBD

References
Allton, J. H., 1989, Catalog of Apollo Lunar Surface Geological Sampling Tools and Containers: Johnson Space Center Publication JSC-23454.

Budney, C. J., Ionasescu, R., Snyder, G. C. and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

1-KILOMETER DRILL

Date: 7/21/92

PAYLOAD SUMMARY	
Estimated Mass	**20,000 kg**
Estimated Volume	**200 m^3**
Estimated Power	**500 KW**
Estimated Data Rate	**1 Kb/s**

Rationale
The 1-km Drill will support investigations of lunar materials and their history to depths of the order of one kilometer. It will allow extraction of usable resource materials from these depths and will permit emplacement of down-hole instrumentation for scientific and resource purposes.

Description
This is a partly-automated drill rig similar in concept to Earth-based oil rigs but designed for transport to and use on the Moon. In the expected absence of drilling fluids, the drill bit and string may have to use entirely different technology from that used on Earth. Otherwise conventional but lightweight technology can be used, modified for minimum human operations and EVA demand. Drill string parts must be limited in length (to approximately 20 m each) in order to fit within the transportation system capacity. Therefore assembly and disassembly must be highly automated. Drilling and movement to new hole sites are assumed to be supported by and powered from base systems.

Payload Breakdown

Component	Mass (kg)	Volume (m^3)	Power (kW)	Data Rate (Kb/s)
Drill String	~10,000	100	0	0
Drive Unit	~5,000	10	500	1
Derrick	~5,000	90	0	0
PACKAGE SUBTOTAL	~20,000	200	500	1
25% MARGIN	5000	50	125	0.25
TOTAL	25000	250	625	1.25

Power Consumption
500 kW

Data Rate
1 Kb/s.

Data Management Strategy
TBD

Operational Constraints
Requires monitoring during drilling, probably including drill-bit temperature, depth, and drive-unit power consumption and temperature. Some type of foundation or prepared excavation must exist for erection of derrick. In addition, sufficient anchoring must be provided to keep support stable during drilling operations.

Crew Interaction
Extensive EVA required for setup, breakdown, transport, and reemplacement. EVA required for examination and selection of extracted cores.

Payload Delivery Options
Delivered (possibly in parts) by large cargo landers. Set up by combination of teleoperations from base and EVA.

Estimated Set-up Time
TBD

Maintenance Needs
Drill bit replacement; drive unit repair and refurbishment; routine inspections; maintenance of power supply and conversion equipment at base to meet drilling demand on shared basis.

Technology Assessment
High mechanical technology will be required throughout because of dry drilling, the strong demand for minimum EVA and best power efficiency, and the difficult of recovering from stuck, broken, etc. equipment. Although the technology exists for terrestrial drilling to this depth, the above uncertainties for operation in the lunar environment give this payload a technology readiness level of 3-4.

Infrastructure Interface Requirements
Drilling and movement to new hole sites are to be supported by and powered from base systems.

Resupply Needs
Drill bits and drill string; initial package includes sufficient drill string to drill one or more 20-cm diameter holes to 1-km depth in lunar mare or polar crater fill materials (depth capability in highland materials in TBD).

Science/Exploration Community Contact
TBD

References

Budney, C. J., Ionasescu, R., Snyder, G. C., and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

Kinney, M. H. and Podnieks, E. R., 1989, Lunar Drill Development Review, PR-T-1241R: U.S. Bureau of Mines, Twin Cities Research Center.

A. Lunar Science Payloads
2. Astronomy and Astrophysics Payloads

SMALL RESEARCH TELESCOPE

Date: 7/30/92

PAYLOAD SUMMARY	
Estimated Mass:	**200 kg**
Estimated Volume:	**2.5 m^3**
Estimated Power:	**500 W**
Estimated Data Rate:	**100 kbps**

Rationale
This telescope will provide an opportunity to perform lunar-based astronomical observations early in the lunar exploration program. Telescopes can be deployed either on an augmented Artemis-class lander or as a payload on the first piloted lunar mission. The chief purpose of the instrument is to provide an early low-cost science return that can be disseminated to educational institutions and to the general public. In addition, there may be opportunities for high school and university programs to select observational targets.

In addition to scientific return, a major objective of the program will be to provide engineering data and experience in the deployment and operation of telescopes in the lunar environment. Some of the issues that will need to be investigated with regard to this telescope facility are the effects of lunar regolith on telescope mounts and pointing systems, the effects of thermal cycling on observation scheduling, and the effects of the lunar radiation environment on the telescope optics and electronics.

Description
This telescope is a 1-m class optical instrument capable of acquiring targets through remote, Earth-based control, tracking these targets, and transmitting images back to a terrestrial ground station. The telescope will be self leveling and self aligning through utilization of a stored catalog of stellar images. The image sensor will be a cooled large format CCD array, possibly with a prism and dichroic filters that can be moved into and out of the optical path to obtain low-resolution spectral data.

Power Consumption
Approximately 500 Watts, supplied through either RTGs or a battery/solar cell combination. The telescope will need to operate during the lunar night as well as lunar day.

Data Rate
Approximately 100 Kb/s.

Data Management Strategy
TBD

Operational Constraints
The small research telescope, like all optical instruments, will need to be located at least 10 km from landing pads and high-traffic areas to avoid dust contamination of the optics and mechanical structures. Problems of thermal cycling and its effect on optics, telescope structure, and usage schedule remain unknown.

Crew Interaction
Setup and initial alignment.

Payload Delivery Options
This payload will be delivered as a single unit to the lunar surface on either an autonomous or piloted mission.

Estimated Set-up Time
5 EVA hours

Maintenance Needs
No routine maintenance is anticipated, although occasional servicing (e.g., cleaning optics) may be necessary.

Technology Assessment
Similar telescopes exist and are in use by the astronomical community, including in remotely operated situations. These existing telescope designs will have to be space-rated, and they will have to be adapted to powering by RTGs. Also, some reduction in instrument weight may be necessary to obtain the desired 200 kg payload mass. All of these factors suggest a technology readiness level 6.

Infrastructure Interface Requirements
For telescopes landed on Artemis-class landers, communications interface may need to be provided that is capable of the data rates projected. Telescopes deployed by a human crew may interface with an outpost or lander communications infrastructure or, alternatively, with an integral communications capability.

Ressuply Needs
Remote telescopes will not be supplied. Telescopes deployed as part of a manned outpost may be resupplied with batteries or RTGs as appropriate.

Science//Exploration Community Contact
James Cutts, Jet Propulsion Laboratory

References
Budney, C. J., Ionasescu, R., Snyder, G. C. and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

LUNAR ULTRAVIOLET TRANSIT EXPERIMENT (LUTE)

Date: 7/30/92

PAYLOAD SUMMARY	
Estimated Mass (telescope only):	**200 kg**
Estimated Dimensions:	**Cylinder 2.7 m long x 1.1 m diameter**
Estimated Power:	**100 W continuous**
Estimated Data Rate:	**200 kbps continuous**

Rationale

The Lunar Ultraviolet Transit Experiment (LUTE) is a stationary, 1-meter UV optical telescope to be placed on the lunar surface early in our return to the Moon. The LUTE will be the first instrument to profit from the unique advantages of the Moon as a superstable astronomical platform with negligible atmosphere. Its scientific potential has been established with an Earth-based analogue.

Science: The LUTE will produce a UV imaging survey of the universe to a limiting magnitude of 27, with higher angular resolution and broader wavelength coverage over a larger fraction of the sky than can be produced on Earth. Each year the LUTE will survey more than 300 sq. deg. of the celestial sphere with 0.5 arcsec resolution. This swath can be reexamined yearly to enable astrometric assessments of interesting targets, or the telescope can be tilted annually to new declinations (maximum of 12 degrees). This will allow the survey of more than 3000 sq. deg. of the celestial sphere during the multi-year missions. The bandwidth accessible with the LUTE extends from 1000 to 3000 A in three bandpasses currently assumed to be 800 A wide. This ensures acquisition of a statistically complete sample of both point and extended sources which are bright in the UV. The LUTE will provide unique access to rest-frame Lyman α, complementing contemporary space observations and supplementing ground-based observations. The data will support research on hundreds of point-source problems ranging from asteroid coma and cometary H and OH to analysis of UV colors in main sequence stars, investigations of cataclysmic variables and accreting binaries, and studies of active galactic nuclei and quasars. Diffuse-source studies which will be enabled include mapping the composition and distribution of the celestial UV background contributed by such things as zodiacal dust, galaxies and clusters, the hot interstellar medium, and the H_2 of "IR cirrus clouds."

Education: Use of the LUTE in educational and public outreach programs has been planned since its initial conception. Spectacular multiband images of the universe, transmitted directly to science classrooms, amateur astronomical organizations, and public forums will be useful to educators in revitalizing student interest in science at all levels of the U. S. educational system.

SEI: The LUTE will significantly benefit the Space Exploration Initiative (SEI) by serving as a lunar long duration exposure facility (LLDEF). Its data stream will include information on the lunar environment and its effects on operational lunar systems. These results will be uniquely valuable to the SEI effort.

Description

The LUTE, a 1-m UV telescope, achieves a wide field of view with a compact optical system using lightweight mirrors. The focal plane instrument is a two-dimensional mosiac of charge coupled devices (CCDs), arranged to give a 1.0° wide field of view. The LUTE will not track specific targets, but will be pointed continuously at a chosen declination. As the Moon rotates during its 28-day revolution about the Earth, the LUTE will observe continuously along a 1-degree-wide path across the celestial sphere. The CCD's will register the photons arriving along that path in multiple spectral bands. Instruments will read the CCD's at the sidereal rate to produce a seamless "picture" to be transmitted continuously to Earth for recording and analysis. Cosmic ray events are detected by using a second CCD mosaic with anti-coincidence counting to eliminate background "noise." Therefore, radiation shielding will not be necessary. The telescope is passively cooled by radiation to the sky; mirrors and focal plane instruments are protected from direct and indirect sunlight and thermal radiation by a sun/light shade. Siting the LUTE near the limb will minimize Earth interference. Power for operation is provided by solar cells but only during the lunar day. Science and housekeeping data are returned directly to Earth by the LUTE communications system for processing, distribution, and archiving.

Power Consumption
150 W provided by solar panels; daytime observation only.

Data Rate
180 Kb/s.

Data Management Strategy
Data returned directly to Earth by LUTE communications system for processing, immediate distribution, and archiving. Data handling proved by existing CCD/Transit Instrument (CTI).

Operational Constraints
To minimize power-related mass, the LUTE is designed for daytime observation only. It is proposed that the LUTE initially observe at selenographic declination +30, optimized for observing the North Galactic Cap. The scientifically preferred site would be at an intermediate northern latitude near the western limb of the Moon, e.g., in Mare Crisium or the crater Berosus. The final choice will consider the location of the lunar outpost (>10 km distant) to provide crew support for emplacement and for operations in the outpost years. Continuous day/night operations will then be enabled by adding a radioisotope thermal generator (RTG).

Crew Interaction
If the LUTE is auto-landed, crew is not needed; if landed on a piloted mission, crew emplacement will be advantageous.

Payload Delivery Options
Auto-landed as single payload; or delivered as first of two-flight piloted mission.

Estimated Set-up Time
TBD

Maintenance Needs
Cleaning, alignment, minor mechanical/electronic repair and installing upgrades: e.g., focal plane instruments, RTG.

Technology Assessment
New technology and advanced development required in lightweight beryllium mirrors, passive system thermal management, dust and micrometeoroid mitigation, large CCD mosaic development, cosmic ray noise, and damage mitigation.

Infrastructure Interface Requirements
Transportation to Moon and on surface required significant interfacing. Operations are autonomous.

Resupply Needs
Maintenance parts and cleaning materials as needed; focal plane and power upgrades.

Science/Exploration Community Contact
Max Nein, MSFC.

References

McGraw, John T. (1992), "Lunar Ultraviolet Transit Experiment (LUTE) (A Lunar Transit Telescope [LTT] Precursor Mission), "Proposal to Johnson Space Center, Steward Observatory, Univ. of Arizona, Tucson, AZ.

McGraw, John T. (1990), "An Early Lunar-based Telescope: The Lunar Transit Telescope (LTT), " p. 433, AIP Conf. Proc. 207, "Astrophysics from the moon, " eds. M. J. Mumma and H. J. Smith, Annapolis MD.

McGraw, John T. and G. F. Benedict (1990), "Scientific Programs of a Lunar Transit Telescope (LTT)," p. 464, AIP Conf. Proc. 207, "Astrophysics from the Moon," eds. M. J. Mumma and H. J. Smith, Annapolis MD.

MSFC Lunar Telescope Working Group, (In Preparation), "Lunar Ultraviolet Transit Experiment (LUTE)," Report No. LLT-005, Program Development Directorate, Geo. C. Marshall Space Flight Center, Huntsville, AL.

MSFC Lunar Telescope Working Group, (1992), "Lunar Transit Telescope (LTT): 2-m Aperture UV/VIS/IR Telescope," Report No. LLT-004, Program Development Directorate, Geo. C. Marshall Space Flight Center, Huntsville, AL.

LUNAR TRANSIT TELESCOPE

Date: 7/30/92

PAYLOAD SUMMARY	
Estimated Mass:	**1,000 kg**
Estimated Volume:	**2 m^3**
Estimated Power:	**350 W continuous**
Estimated Data Rate:	**30 Mb/s continuous**

Rationale
The Lunar Transit Telescope (LTT) is a 1-m class telescope which is designed to conduct a continuous sky survey by using the rotation of the Moon as the telescope drive mechanism. As the Moon slowly rotates, the telescope will sweep out a portion of the sky and conduct a continuous survey of all stellar objects to a limiting magnitude of 28. This will result in billions of objects being imaged, and a larger volume of space being cataloged than could be imaged by the Hubble Space Telescope in thousands of years. The LTT should be able to obtain better data than the Hubble Space Telescope over the part of the sky which it can see at a reaction of the operations cost. The Time Delay and Integrate mode of the CCD detector, used in conjunction with the slow lunar rotation rate, should allow integration times on the order of hours. The limiting magnitude of 28 will mean that billions of objects will be detected and imaged on a monthly basis in the spectral range of 0.1 to 2.0 µm. Among the objects which will be visible will be 10,000 to 100,000 galaxies per square degree, supergiant stars out to 40 megaparsecs, and brown dwarfs out to 4 kilo parsecs. While the predictable science return is likely to be impressive, many important results likely will come in unforeseen areas.

Description
The LTT is an optical telescope with an aperture of ~1 m and no drive system. Lunar rotation will provide one axis of motion. The CCD register is used as a shift register at the proper rate to compensate for the Moon's rotation, allowing long integration times. A crater or man-made shield (emplacement in an excavated hole, or regolith piled around the telescope) will be used to shield the LTT from cosmic rays. A reflective screen will shield the telescope from Sun and Earth light and allow detectors to be passively cooled to 100°K. The LTT's detector will consist of a 72,000 x 72,000 pixel array of CCDs. The combined system will have a resolution to 0.1 arcsecond, with the ability to see objects to the 28th visual magnitude. Image field of view will be 2° by 2°.

Power Consumption
350 W continuous.

Data Rate
30 Mb/s continuous.

Data Management Strategy
Data from the Transit Telescope will be transmitted continuously to a terrestrial ground station, with no present plans for store-forward capability. Data acquired during periods of time when the data transmission system is off line will be lost.

Operational Constraints
A high bandwidth telemetry system with an associated Earth-based high capacity data processing, storage and analysis system will be required because of the high continuous data rate. To provide adequate shielding from both thermal and radiation effects, the telescope and electronics should be emplaced below ground. The telescope should be located on the near side of the moon and at least 5° away from the equator to limit the amount of sunlight shining into the telescope. The location should also be far enough away from outpost activities (~10 km) to limit regolith movement.

Crew Interaction
Construction of emplacement facilities; telescope set-up and initial operations; maintenance and component replacement as required.

Payload Delivery Options
Delivered as a single payload.

Estimated Set-up Time
10 IVA hours, 5 EVA hours

Maintenance Needs
Repair and cleaning; replacement of electronic components as necessary.

Technology Assessment
Developments will be needed in passive detector cooling, shielding, automatic compensation for thermal cycling, large CCD mosaics, dust exclusion and cosmic ray compensation. High capacity Earth-basedtelemetry and data processing, storage, and a distribution system also are needed. This implies a technology readiness level of approximately 3.

Infrastructure Interface Requirements
Access to high bandwidth telemetry system.

Resupply Needs
Spare parts as needed.

Science/Exploration Community Contact:
John McGraw, Steward Observatory, University of Arizona

References
Budney, C. J., Ionasescu, R., Snyder, G. C. and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

STEERABLE AUTOMATIC LUNAR ULTRAVIOLET TELESCOPE EXPLORER (SALUTE)

Date: 8/14/92

PAYLOAD SUMMARY

Estimated Mass:	**200 kg**
Estimated Volume:	**Cylinder TBD**
Estimated Power:	**80 W normal operations**
Estimated Data Rate:	**512 Kb/s** **171 Kb/s if 3:1 data compression used**

Rationale

The scientific areas that could be covered with small, steerable lunar telescopes in the UV, optical, and IR regions of the electromagnetic spectrum cuts across almost all areas of astronomical research and includes extragalactic, stellar, planetary, and solar research. The ability to continuously view (or frequently sample) objects for extended periods of time without the interruptions of the Earth's day/night cycle, weather, or orbital blockage from the Earth would be a valuable asset in many research areas.

The first small telescopes to be landed on the Moon also will be explorers of the lunar environment itself and its effects on the long-term operation of telescope optics, computers, instruments, communications equipment, pointing and tracking mechanisms, ground-based operations, user access, etc. We need, early on, to increase our knowledge of the lunar environment and its effects on a range of equipment so that we can more efficiently design the large steerable telescopes, arrays of interferometric telescopes, etc., that will follow. We also need to develop and refine the operations of lunar telescopes and user access to them. SALUTE is intended as the small explorer that will pave the way for the larger and more numerous telescopes that are sure to follow. Numerous educational opportunities for high school and college students to perform actual research using SALUTE also exist.

Description

SALUTE contains a 0.8 meter fused silica primary mirror with a 2.5 cm secondary mirror in a Cassegrain configuration. The effective f-ratio of the system is 6.0. The optics are diffraction limited in the UV, providing exquisite imaging resolution. The telescope mount will be a standard altitude-azimuth design since equatorial designs require tight lander orientation. Daytime operations on the lunar surface require extensive baffling, in addition to a sun shade to keep sunlight from directly striking any inside portion of the optical tube assembly. The converging light beam behind the primary mirror can be directed to any one of four instruments (e.g., CCD cameras, aperture photometers, etc.) by an instrument rotator (a mirror on a stepper with redundant windings, drives, etc.). This instrument rotator is desired because, in a non-equatorial telescope, the field rotates as the telescope tracks the object being observed, causing a slight but unacceptable smearing of images on long exposure images.

Numerous applications for the SALUTE have been proposed. Among the projects expected to be undertaken by the instrument are photometric observation, a UV survey of the entire sky visible from the telescope, UV imaging of selected individual objects such as quasars and active galactic nuclei, and UV spectroscopy.

Payload Breakdown

Component	Number	Mass per unit (kg)	Total Mass (kg)	Volume (m^3)	Total Power (W)	Data Rate (Kb/s)
Optical Tube Assembly		**50**	**50**	**TBD**	**N/A**	**N/A**
Primary Mirror and Support	1	23	23			
Secondary Mirror and Support	1	4	4			
Internal baffles and secondary support spider	1	2	2			
Sunshade	1	7	7			
Main Optical Tube	1	14	14			
Instrumentation		**14**	**14**	**TBD**	**14**	**171**
CCD cameras	2				10	171
Aperture photometers	2				4	
Instrument selector	1					
Misc. Environmental Sensors	TBD					
Misc. cables	TBD	3				
Azimuth Assembly		**18**	**18**	**TBD**	**N/A**	**N/A**
Azimuth fork, altitude and azimuth bearings and drives						
Electronics and Base Assembly		**63**	**102**	**TBD**	**65**	**N/A**
Base structure	1	9	9			
Computers	2	2	4		20	
Misc. electronics units (includes stepper drives, signal conditioners, power control, etc.)	2	5	10		21	
Ka Band transponders	2	23	46		24	
Low gain and high gain antennas and pointing drives	2 of each	9	18			
Miscellaneous cables		15	15			
Power units						
RTG unit	1	36	36		80	
Solar Panels		25	25		1000	
RHU or TSU		14	14			
SUBTOTAL FOR RTG POWERED OPTION			187		79	171
25% MARGIN			47		20	43
TOTAL FOR RTG POWERED OPTION			234	TBD	99	214
SUBTOTAL FOR SOLAR POWERED OPTION			190		79	171
25% MARGIN			48		20	45
TOTAL FOR SOLAR POWERED OPTION			238	TBD	99	214

Power Consumption
Total power for computers, transponders, drivers, CCD cameras, photometers, and miscellaneous electronics totals approximately 80 W, supplied either by RTGs or solar panels (with thermal storage units for nighttime operations).

Data Rate
Data rate for continuous return of CCD camera data prior to compression would be 512 Kb/s. Assuming a 3:1 compression, the data rate can be reduced to about 171 Kb/s.

Data Management Strategy
The amount of data is expected to be too voluminous for recorder storage within the power and mass limitations of this payload, so data are expected to be sent to Earth as it is gathered. The data will be sent to a ground terminal antenna (3.9-m diameter at S-band, 1.1-m diameter at X-band, and 0.3-m diameter at Ka band) for distribution from a central control station.

Operational Constraints
SALUTE will need to be located at least 10 km away from an occupied outpost to reduce dust contamination to the optics and mechanical systems.

Crew Interaction
None required.

Payload Delivery Options
This payload will be delivered remotely to the lunar surface using a soft landing spacecraft such as Artemis.

Estimated Set-up Time
The payload will be deployed autonomously atop the Artemis lander.

Maintenance Needs
None

Technology Assessment
Prototypes of SALUTE are being successfully operated on Earth in several locations, including Fairborn Observatory in Arizona. However, the operation of such telescopes under lunar environmental conditions has not been demonstrated, giving this payload a technology readiness level of 3.

Infrastructure Interface Requirements
The telescope will be bolted to the top of the Artemis lander and remain there to keep it as far above the lunar surface as possible (to avoid dust levitation during the day/night lunar cycle). The telescope will have no other interface with the lander, electrical or mechanical.

Resupply Needs
None

Science/Exploration Community Contact
Russell Genet, AutoScope Corp., Mesa, AZ

References
Genet, R., 1992, Steerable Automatic Lunar Ultraviolet Telescope Explorer (SALUTE) Study Report.

LUNAR OPTICAL INTERFEROMETER

Date: 7/30/92

PAYLOAD SUMMARY	
Estimated Mass:	**5,050 kg (minimum 3 interferometer array)**
	7,469 kg (complete 12 interferometer array)
Estimated Volume:	**156 m^3 (minimum 3 interferometer array)**
	404 m^3 (complete 12 interferometer array)
Estimate Power:	**1330 W (minimum 3 interferometer array)**
	1775 W (complete 12 interferometer array)
Estimated Data Rate:	**20 Mbits/second (all configurations)**

Rationale

This observatory will conduct ultra high resolution optical astronomy via direct (non-heterodyne) interferometry. In its final configuration, the interferometer will be capable of producing direct images with approximately 5 orders of magnitude better resolution than terrestrially-based telescopes.

The Moon is an ideal site for this system for several reasons. The absence of an atmosphere eliminates the atmospheric distortion which limits terrestrial telescopes. In addition, the presence of a hard vacuum eliminates the need for vacuum housing of optical delay lines, a requirement in terrestrially-based interferometers. The Moon's low seismicity permits accurate alignment of interferometers over long baselines and for long observation periods. Accurate knowledge of the Moon's rotation and orbit makes it possible to correct for stellar aberration for pointing and astrometry. Low nighttime temperatures assist in cooling optics for infrared observations.

Description

The Optical Interferometer, in its final configuration, consists of a central beam combining station, three banks of delay line mirrors, and 12 siderostat/beam compressor assemblies (SBCA). The siderostat is a gimballed flat mirror which directs light from the desired object into the beam compressor, which is similar to a telescope but puts out a parallel beam of light rather than a focused image. The SBCAs are distributed in a "Y" configuration about the central station, up to 10 km from the central station. The banks of delay line mirrors are used to equalize the optical path lengths from the SBCAs to within the 10-meter capability of the fast delay lines at the central station. One bank has 10-meter increments in path length, one bank has 100-meter increments and the third has 1-kilometer increments.

All the optical surfaces have arch or dome sun shades to keep direct sunlight from ever striking them. During the lunar day observation is limited to the visual spectrum, but at night infrared also can be used, requiring passive cooling of all optics to 70°K with the detector cooled to <4°K by mechanical coolers.

Preliminary estimates of the interferometers capabilities are as follows:

Wavelength range:	0.1 - 20 μm
Spectral resolution ($\lambda/\Delta\lambda$):	>5,000

Spatial resolution:	1 milliarcsec @ initial baseline of 100-m, 10-μarcsec @ final baseline of 10-km
Astrometric resolution:	0.1 μarcsec at 1-km baseline
Sensitivity:	• 30 magnitude/pixel @ 0.5 μm • 19 magnitude @ 10 μm
Image complexity:	1,000 x 1,000 pixels

When completed, the interferometer will be able to perform tasks such as:

Imaging:

- Imaging mass transfer binary systems where one component is a massive compact object such as a white dwarf, neutron star or black hole
- Resolving the broad-line and narrrow-line regions in active galactic nuclei
- Imaging accretion disks around super-massive black holes within active galactic nuclei
- Imaging white dwarfs with 10 x 10 pixel resolution
- Direct detection and characterization of Earth-like planets around ~1,000 nearby stars
- High resolution (Voyager capability) imaging of solar system objects
- Stellar astrophysical studies of nearby stars (most of these studies are presently confined to the Sun)

Astrometry

- Observing parallax of objects to several megaparsecs
- Studying the isotropy of the Hubble flow to 1%
- Indirect detection of Jupiter-sized planets within the visible part of our galaxy
- Determination of masses of Earth-like planets which were discovered with imaging

Power Consumption
Three interferometer array: 1330 W.
Twelve interferometer array: 1775 W.

Data Rate
All configurations: 20 Mbits/second.

Operational Constraints
Entrained dust landing on mirrors is the biggest operational constraint. The interferometer site should be a minimum of 10 km from the outpost site and/or spacecraft landing areas. Delay lines should be constructed so that delay line carts do not kick up dust.

Estimated Set-up Time
TBD, based on final instrument design.

Crew Interaction
Construction of facilities, routine maintenance.

Payload Breakdown

Component	Number	Mass (kg)	Volume (m^3)	Power (W)	Data Rate (Kb/s)
Central Station		**1015**	**21**	**900**	**20000**
Metrology system	1	100	3	150	
Science instrument set	1	100	3	100	
Auto guider	1	50	2	100	
Electronic components	1	60	2	100	
Enclosure	1	50	2		
Cabling	1	500	3		
Telecomm electronics	1	40	2	100	
Telecomm antenna	1	40	2		
Cooler	1	75	2	350	
Delay Line Assembly		**1650**	**33**	**200**	
Delay line steering mirror set	3	600	6	50	
Delay line steering mirror encl.	1	50	1		
Delay stationary mirrors	25	500	8		
Delay stationary mirror domes	20	200	2		
Vernier delay line set	1	250	14	150	
Vernier delay line enclosure	1	50	2		
Other Common Equipment		**330**	**2**	**0**	
Laser survey retroreflectors	3	15	1		
Anchor posts	65	195	1		
Earthlight shields	12	120			
Power System		**400**	**3**	**200**	
Dynamic Isotope Power System	1	250	1		
Power conditioner	1	150	2	200	
Interferometer Assembly (each)		**215**	**22**	**10**	
Siderostats (SBCAs)	1	200	18	10	
Thermal shields	1	15	4		
Subtotal for complete, 12 element interferometer system		**5975**	**323**	**1420**	**20000**
25% Contingency		**1494**	**81**	**355**	**5000**
TOTAL		**7469**	**404**	**1775**	**25000**

Payload Delivery Options

The individual components of this system (siderostats, beam compressors, beam combiner, and delay line mirrors) will be transported from Earth and delivered to the lunar surface within the constraints of the transportation system. They will be emplaced by a combination of robotics and astronauts using construction equipment. It is possible that some assembly of these units could be done on the lunar surface.

Alternately, the interferometer can be broken down into its major component sets. The minimum set of components necessary for conducting interferometry are the Central Station, Delay Line Assembly, all other common equipment, the power system, and 3 interferometry assemblies. Any combination of components less than the minimum may be transported to the lunar surface, but interferometry can only begin with delivery and construction of the minimum component set.

Maintenance Needs

Periodic servicing and facility upgrades; removal of dust from optical surfaces. Periodic servicing and cleaning may be done robotically.

Technology Assessment

Although interferometry using radio telescopes has been performed routinely, at present optical interferometry has not been attempted using a terrestrial telescope. Accordingly, the overall concept of an optical interferometer can be considered Technology Readiness Level 1. Some critical component requirements are as follows:

Telescope tracking encoders: accuracy of 3-4 arcsec
Fast steering mirrors: accuracy of 0.01 arcsec
Precision delay lines: accuracy of 2-5 nm
Metrology measurements: accuracy of 1 nm

Areas of enabling or enhancing technology development are:

- Active optics and lightweight components for telescope and optical train
- Precision automated optical systems for delay lines
- Frequency stabilized solid-state laser metrology systems to measure and maintain element spacing and orientation
- Photon counting detectors in the visible, UV and IR spectral regions
- Robotic systems capable of conducting remote alignment, operation and servicing (final alignment of optical path components and telescopes may have to be carried out by robotic means to eliminate problems with heat absorption and dust contamination that may be caused by a human crew)
- Precision optics, which will maintain optical beam configuration through wide day/night temperature cycles
- High capacity telemetry and data processing, compression, storage and analysis systems

Infrastructure Interface Requirements

Sufficient human/robotic crew to construct system.
Sufficient heavy lift transport/lifting capability to construct system.
Access to outpost or independent power source.
Access to comm/data links to terrestrial control centers.

Resupply Needs

Electronics spares.

Science/Exploration Community Contact

Michael Shao, Jet Propulsion Laboratory

References

Budney, C. J., Ionasescu, R., Snyder, G. C. and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

National Aero. Space Admin., 1989, Lunar Outpost Astrophysics Program, Program Overview: NASA Headquarters, Astrophysics Division.

SUB-MILLIMETER INTERFEROMETER

Date: 7/30/92

PAYLOAD SUMMARY	
Estimated Mass:	**2,738 kg (minimum 3 antenna array)** **6,675 kg (complete 12 antenna array)**
Estimated Volume:	**313 m^3 (minimum 3 antenna array)** **875 m^3 (complete 12 antenna array)**
Estimated Power:	**3250 W**
Estimated Data Rate:	**500 kbits/second**

Rationale
This system will examine astronomical objects at sub-millimeter wavelengths with spatial resolutions many orders of magnitude better than that currently possible from Earth orbit. Location of this interferometer on the lunar surface will permit observation of compact sources over a wide frequency range, including frequencies unobservable from Earth because of atmospheric attenuation and absorption. Protostellar and protoplanetary disks in star-forming regions in our galaxy and distant protogalaxies are typical of the more exciting targets.

Description
The signal receiver part of this interferometer consists of twelve 3.5-meter antennas arranged in a "Y" configuration, with a maximum baseline of about 1 kilometer. Each antenna acts as a beam compressor and the front end of a waveguide. The central station acts as the receiving end of the waveguides and has all the electronics for the receivers and correlators. The Silicon-Insulator-Silicon detectors in the receivers operate at 4 K, with refrigeration provided by a combination sorption/mechanical cooler driven half by electricity generated by the Dynamic Isotope Power Supply and half by waste heat from the same source. This configuration has the advantage of concentrating the power and cryogen use at the central station. An alternative would be to have the receiver electronics at the antennas and use fiber optic cables to send the data to the central station for correlation. This, however, would require distribution of power over a wide area and a cooler/cryogen dewar at each antenna.

Preliminary estimates of the interferometer's capabilities are as follows:

Spectral Resolution ($\lambda/\Delta\lambda$):	10^6
Spatial Resolution:	10 to 100 milliarcsec over the range of 30 to 1000 μm
Sensitivity:	10 to 50 mK

Power Consumption
Up to 3250 W, primarily to accommodate cooling systems

Data Rate
500 Kb/s.

Data Management Strategy
Telemetry and data processing, storage and analysis capabilities will be required. Present plans call for all data to be sent directly to a terrestrial control center for further processing and dissemination.

Payload Breakdown

Component	Mass per element (kg)	Volume (m^3)	Power (W)	Data Rate (Kb/s)
Per Each Antenna Element*	**350**	**50**	**8.3**	**TBD**
Reflector/mount (includes beam transport and electronics)	300			
Enclosure	50			
Central Station*	**890**	**100**	**2500**	**TBD**
Active coolers	75		350	
Receivers	150		100	
Correlator	180		1950	
Beam combiner	135			
Command and data handling	50		50	
Telecom electronics	40		50	
Telecom antenna	40			
Enclosure	120			
Cabling for all elements	100			
Dynamic Isotope Power Supply (DIPS)	**250**			
SUBTOTAL (for complete, 12 antenna interferometer)	5340	700	2600	TBD
25% MARGIN	1335	175	650	
TOTAL	6675	875	3250	TBD

*The complete interferometer will consist of 1 Central Station, 1 DIPS, and 12 Antenna Elements; minimum components will be 1 Central Station, 1 DIPS, and 3 Antenna Elements.

Operational Constraints
Plans call for the facility to be located on the Earth-facing side of the Moon near the equator. The facility needs to be at least 10 km distant from the occupied outpost to avoid dust contamination.

Crew Interaction
Initial construction of the interferometer on the Moon, maintenance, replacement of components, instrument upgrades.

Payload Delivery Options
Although data can be acquired with a single antenna element, and interferometry can begin with two antennas, the minimum optimum set of equipment is the central station, dynamic isotope power supply and three antenna elements. Additional antenna elements will improve the sensitivity of the array and allow shorter observation times.

Estimated Set-up Time
50 IVA hours, 10 EVA hours, 200 robotic hours.

Maintenance Needs
Periodic servicing and facility upgrades.

Technology Assessment
Multiple antenna interferometry is a proven technology for terrestrial radio astronomy. The actual components for this interferometer array have not been designed or tested, suggesting a technology readiness level of 2.

Infrastructure Interface Requirements
Access to communications bands to transmit data to terrestrial control station.

Resupply Needs
Electronics spares.

Science/Exploration Community Contact
M. J. Mahoney, Jet Propulsion Laboratory

References
Budney, C. J., Ionasescu, R., Snyder, G. C. and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

LUNAR NEARSIDE VERY LOW FREQUENCY IMAGING ARRAY

Date: 7/30/92

PAYLOAD SUMMARY	
Estimated Mass:	**700 kg**
Estimated Volume:	**TBD (>4 m^3)**
Estimated Power:	**175 W**
Estimated Data Rate:	**20 Mbits/second**

Rationale
The Lunar Nearside Very Low Frequency Imaging Array will study regions of the electromagnetic spectrum not observable through the Earth's atmosphere. This observatory will study diverse phenomena in the fields of extragalactic astronomy, galactic astronomy and solar system science, including mapping the auroral kilometric radiation around the Earth. Targets of study include quasars, active nuclei, galactic halos, inhomogeneities in the interstellar medium, solar activity and the outer planets. Since this frequency range is so little explored, perhaps the most important scientific results will be the discovery of new classes of objects and new phenomena.

Description
The complete system consists of 20 stations which are located in a "T" formation with 3 arms, each 36-km long. Each station has two 10-meter dipole antenna with receivers and digitizers. Data are transmitted to the central station and relayed from more distant stations by way of UHF antennas on 3-meter masts. Command and timing signals are relayed outward. Data are sent directly to Earth either raw at a bit rate of 20 Mbps or after processing through a central digital correlator, at 32 kbps.

The capability of the system is as follows:

Frequency range:	150 kHz to 30 MHz
Band width:	up to 22 kHz
Angular resolution:	Tens of arcmin at 1 MHz to a few arcmin at 10 MHz
Sensitivity:	limited by galactic emission not by the instrument

PAYLOAD BREAKDOWN

Component	Quantity	Mass per (kg)	Volume (m^3)	Power (W)	Data Rate (Kb/s)
Antenna Stations*	20	30	0.2	5	
Central Station	1	47	TBD	50	
Laser Telemetry System	1	35	0.1	25	
Subtotal		682	4.1	175	20000
25% margin		170.5	1.0	43.8	5000
PAYLOAD TOTAL		852.5	5.1	218.8	25000

*per each station
The total imaging array will consist of the central station, laser telemetry system and all 20 antenna stations; minimum array will consist of the central station, the telemetry system and 3 antenna stations.

Power Consumption
Each antenna station consumes 5 W, supplied by an internal battery. The central station and laser telemetry system require 50 and 25 W, respectively, to be supplied by either RTG's or a battery/solar cell combination. The instrument will need to work continuously, so power systems will need to supply power throughout the lunar night.

Data Rate
20 Mbps for unprocessed data, 32 kbps after processing through a digital correlator.

Data Management Strategy
TBD

Operational Constraints
The system will have to be placed near an outpost in order to facilitate routine maintenance and component repair/replacement. Radio telescope systems are not subject to the dust constraints of optical systems; consequently, the placement distance from the outpost/habitat is not as constrained as for the optical case.

Crew Interaction
Construction and alignment, normal maintenance and component repair/replacement.

Payload Delivery Options
The minimum delivery to allow interferometry will be a central station, the laser telemetry system and three antenna stations. Addition of more antenna stations will progressively increase the resolution power of the entire system.

Estimated Set-up Time
50 IVA hours, 50 EVA hours, 150 robotic hours.

Maintenance Needs
Routine adjustments, repair and alignment of the system; may be accomplished robotically.

Technology Assessment
None of the components have been developed, although multiple antenna interferometry is a routine practice in terrestrial radio astronomy. This suggests a Technology Readiness Level 3.

Infrastructure Interface Requirements
Access to high data rate telemetry system to transmit data to terrestrial receiving stations.

Resupply Needs
Electronics spares.

Science/Exploration Community Contact
Thomas Kuiper, Jet Propulsion Laboratory

References
Budney, C. J., Ionasescu, R., Snyder, G. C. and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

LUNAR FARSIDE VERY LOW FREQUENCY INTERFEROMETER

Date: 7/21/92

PAYLOAD SUMMARY	
Estimated Mass	1000 kg
Estimated Volume	4-6 m^3
Estimated Power	1000 W
Estimated Data Rate	10 Mb/s

Rationale
The Earth's ionosphere limits Earth based low-frequency observations to approximately one degree resolution and is opaque, due to scintillation, over some of the frequency range. Natural (magnetospheric and ionospheric) and man-made radio frequency interference (RFI) limit the useful sensitivity of any near-Earth VLF radio telescopes. This instrument eliminates the ionospheric interference through lunar basing and eliminates RFI by using the Moon as a shield. Since the frequency range is relatively unexplored, the first work of the array will be to perform an all-sky survey to identify sources. Objects of interest would later be studied in detail.

Description
The system is a cross- or "Y"-shaped array of a large number of dipole antennas and simple receivers covering hundreds of kilometers. Preferred location is the far side of the Moon near the equator, far enough away from the limb (~300 km) to avoid Earth radio frequency interference. The frequency range will be 1 MHz to 25 MHz. Spatial resolution will be from a few arcmin at 1 MHz to several arcsec at 25 MHz. Spectral resolution of the instrument will be 1 MHz with a sensitivity of 1 Jy.

Power Consumption
Approximately 1000 W.

Data Rate
Approximately 10 Mb/s.

Data Management Strategy
TBD

Operational Constraints
A high bandwidth telemetry system along with associated Earth-based high capacity data processing, storage, and analysis capabilities will be required. These systems will be housed in a dedicated control center on Earth which will operate the system continuously and disseminate data to scientists.

Crew Interaction
Deployment of equipment on the Moon (if not automated) and maintenance.

Payload Delivery Options
Delivery is to the far side of the Moon. Because of the low total mass, the entire array could be carried on a single mission, but because of the high degree of modularity, the delivery could be spread over several missions if necessary. The system is also modular in operation, so that additional elements can be added as the experiment progresses.

Placement of the individual antennas is not critical, since the locations can be solved for by analysis of signals from compact sources.

Estimated Set-up Time
TBD

Maintenance Needs
Repair only; no preventative maintenance.

Technology Assessment
Space qualification of commercial communications technology is needed, indicating a technology readiness level of 3. An early smaller nearside array is desirable for engineering evaluation.

Infrastructure Interface Requirements
Access to a high data rate telemetry system to transmit data to the terrestrial receiving station. A communications satellite may be necessary to transmit the data from the interferometer's farside location.

Resupply Needs
Electronics spares.

Science/Exploration Community Contact
Dayton Jones, Jet Propulsion Laboratory.

References
Budney, C. J., Ionasescu, R., Snyder, G. C., and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsions Laboratory Publication JPL D-7955.

LARGE LUNAR OPTICAL TELESCOPE

Date: 7/27/92

PAYLOAD SUMMARY	
Estimated Mass:	8000 kg Precursor 4-m 33,000 kg Final 16-m
Estimated Volume:	5 m x 8 m Precursor 4-m 7 m x 25 m Final 16-m
Estimated Power:	1500 W Precursor 4-m 6000 W Final 16-m
Estimated Data Rate:	400 Kb/s Precursor 4-m 2.5 Mb/s Final 16-m

Rationale

This observatory will be capable of various ultra-high sensitivity UV-visible-IR wavelength astronomical studies such as spectroscopic observations of faint and low-albedo objects at resolutions 3-100 milliarcsec from the UV to the IR, detecting Earth-like planets around nearby stars, studying the structure of highly red-shifted galaxies, determining stellar populations throughout the local supercluster, studying star formation, measuring distances to the Large Magellanic Cloud, and determining the geometry of the universe by stepping the distance scale out to high redshifts. The telescope will have a wavelength range of 0.1 - 10 μm with a sensitivity to visual magnitude 32 for point sources. It will have a spectral resolution of 10^3 to greater than 10^5 depending on observational mode and its spatial resolution will be from 3 milliarcsec in the UV to 100 milliarcsec in the IR.

The advantages of lunar basing for this system are

- The near-vacuum environment eliminates atmospheric distortion and permits observations over a broad spectral range.
- The Moon provides a stable base, allowing accurate pointing and control.
- The Moon is a potentially easier site, compared to Earth orbit, for in-situ assembly.
- Maintenance, servicing, and upgrades will maximize lifetime and return on investment.
- Shielding of detectors beneath the lunar surface can greatly reduce cosmic ray background noise.

Description

This unit is a 16-meter filled-aperture, diffraction-limited, wide field-of-view telescope. The structure and optics are passively cooled to 80 K (detectors may require active cooling). This telescope should be preceded by a 2 to 4 m class telescope which can accomplish significant science objectives and serve as a technology test bed for the 16 m telescope.

Alternatively, the system could consists initially of a single 4-m class telescope to which additional identical units are added. The multiple units could be mounted together on a single aimable platform. However, to provide the same collecting aperture area as one 16-m telescope would required sixteen telescopes with 4-m apertures, complex phasing mechanisms, and at least 8 reflections of the optical beam (which would reduce UV sensitivity).

In addition to its role as a high sensitivity, large aperture observatory, the Large Lunar Optical Telescope can be used as an important additional element in the Optical Interferometer. The optical beam from the Large Optical Telescope can be fed into the Interferometer, thus significantly increasing the Interferometer's effective collecting area.

Payload Breakdown

Component	Mass (kg)	Size (m)	Power (W)	Data Rate (Kb/s)
Precursor configuration				
4-m telescope	~8000	5m D x 8m L	~1500	400
Final configuration				
16-m telescope	~33,000	7m D x 25m L	~6000	2500

Power Consumption
~1500 W for 4-m Precursor; ~6000 W for final 16-m telescope.

Data Rate
400 Kb/s for 4-m Precursor; 2.5 Mb/s for final 16-m telescope.

Data Management Strategy
A high bandwidth telemetry system along with associated Earth-based high capacity data processing, storage, and analysis capabilities will be required. These systems will be housed in a dedicated control center on Earth which will operate the telescope continuously and will disseminate data to scientists.

Operational Constraints
Low vibration, low temperature, low contamination site. Preferred site is equatorial for full sky coverage, on lunar nearside to facilitate communications, and towards limb to facilitate effective shielding of earthshine. Avoidance of dust and other contamination in the optical path is required; thus the telescope needs to be located some distance away from the outpost.

Crew Interaction
Assembly, maintenance, and instrument upgrades. Mechanized alignment may be required because of small tolerance and sensitivity to temperature.

Payload Delivery Options
The Large Lunar Optical Telescope is placed on the Moon by SEI transportation components. Assembly on the lunar surface will be required. Modules which are as large as can be accommodated by the transportation systems could be assembled on Earth and then delivered to the lunar surface for assembly by astronauts into the complete telescope. Construction equipment such as a crane would be required for this operation.

Estimated Set-up Time
Construction times are estimated as one year (3 person crew, single shifts, daylight only).

Maintenance Needs
Periodic servicing and facility upgrades by astronauts, removal of dust from optical surfaces.

Technology Assessment
A structure and mirror elements must be developed which will maintain a precise optical configuration through large day/night temperature variations, have a minimum of outgassing, and exclude dust. Other requirements include mechanized alignment systems; lightweight optics with diffraction-limited surfaces; high capacity telemetry and data processing, storage, and analysis systems; and large array detectors covering the 0.1 - 10 μm range. These considerations imply a technology readiness level of 2.

Infrastructure Interface Requirements
Communications link to Earth.

Resupply Needs
TBD

Science/Exploration Community Contact
Max Nein, Marshall Space Flight Center

References
Budney, C. J., Ionasescu, R., Snyder, G. C., and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

A. Lunar Science Payloads
3. Space Physics Payloads

SOLAR SYSTEM PHYSICS EXPERIMENT PACKAGE

Date: 8/3/92

PAYLOAD SUMMARY

Estimated Mass:	**215 kg**
Estimated Volume:	**0.4 m^3**
Estimated Power:	**219 W**
Estimated Data Rate:	**TBD**

Rationale

The Solar System Physics Experiment Package contains the necessary instrumentation to monitor the lunar atmosphere and the Moon-Earth physical environment. The station must be long lived (design lifetime of 5-10 years) to provide the long-term continuous data base necessary to characterize these parameters. Approximately 18 stations deployed around the Moon will provide data on the Moon-wide variation of the noted parameters for the lifetime of the network. In addition, deployment at the inhabited outpost will monitor changes in the ambient lunar environment that result from human activities.

Description

A number of the proposed instruments have a pedigree that extends back to the Apollo Program ALSEP stations. Other instruments have been flown, or are scheduled to fly on various spacecraft such as the Space Shuttle Orbiter, as part of the Strategic Defense Initiative, or on planetary probes such as Cassini. The purpose of each instrument is as follows:

Solar System Physics Instruments

Neutral Mass Spectrometer/Ion Mass and Energy Spectrometer	Monitor the composition and energy and spectrum of neutral atoms and ionic species in the lunar atmosphere.
Electron Energy Spectrometer	Determine the energy spectrum of electrons in the lunar atmosphere
Magnetometer	Determine the ambient and solar wind induced magnetic fields
Electric Field Meter	Determine the magnitude and direction of the lunar surface electric field.
Dust Detector	Sample the population of dust ejected in meteorite impact, material moving as cosmic dust, and ambient lunar dust.
Solar Wind Detector	Monitor the composition and energy of solar wind ions.
Charged Particle Spectrometer	Measure the fluxes of protons, α-particles, and solar flare and cosmic ray nuclei.
Laser Ranging Transponder	Provide accurate calibration of Earth-Moon distance

Background and Radiation Experiment

Tissue Equivalent Proportional Counter	Measure the ambient radiation level.
Active Neutron Probe	Sample the ambient neutron population.

Payload Breakdown

Component	Mass (kg)	Volume (m^3)	Power (W)	Data Rate (Kb/s)
Central Station	**85**	**0.05**	**85**	**TBD**
Solar System Physics Instruments				
Neutral Mass Spectrometer	15	0.01	15	TBD
Electron Energy Spectrometer	6	0.003	5	TBD
Magnetometer	10	0.005	5	TBD
Electric Field Meter	14	0.003	10	TBD
Dust Detector	5	0.005	6	TBD
Solar Wind Detector	5	0.003	5	TBD
Charged Particle Spectrometer*	8	0.007	16	TBD
Laser Ranging Transponder	10	0.008	4	TBD
Background Radiation Experiments				
Tissue Equivalent Proportional Counter	4	0.002	4	TBD
Active Neutron Probe	10	0.2	20	TBD
SUBTOTAL	172	0.3	175	TBD
25% MARGIN	43	0.07	44	
TOTAL	215	0.4	219	TBD

*two flight units

Power Consumption

Power will be supplied to each instrument after conditioning and distribution by the central station. ALSEP stations successfully used radioisotope thermal generators for power, although some form of advanced solar cell/battery technology may be available for this package. Because geophysical packages may be deployed in areas remote from a lunar outpost, the power source selected will have to be maintenance free and provide reliable power for a period of several years without human interaction. Conventional batteries are therefore unlikely to be used.

Planned power consumption on each instrument is as follows:

Central Station	85 W
Neutral Mass Spectrometer	15 W
Electron Energy Spectrometer	5 W
Magnetometer	5 W
Electric Field Meter	10 W
Dust Detector	6 W
Solar Wind Detector	5 W
Charged Particle Spectrometer	8 W
Laser Ranging Transponder	4 W
Tissue Equivalent Counter	2 W
Active Neutron Probe	10 W

Data Rate

TBD.

Data Management Strategy

TBD

Operational Constraints
A portion of the completed network will be emplaced on the lunar farside, which will require communications satellite support to return data to terrestrial control stations. Given that substantial human activity will change the lunar atmospheric environment, it may be necessary to deploy stations robotically prior to human arrival or very early in a human mission to document changes to the lunar atmospheric environment.

Crew Interaction
Setup and adjustment as necessary for non-robotically deployed stations. After deployment, remote human-emplaced sites are to be isolated as much as possible to mitigate contamination by entrained dust or outgassing from EVA suits and rovers.

Payload Delivery Options
Human crew or robotic spacecraft

Estimated Set-Up Time
TBD

Maintenance Needs
None.

Technology Assessment
A number of instruments similar to these were deployed on ALSEP, suggesting a Technology Readiness level of 13 for those instruments. Instruments flown on other spacecraft (eg., Space Shuttle) likely will need modifications for deployment in the lunar environment, but should otherwise be level 13 as well. For those instruments not already flown, a Technology Readiness level of 2 would appear appropriate.

Infrastructure Interface Requirements
Due to the variable locations of proposed deployment, each station should be independent of an outpost communications/data infrastructure and capable of transmitting its own data stream to a terrestrial ground station. Those stations deployed on the lunar farside will need communications satellite relay of data streams.

Resupply Needs
None.

Science/Exploration Community Contact
Thomas Wilson, Johnson Space Center

References
Budney, C. J., Ionasescu, R., Snyder, G. C. and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

SPACE PHYSICS MONITORING STATION

Date: 8/3/92

PAYLOAD SUMMARY

Estimated Mass:	**234 kg**
Estimated Volume:	**1.0 m^3**
Estimated Power:	**143 W**
Estimated Data Rate:	**variable for individual instruments; maximum planned is 100 kbps**

Rationale

The Space Physics Monitoring Station contains the necessary instrumentation to monitor the lunar atmosphere and the Moon-Earth physical environment. The station must be long lived (design lifetime of 5-10 years) to provide the long-term continuous data base necessary to characterize these parameters. Approximately 18 stations deployed around the Moon will provide data on the Moon-wide variation of the noted parameters for the lifetime of the network.

Description

A number of the proposed instruments have a pedigree that extends back to the Apollo Program ALSEP stations. The purpose of each instrument is as follows:

Space Physics Instruments	
Fast Plasma Analyzer	Monitor the solar wind; detect photoelectrons release from the lunar surface; provide information on ions responsible for surface sputtering.
DC Electric Fields	Determine wave propagation in the solar wind and magnetosphere; study the charging of the lunar surface.
Plasma Wave	Determine the spectral characteristics of electric and magnetic fields at the lunar surface; study wave-particle-plasma interactions in the magnetosphere and ionosphere.
Energetic Ions	Determine the energetic ion environment on the lunar surface; examine energetic ions in the magnetosphere

Lunar Atmospheric Instruments	
Ion and Neutral Mass Spectrometer	Measure the characteristics of the lunar atmosphere/ionosphere; look for changes in atmospheric conditions as a possible signature of outgassing; determine the composition of material sputtered from the lunar surface.
Ultraviolet Spectrometer	Measure the ultraviolet spectra of gases in the lunar atmosphere.
Charged Particle Experiment	Measure the fluxes of electrons and protons.

Discretionary PI Science	Placeholder to allow augmentation with additional instruments, based on future experiment designs.

Power Consumption
Power will be supplied to each instrument after conditioning and distribution by the central station. ALSEP stations successfully used radioisotope thermal generators for power, although some form of advanced solar cell/battery technology may be available for this package. Because geophysical packages may be deployed in areas remote from a lunar outpost, the power source selected will have to be maintenance free, and provide reliable power for a period of several years without human interaction. Conventional batteries are, therefore, unlikely to be used.

Planned power consumption on each instrument is as follows:

Central Station	30 W
Fast Plasma Analyzer	15 W
DC Electric Fields	3 W
Energetic Ions	9 W
Ion and Neutral Mass Spectrometer	15 W
Ultraviolet Spectrometer	5 W
Charged Particle Experiment	6.5 W

Payload Breakdown

Component	Mass per (kg)	Volume (m^3)	Power (W)	Data Rate (Kb/s)
Central Station	85	0.1	30	
Space Physics Instruments				
Fast Plasma Analyzer	13	0.1	15	10
DC Electric Fields	2	0.1	3	1.4
Plasma Wave	6	0.1	6	100
Energetic Ions	9	0.1	9	0.9
Lunar Atmospheric Instruments				
Ion and Neutral Mass Spec.	15	0.1	15	1
Ultraviolet Spectrometer	4	0.1	5	1
Charged Particle Experiment	3	0.1	7	0.1
Discretionary PI Science	100	0.1	25	TBD
SUBTOTAL	237	1	115	115+
25% MARGIN	59	0.2	29	29
TOTAL	296	1.2	144	144

Data Rate
Up to 100 kbps maximum.

Data Management Strategy
TBD

Operational Constraints
A portion of a completed network will be emplaced on the lunar farside, which will require communications satellite support to return data to terrestrial control stations. Given that substantial human activity will change the lunar atmospheric environment, it may be

necessary to deploy stations robotically prior to human arrival or very early in a human mission to document changes to the lunar atmospheric environment.

Crew Interaction
Setup and adjustment as necessary for non-robotically deployed stations.

Payload Delivery Options
Human crew or robotic spacecraft.

Estimated Set-Up Time
TBD

Maintenance Needs
None.

Technology Assessment
A number of instruments similar to these were deployed on ALSEP, suggesting a Technology Readiness level of 13 for those instruments. For those instruments not flown on Apollo, a Technology Readiness level of 2 would appear appropriate.

Infrastructure Interface Requirements
Due to the variable locations of proposed deployment, each station should be independent of an outpost communications/data infrastructure and capable of transmitting its own data stream to a terrestrial ground station. Those stations deployed on the lunar farside will need communications satellite relay of data streams.

Resupply Needs
None.

Science/Exploration Community Contact
TBD

References
Budney, C. J., Ionasescu, R., Snyder, G. C. and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

SMALL SOLAR TELESCOPE

Date: 7/30/92

PAYLOAD SUMMARY	
Estimated Mass:	**100 kg**
Estimated Volume:	**1 m^3**
Estimated Power:	**50 W (daytime) ≤5 W (night standby)**
Estimated Data Rate:	**1.7 Mbps average, 256 Mbps maximum**

Rationale
Obtain high resolution images of the Sun to support studies of solar flare events and other solar processes. The telescope can serve as an early detection and warning system for solar flare events which produce radiation levels hazardous to human health.

Description
The Small Solar Telescope is a 25 cm diameter telescope with a filter designed to take images of the sun at a $\lambda = 25$ nm. The telescope will track the Sun continuously during the lunar day and will be powered by solar cells, with battery storage for night standby power. The telescope will have 4,000 by 4,000 pixel CCD array that has 1/4 arcsecond resolution, with an 8 bit dynamic range and a 10:1 data compression. It will have a narrowband filter wheel (which includes the Mg line at 280 nm) and a 0.02 – 0.0125 nm bandpass. The telescope will typically image the Sun once every 15-30 seconds, with a maximum capability of 1 image every 0.1 seconds with storage of the data for later return.

Power Consumption
50 W daytime power, with ≤5 W night or standby power.

Data Rate
Typical data rate will be on the order of 1.7 Mb/s. Maximum data rate of 256 Mb/s occurs for 1 minute only.

Data Management Strategy
Depending on the image rate, a majority of data may have to be stored for later transmission to terrestrial ground stations.

Operational Constraints
Operates only during the lunar day.

Crew Interaction
Unpack, assemble as necessary and place on the lunar surface.

Payload Delivery Options
Delivered as a single payload.

Estimated Set-up Time
TBD.

Maintenance Needs
None.

Technology Assessment
Technology Readiness Level 3.

Infrastructure Interface Requirements
If the instrument does not have its own data transmission capability, it will require external data links.

Resupply Needs
None.

Science/Exploration Community Contact
John Jefferies, National Solar Observatory, National Optical Astronomy Observatories.

References

Budney, C. J., Ionasescu, R., Snyder, G. C. and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

LUNAR SOLAR OBSERVATORY

Date: 7/23/92

PAYLOAD SUMMARY	
Estimated Mass:	**2500 kg Initial Phase** **38,500 kg Growth Phase** **82,500 kg Advanced Phase**
Estimated Volume:	**TBD**
Estimated Power:	**3 kW Initial Phase** **15 kW Growth Phase** **30 kW Advanced Phase**
Estimated Data Rate:	**20 Mb/s Initial Phase** **40 Mb/s Growth Phase** **60 Mb/s Advanced Phase**

Rationale

The Moon can provide a stable platform for large telescope structures and the environment for a permanently occupied base, both of which would be needed to support the long term, evolutionary buildup of a comprehensive, multi-telescope solar observatory. The observatory will have the capability for simultaneous, high resolution (0.1 arcsec) multispectral observations of the Sun and the Sun's chromosphere and corona at X-ray frequencies with the Pinhole Occulter Facility, and at visible, UV, and extreme UV wavelengths for two weeks every month. The observatory also will include a radio array to investigate the radio frequency emissions associated with solar events. The observations of solar flares will supply the flare alert and warning capability necessary for the operation of the lunar base.

The science goals envisioned for the Lunar Solar Observatory are the investigation of

1. the basic plasma physics processes responsible for the metastable energy storage and impulsive energy release in solar flares.
2. the root cause of the solar activity cycle and the factors that control the structure and dynamical behavior of the solar magnetic field, the photosphere, chromosphere, and corona.
3. the mechanisms that determine the MHD structure and behavior of the convective zone.
4. the structure and dynamics of the heliosphere as it is affected by the solar wind.

Description

The Lunar Solar Observatory will evolve over a period of years that will encompass three phases: an Initial Phase, a Growth Phase, and an Advanced Phase. Each phase will add more elements to the observatory with increasing degrees of complexity.

During the Initial Phase, the solar observatory will consist of an UV/Optical Telescope, a Soft X-Ray Telescope, an initial High Energy Instrument Package, a small Pointer, and an Earth-based control and data processing facility.

The Growth Phase will add an Advanced Pinhole Occulter Facility, a High Energy Facility, a second Pointer, and a Command/Processing Center.

During the Advanced Phase, the UV Telescope will be upgraded and an Optical and Near IT Telescope cluster, a large Pointer, and a Radio Facility will be added.

Payload Breakdown

Component	Initial Phase	Growth Phase	Advanced Phase
Mass (kg)			
UV Telescope	750	750	4000
Optical Telescope	-	-	4000
Near IR Telescope	-	-	4000
Soft X-Ray Telescope	750	750	4000
High Energy	500	1500	1500
Pinhole Occulter	-	10000	10000
Radio Facility	-	-	10000
Pointer	500	5500	15000
Support Facilities	-	20000	30000
TOTAL	2500	38500	82500
Power (kW)	3	15	30
Data Rate (Mb/s)	20	40	60
Data Storage (Bits)	10^11	10^12	10^14
Command Rate (Kb/s)	5	5	5
Thermal Control (kW)	3	13	30

Power Consumption
3 kW for the Initial Phase, 15 kW for the Growth Phase, and 30 kW for the Advanced Phase.

Data Rate
20 Mb/s for the Initial Phase, 40 Mb/s for the Growth Phase, and 60 Mb/s for the Advanced Phase.

Data Management Strategy
TBD

Operational Constraints
Need view of the Sun; thus the observatory will operate for ~2 weeks each month.

Crew Interaction
Astronauts must deliver and set up the system at the operational site. This would involve carrying the system to its site on a rover, preparing the site, setting up and aligning the telescopes.

Payload Delivery Options
Standard cargo.

Estimated Set-up Time
TBD

Maintenance Needs
The Lunar Outpost can support the maintenance of the observatory, its servicing, and change of instruments.

Technology Assessment
Ground based telescope heritage exists for the Lunar Solar Telescope. However, due to its location on the Moon and the desired improvements in the quality of observations, the following studies still need to be performed:

1. Lunar based pointing systems (with 1-2 orders of magnitude improvement in the pointing precision and stability).
2. Effects of lunar dust on optics, mechanical/electrical systems.
3. Assessment of evolutionary buildup.
4. Assessment of interrupted operations on observations.
5. Assessment of alternative siting
6. Assessment of on-site versus remote data processing.

With these considerations, the Lunar Solar Telescope currently has a technology readiness level of 9.

Infrastructure Interface Requirements
Deployment of the payload will utilize the rover capabilities.

Resupply Needs
TBD

Science/Exploration Community Contact
John Davis, Marshall Space Flight Center

References
Budney, C. J., Ionasescu, R., Snyder, G. C., and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory publication JPL D-7955.

LUNAR NEUTRINO TELESCOPE

Date: 7/24/92

PAYLOAD SUMMARY	
Estimated Mass:	**1270 kg**
Estimated Volume:	**TBD**
Estimated Power:	**500 W**
Estimated Data Rate:	**12-20 Kb/s**

Rationale

Observations of diffuse extraterrestrial neutrino fluxes cannot be made on the Earth due to the atmospheric background. The Moon is an ideal environment since the atmospheric background is about three orders of magnitude lower than on Earth at neutrino energies between 1-100 GeV. The Moon also can provide the large target mass (>10,000 tons of lunar rock) for the estimated 200 events/yr/1000 m^2, mass which cannot be made available in Earth orbit. The Lunar Neutrino Telescope also will measure the directional flux of Weakly Interactive Massive Particle (WIMP) annihilation products from the Earth or the Sun and identify discrete sources of cosmic neutrinos.

Description

The detector is to be located in a natural underground cavity with a thick roof or buried under lunar regolith for cosmic ray shielding. Large, natural caverns called lava tubes are postulated to exist on the Moon and would provide a safe, long-term shelter against radiation and meteorite impacts. In addition, the floor of the cavern would supply target mass for upward-moving neutrinos. The neutrino flux would be detected by light-weight, gas-filled, ionization detectors which can be deployed on plastic mesh supports with no need for massive rock moving or construction. The telescope consists of a 1000 m^2 detector which is made up of 5 layers of about 2.5 cm thick prefabricated detectors supported on a plastic mesh structure. The telescope is position-sensitive, which enables it to determine the trajectory of the neutrinos, and its time-of-flight capability allows it to discriminate between up-down directions and perform background rejection.

Thermal control is passive; the system operates at the temperature of the lunar cavern in which it is located.

Payload Breakdown

Component	Mass (kg)	Volume (m^3)	Power (W)	Data Rate (Kb/s)
Detector	1235	TBD	500	12.0 - 20.0
Support System	35	TBD	n/a	n/a
SUBTOTAL	1270	TBD	500	12.0 - 20.0
25% MARGIN	317		125	3.0 - 5.0
TOTAL	1587	TBD	625	15.0 - 25.0

Power Consumption

500 W

Data Rate
12-20 Kb/s

Data Management Strategy
TBD

Operational Constraints
It is desired that the cavern in which the system is located be close to the outpost in order to provide power and maintenance.

Crew Interaction
Astronauts might have to survey the lunar surface in the proximity of the outpost in search of naturally occurring caverns. Once the site is selected, they will deploy the gas-filled detectors on plastic mesh supports at the operational site with no need for massive rock moving or construction.

Payload Delivery Options
This telescope is delivered to the lunar surface as standard cargo and deployed by astronauts.

Estimated Set-up Time
TBD

Maintenance Needs
TBD

Technology Assessment
A detector with a fast time-of-flight capability and background rejection is required for up-down discrimination and identification of upward-moving neutrino events in the presence of a large downward-penetrating cosmic ray flux. Fiber optics could be used as an alternative to gas counters. Studies that need to be undertaken for the detector development include background rejection, optimum detector dimensions, power, data rate, gas system, weight, and reliability.

Infrastructure Interface Requirements
TBD

Resupply Needs
None

Science/Exploration Community Contact
Michael Cherry, Louisiana State University

References
Budney, C. J., Ionasescu, R., Snyder, G. C., and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory publication JPL D-7955.

LUNAR PINHOLE OCCULTER FACILITY

Date: 7/23/92

PAYLOAD SUMMARY	
Estimated Mass:	10,000 kg
Estimated Volume:	TBD
Estimated Power:	5000 W
Estimated Data Rate:	TBD

Rationale

The Lunar Pinhole Occulter Facility will perform X-ray astronomy from the lunar surface. The Moon provides a stable and slowly rotating platform with no interfering atmosphere. The observatory will provide the capability to study the following:

1. Rapid non-thermal energy releases in the solar corona
    a. Magnetic energy storage
    b. Energy release, transport, and dissipation mechanisms
    c. Mass ejection and high energy particle acceleration mechanisms
2. Spatial relationships between high and low energy emitting regions in cosmic hard X-ray sources.

Description

The key components of this observatory are a pinhole occulter mask and various types of detectors. The mask is positioned perpendicular to the detectors at a distance of approximately 100 m. When the entire arrangement is aimed at the desired target, X-ray photons from the target pass through the mask and are counted by the detectors. The mask also functions as a visible/UV solar occulting disk for coronal studies.

There are several possible configurations for this observatory. One consists of a vertical arch, made up of 2 tracks, which carries the mask. The mask moves along the arch to provide elevation control. The ends of the arch are mounted on a circular track, allowing the arch to rotate about the vertical and thus providing azimuthal control. The detectors sit on the lunar surface in the center of the circular track and point at the mask.

One alternative configuration involves moving the detectors rather than the mask. In this option, the mask is mounted on an approximately 100-m tower and is gimballed in azimuth and elevation. The detectors are mounted on a rover vehicle on the lunar surface and track the mask while the vehicle moves.

Power Consumption

5000 W

Data Rate

TBD

Data Management Strategy

Data will be telemetered to a terrestrial control center from which the data will be distributed to the scientific community.

Operational Constraints

It is assumed that the data will be routed via the outpost, multiplexed with the outpost downlink to Earth, and then distributed to the control center.

Payload Breakdown

Component	Mass (kg)	Volume (m^3)	Power (W)	Data Rate (Kb/s)
Science Instrumentation				
Coded aperature imager	500	TBD	250	TBD
Fourier transform imager	500	TBD	250	TBD
Rotating modulation collimator	2000	TBD	200	TBD
Bragg spectroheliograph	500	TBD	250	TBD
Visible/UV coronograph	200	TBD	200	TBD
EUV imager/spectrograph	410	TBD	140	TBD
Structure	6000	TBD	TBD	TBD
Power System	TBD	TBD	TBD	TBD
Telemetry, Command, and Data Processing System	TBD	TBD	TBD	TBD
SUBTOTAL	~10000	TBD	TBD	TBD
25% MARGIN	2500			
TOTAL	~12500	TBD	TBD	TBD

Crew Interaction
Astronauts may be required to construct the system if telerobotic deployment is not used. Astronauts would perform occasional maintenance.

Payload Delivery Options
This telescope can be delivered to the lunar surface as standard cargo and deployed by astronauts and/or telerobotic systems. Extensive human EVA or (tele)robotic activity will be required for deployment and setup.

Estimated Set-up Time
TBD

Maintenance Needs
Occasional repair as required. Routine maintenance may be required.

Technology Assessment
Technology Readiness Level 1.

Infrastructure Interface Requirements
Communications connections.

Resupply Needs
TBD

Science/Exploration Community Contact
John Davis, Marshall Space Flight Center.

References

Budney, C.J., Ionasescu, R., Snyder, G.C., and Wallace, R.A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

LUNAR CALORIMETER

Date: 7/23/92

PAYLOAD SUMMARY

Estimated Mass:	**3700 kg**
Estimated Volume:	**86.4 m^3**
Estimated Power:	**1 kW**
Estimated Data Rate:	**1 Kb/s**

Rationale

The Lunar Calorimeter is designed to explore cosmic ray nuclei with energies in excess of 10^{15} eV and determine the source of the highest energy cosmic rays. The calorimeter will help identify the acceleration mechanisms of these high energy cosmic rays, and determine how particles escape from the galaxy. The lack of any atmosphere on the Moon implies that the cosmic ray flux arrives at the lunar surface unattenuated. By comparison, the Earth's atmosphere alters the primary character of the cosmic particles. The Moon also provides the significant amount of mass necessary for the construction of the large aperture detector required for high energy particles, mass which otherwise would be hard to launch into orbit for observations from space.

Description

The calorimeter consists of 10 layers of plastic scintillation counters viewed by photomultiplier tubes. Each layer is separated by approximately 30-35 cm of lunar regolith. The cosmic ray measurements are sensitive to the position of the calorimeter for determining their trajectory and time-of-flight. Thermal control is passive since the system operates at the temperature of the regolith in which it is buried.

Payload Breakdown

Component	Mass (kg)	Volume (m^3)	Power (W)	Data Rate (Kb/s)
Scintillators	1700	TBS	TBS	TBS
Photomultiplier Tubes & Electronics	1000	TBS	TBS	TBS
Mechanical Support	1000	TBS	TBS	TBS
SUBTOTAL	3700	86.4	1000	1
25% MARGIN	925	21.6	250	0.25
TOTAL	4625	108	1250	1.25

Power Consumption

1 kW

Data Rate

1 Kb/s

Data Management Strategy
TBD

Operational Constraints
Issues of concern in the operation/construction of the calorimeter could be:
1. Backsplash due to calorimeter albedo particles caused by cosmic ray nuclei interacting with the lunar regolith. By spatially segmenting the top counter of the calorimeter, the area over which the backsplash would be distributed will be reduced, thus lessening the probability of the backsplash hitting the same spot as the primary particle.
2. Background due to solar energetic particle events (flares) that lead to pileup. It is felt that the duration of a solar flare will not be so long as to damage the calorimeter equipment. However, pileup could prohibit the differentiation of particles entering the calorimeter.
3. The mass of scintillator material could be a constraint depending on the type of launch/transfer vehicle that will be used to transport the payload to the Moon.

Crew Interaction
Astronauts must set up the system at the operational site. This would involve finding or digging a hole in the lunar regolith and emplacing and layering the scintillators and the photomultipliers with regolith.

Payload Delivery Options
The calorimeter will be built at the location site.

Estimated Set-up Time
TBD

Maintenance Needs
TBD

Technology Assessment
The present technology is adequate. However, computer simulations are necessary to track the backsplash and understand its effects for the cosmic ray measurements to be highly reliable. It also is desirable that the power consumption of the calorimeter be reduced. These considerations give the calorimeter a technology readiness level of 11.

Infrastructure Interface Requirements
None.

Resupply Needs
None.

Science/Exploration Community Contact
Simon Swordy, University of Chicago.

References
Budney, D. J., Ionasescu, R., Snyder, G. C., and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

EARTH EXOSPHERIC ULTRAVIOLET IMAGING TELESCOPE

Date: 7/24/92

PAYLOAD SUMMARY	
Estimated Mass:	**312 kg**
Estimated Volume:	**1.4 m^3**
Estimated Power:	**80 W**
Estimated Data Rate:	**6 Kb/s**

Rationale
The Earth Exospheric Ultraviolet Imaging Telescope will perform imaging of the Earth's exosphere and magnetosphere in the extreme ultraviolet (EUV) band. The emissions in this band are produced by the resonance scattering of solar radiation by exospheric ions and neutrals (He^+, O^+, and O^0). The lunar surface provides a stable platform with advantageous perspective for obtaining detailed EUV images at a rate high enough to provide a new global means of observing the dynamics of auroral substorm and magnetosphere-ionosphere coupling processes.

Description
This system consists of two telescopes mounted together on a single platform and sharing common pointing, power, data, etc., systems. One telescope observes O^+ ions at 834 Å and the other observes He^+ ions at 304 Å and O^0 neutrals at 1304 Å. The telescopes are deployed on the lunar nearside and permanently aimed at the mean Earth position (they do not actively track the Earth through librations).

The 304/1304 Å telescope is a 20-cm Cassegrain design with a 10 x 10 degree field-of-view. It utilizes multilayer normal incidence reflective filter mirror surfaces and a position-sensitive photon-counting detector. A mechanical filter wheel switches between an aluminum-carbon 304 Å filter and a combination Earth occulting disk and 1304 Å filter.

The 834 Å telescope is a 30-cm aperture prime focus type with a 30 x 30 degree field-of-view. It utilizes a silicon carbide mirror, an indium foil filter for background suppression, and a position-sensitive photon-counting detector.

Since night operation is not required, a solar power system is sufficient if outpost power is not convenient. A solar power system is assumed here, involving a solar array with mechanisms to track the sun and a battery to provide standby power during the lunar night.

Power Consumption
80 W, self-supplied.

Data Rate
6 Kb/s

Data Management Strategy
A relatively simple Earth control center will process the telemetry and control the system. It is assumed that data will be routed via the outpost, multiplexed with the outpost downlink to Earth, and then distributed to the control center. Alternatively, there could be a direct link between the telescope and an Earth station; this would require a more capable communication system.

Payload Breakdown

Component	Mass (kg)	Volume (m^3)	Power (W)	Data Rate (Kb/s)
834 Å Telescope	90	0.27	30	3
304/1304 Å Telescope	60	0.16	30	3
Platform and support structure	80	0.65	0	0.01
Solar array sun tracking mechanism	20	TBD	2	0.01
Power system				
Solar array (400 W)	30	2.6 deployed TBD stowed	n/a	0
Power supply	10	TBD	n/a	0.01
Battery	10	TBD	n/a	0
Communications system	10	TBD	5	0.03
Computer system	2	TBD	10	0.03
SUBTOTAL	312	3.68+	77	6
25% MARGIN	78	0.92	19	2
TOTAL	390	4.6+	96	8

Operational Constraints

The system is deployed on the lunar nearside close enough to the outpost to allow occasional maintenance but far enough to avoid contamination. The system must be located at a latitude and longitude which maintain the 30 x 30 degree Earth-centered field-of-view requirement. For an equatorial outpost, this would mean placement no closer than approximately 30 degrees to the mean limb.

Crew Interaction

Astronauts must deliver and set up the system at the operational site (although the system could alternatively be autonomously delivered). Astronauts will perform initial alignment of telescopes toward the Earth, solar arrays toward the Sun, and communications antenna toward the outpost.

Payload Delivery Options

This telescope can be delivered to the lunar surface as standard cargo and deployed by astronauts or delivered by an robotic soft lander. In the latter case, deployment and alignment must be autonomous.

Estimated Set-up Time

TBD

Maintenance Needs

Occasional repair as required. No routine maintenance is envisioned.

Technology Assessment

This system has no new technology requirements. However, 834 Å multilayer normal incidence reflective filter mirrors, if available, could replace the silicon carbide mirror and indium filter in the 834 Å telescope, resulting in a simpler and improved design. Such mirrors are currently under development.

This system is estimated to have a technology readiness level of 9.

Infrastructure Interface Requirements
System will be transported to its operational site by the rover.
Communication links.

Resupply Needs
None

Science/Exploration Community Contact
TBD

References
Budney, C. J., Ionasescu, R., Snyder, G. C., and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory publication JPL D-7955.

ENERGETIC NEUTRAL ATOM MAGNETOSPHERIC IMAGER

Date: 7/24/92

PAYLOAD SUMMARY	
Estimated Mass:	**290 kg**
Estimated Volume:	**10 m^3**
Estimated Power:	**175 W**
Estimated Data Rate:	**30 Kb/s**

Rationale

This system will perform imaging of the Earth's magnetosphere by detecting energetic (20 keV/nucleon to 500 keV/nucleon) neutral atoms emitted by hot magnetospheric plasma. The lunar surface provides a stable platform with advantageous perspective for obtaining images over periods of years. This will permit scientists to study the global dynamics and structure of the magnetosphere. In particular, this instrument will provide insight into the nature and causes of magnetospheric activity and substorms.

Description

The main structure of the Energetic Neutral Atom Magnetospheric Imager is a 2 x 2 x 2 m box, buried in lunar regolith with only the front Earth-pointing face exposed. At the rear of the box is a segmented thin-foil time-of-flight neutral atom detector, composed of 25 individual detectors, each 20 x 20 cm. Atoms from the Earth's magnetosphere reach the detector after passing through a 2 m^2 coded aperture mask on the front of the box. The position and velocity of the atoms, as they pass through the detector, are determined by sensing electrons scattered from the foil and from this information an image of the atom source can be reconstructed. The system will have an angular resolution of 0.5 degree, a pointing accuracy of 3 arcmin, and a field of view of 40 degrees.

Detection of the scattered electrons is accomplished with a high-voltage electron optics system. Since dust can interfere with the high-voltage detector system, the unit must be protected from heavy dust exposure. Therefore, a dust cover will be closed over the Imager whenever outdoor outpost activities occur.

Thermal control is passive; the system operates at the temperature of the regolith in which it is buried.

Power Consumption

175 W, supplied from the outpost. Alternatives include solar power, which would require a large battery (~800 kg) plus a solar array, an RTG (~30 kg), or sharing a power bus cable which leads from the outpost to multiple observatories.

Data Rate

30 Kb/s.

Data Management Strategy

It is assumed that data will be routed via the outpost, multiplexed with the outpost downlink to Earth, and then distributed to the control center. Alternatively, there could be a direct link between the Imager and Earth stations; this would require a communication system.

Payload Breakdown

Component	Mass (kg)	Volume (m^3)	Power (W)	Data Rate (Kb/s)
Box Structure	40	8	0	
Coded aperture mask	10	2 x 2 m	0	0
Detectors, electron optics, and support electronics	175	TBD	165	30
Dust cover (not active during imaging operations)	5	2 x 2 m	15	0.03
Power system	15	TBD	n/a	0.01
Computer/data handling system	5	TBD	10	0.03
Outpost power & data cable	40	0.5	n/a	n/a
SUBTOTAL	290	>10	175	30
25% MARGIN	72.5	2.5	43.8	7.5
TOTAL	362.5	12.5	218.8	37.5

Operational Constraints
Deployed on the lunar nearside close enough to the outpost to allow occasional maintenance by the astronauts but far enough to avoid severe dust. Dust is acceptable below the level at which it begins to interfere with the high voltage electronics. The system should be located at a latitude and longitude which maintain the 40° Earth-centered field of view (±20° cone angle). Deployment near the equator therefore would imply a location within approximately ±70° longitude from sub-Earth point. A relatively simple Earth control center would process the telemetry and control the system. The control center will require advance warning of outpost dust-raising activities so that the dust cover can be closed.

Crew Interaction
Astronauts must deliver and set up the system at the operational site. This would involve carrying the system to its site on the rover, digging a hole, emplacing the system at the proper Earth-pointing orientation, covering it with regolith, and deploying the power and data cable between the system and the outpost.

Payload Delivery Options
The Energetic Neutral Atom Magnetospheric Imager is delivered to the lunar surface as standard cargo and deployed by astronauts.

Estimated Set-up Time
TBD

Maintenance Needs
No routine maintenance is envisioned. In case of a malfunction, astronauts could excavate the system and repair it.

Technology Assessment
No new technology is required. However, studies should be undertaken to establish requirements in the following areas:

1. Operations -command and data handling
2. Imager -sensitivity and resolution
   -sensor design
   -imaging technique assessment
   -charged particle rejection
3. Support Systems -communications, power, and high voltage supplies

This system has a technology readiness level of 9.

Infrastructure Interface Requirements
System will be transported to its set up location by the rover.
Communication link to habitat.

Resupply Needs
None

Science/Exploration Community Contact
Andrew Cheng, Applied Physcis Laboratory

References
Budney, C. J., Ionasescu, R., Snyder, G. C., and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory publication JPL D-7955.

LUNAR BASED MAGNETOPAUSE SOUNDER

Date: 8/13/92

PAYLOAD SUMMARY	
Estimated Mass:	**9000 kg**
Estimated Volume:	**35 m^3**
Estimated Power:	**200 W per transceiver unit; total of 1800 W**
Estimated Data Rate:	**100 Kb/s per transceiver unit; total of ~900 Kb/s**

Rationale

The lunar surface provides a minimum low frequency (2-100 kHz) background noise environment and a stable platform for large scale antenna arrays. In addition, the Moon itself is in the right location with respect to the orientation of the Earth's magnetopause boundary. The Lunar Based Magnetopause Sounder will be able to

1) Conduct active "sounding" of the magnetopause boundary.
2) Determine plasma gradients in the magnetopause boundary layer.
3) Determine magnetopause boundary motions using a phase stepped transmitted pulse to the transmitting antenna.
4) Determine the waveguide propagation characteristics of the magnetosphere.
5) Investigate structures and dynamics of the magnetotail, including both the low-latitude boundary layer and the distant plasma mantle.
6) Determine changes in the magnetosphere tail configuration and magnetic flux caused by both external forcing and internal processes.

The location for the Lunar Based Magnetopause Sounder is preferably on the lunar backside to avoid electromagnetic noise generated at the inhabited outpost and processing center as well as the background continuum radiation from Earth. However, the lunar front side will be scientifically useful for proof-of-concept.

Description

The sounder consists of a transmitting antenna and a transmitter, a receiving antenna and a receiver, and a support system for each unit. The transmitting antenna has one or more dipole arrays, and uses the transceiver arrays. Its pulsed, coded output sounds the magnetopause boundary in the frequency range of 5 kHz to 100 kHz in 5 kHz step increments. The receiving antenna consists of nine 2500 m long dipole arrays, each mounted on a short mast, and has an effective aperture of 20,000 m. The receiver is of digisonde type. Each unit has its own support system with solar power, communication capability, and a controller. Each transceiver unit is tied to a processing center. Thermal control is passive.

Power Consumption

200 W per transceiver unit, giving a total of 1800 W of power. Energy storage for nighttime operation is required.

Data Rate

100 Kb/s per transceiver unit, giving a total of ~900 Kb/s.

Data Management Strategy

TBD

Payload Breakdown

Component	Mass per (kg)	Volume (m^3)	Power (W)	Data Rate (Kb/s)
9 Transceiver Units	~9000	TBD	1800	900
Transmitting/Receiving Antenna	TBD	TBD	TBD	
-Dipole Arrays	TBD	TBD	TBD	
Transmitter	TBD	TBD	TBD	
Receiver (Digisonde Type)	TBD	TBD	TBD	
Support System (Each Unit)				
-Solar Power	TBD	TBD	TBD	
-Communications	TBD	TBD	TBD	
-Controller	TBD	TBD	TBD	2
SUBTOTAL	9000+			902
25% MARGIN	2250			225
TOTAL	11250+	TBD	TBD	1127

Operational Constraints
If the magnetopause sounder is located on the nearside of the Moon, a higher transmitting power will be required because of the background continuum radiation from Earth. However, if the magnetopause sounder is located on the farside of the Moon, only 1 W of power will be required, which can be supplied by a battery. The farside magnetopause sounder would be used for only about a week a month when the Moon is in the Earth's magnetotail. As such, the sounder could time-share the receiver from the Very Low Frequency Interferometer with no overlap in the operating frequency (30 MHz).

Crew Interaction
Astronauts must deliver and set up the system at the operational site. This would involve carrying parts of the system to its site on a rover, preparing the site, emplacing the system at the proper Earth-pointing orientation, and linking the dipole arrays to the processing center. The mast and dipole antennas are deployable.

Payload Delivery Options
This payload is delivered to the lunar surface as standard cargo and deployed by astronauts.

Estimated Set-up Time
TBD

Maintenance Needs
Routine maintenance.

Technology Assessment
The present technology is adequate. However, further studies are required to address the operation of the magnetopause sounder and the sounder's interface with the support systems (power, command and data systems, and data processing center). Technology readiness level is estimated at about a 6.

Infrastructure Interface Requirements
Data communications link to Earth is required. If system is deployed on the lunar farside, this requirement suggests that a communications satellite will be necessary to relay the data back to Earth.

Resupply Needs
TBD

Science/Exploration Community Contact
Patricia Reiff, Rice University

References
Budney, C. J., Ionasescu, R., Snyder, G. C., and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

A. Lunar Science Payloads
4. Life Sciences

BIOMEDICAL LABORATORY I

Date:

PAYLOAD SUMMARY	
Estimated Mass:	**2000 kg**
Estimated Volume:	**50 m^3**
Estimated Power:	**TBD**
Estimated Data Rate:	**TBD**

Rationale

Description

Power Consumption

Data Rate

Data Management Strategy

Operational Constraints

Crew Interaction

Payload Delivery Options

Estimated Set-up Time

Maintenance Needs

Technology Assessment

Infrastructure Interface Requirements

Resupply Needs

Science/Exploration Community Contact

BIOMEDICAL LABORATORY II

Date:

PAYLOAD SUMMARY

Estimated Mass:	3000 kg
Estimated Volume:	90 m^3
Estimated Power:	TBD
Estimated Data Rate:	TBD

Rationale

Description

Power Consumption

Data Rate

Data Management Strategy

Operational Constraints

Crew Interaction

Payload Delivery Options

Estimated Set-up Time

Maintenance Needs

Technology Assessment

Infrastructure Interface Requirements

Resupply Needs

Science/Exploration Community Contact

PLANT/ANIMAL LABORATORY I

Date:

PAYLOAD SUMMARY	
Estimated Mass:	2000 kg
Estimated Volume:	65 m^3
Estimated Power:	TBD
Estimated Data Rate:	TBD

Rationale

Description

Power Consumption

Data Rate

Data Management Strategy

Operational Constraints

Crew Interaction

Payload Delivery Options

Estimated Set-up Time

Maintenance Needs

Technology Assessment

Infrastructure Interface Requirements

Resupply Needs

Science/Exploration Community Contact

PLANT/ANIMAL LABORATORY II

Date:

PAYLOAD SUMMARY	
Estimated Mass:	7000 kg
Estimated Volume:	165 m^3
Estimated Power:	TBD
Estimated Data Rate:	TBD

Rationale

Description

Power Consumption

Data Rate

Data Management Strategy

Operational Constraints

Crew Interaction

Payload Delivery Options

Estimated Set-up Time

Maintenance Needs

Technology Assessment

Infrastructure Interface Requirements

Resupply Needs

Science/Exploration Community Contact

A. *Lunar Science Payloads*

5. Robotic Science

LUNAR ROBOTIC SCIENCE ROVER

Date: 7/15/92

PAYLOAD SUMMARY	
Estimated Mass:	**500 kg (landed mass; can carry up to 100 kg of additional payload)**
Estimated Volume:	**TBD**
Estimated Power:	**TBD, supplied by internal RTG/solar cell combination**
Estimated Data Rate	**TBD**

Rationale
The lunar exploration mission will be called upon to study a diverse set of problems, initially with limited crew mobility and time. A robotic science rover provides an attractive complement to the human crew as an "extra crew member", able to conduct much of the routine science data gathering at the outpost site and beyond the initial limits of human EVAs. A robotic rover will also be able to conduct sample acquisition and geophysical investigations at long distances between human visits to the outpost site without the risk of stranding or disabling a valuable crew rover beyond the reach of the human crew.

Description
This rover will have a radius of activity of ~100 km from the outpost site and will be able to transport ~100 kg of payload. In addition to its capability to pick up and stow samples, the rover will be equipped with a stereo color video capability, still camera photodocumentation capability, and a suite of analysis tools. The rover will be powered by radioisotope thermal generators (RTGs), with possible solar array backup. The instrumentation is as follows:

Mössbauer/X-ray Fluorescence Analyzer	Iron mineralogy (metal and Fe-bearing minerals, soil maturity); Chemical composition of soil and rock samples, including solar wind implanted particles.
α-Particle Backscattering Instrument	Chemical composition of soil and rock samples. Solar wind implanted particles.
Stereo imaging capability	Navigation, sample provenance, terrain avoidance.
Still camera capability	Sample photodocumentation.
IR Reflection spectrometer	Mineralogy

In addition to the named instrumentation, the rover will have the capability to transport 100 kg of samples back to the outpost, or carry 100 kg of additional science instrumentation, such as geophysical packages.

Power Consumption
TBD

Data Rate
Real time stereo video capability requires about 30 Mb/s; 0.5 sec transmission requires about 15 Mb/s and digital transmission every two seconds only requires 4 Mb/s.

Data Management Strategy
TBD

Payload Breakdown

Component	Mass (kg)	Volume (m^3)	Power (W)	Data Rate
Rover Structure*	250	TBD	NA	NA
Stereo Image/Photodocumentation Assembly	10	TBD	<6	1-50 Mb/s
Sample Analytical Equipment	30	TBD	<7 per unit	1-100 Kb/s
Sample Manipulation Equipment	20	TBD	<30	<500 b/s
Sample Storage Equipment	70	TBD	peak~25	<500 b/s
Power Generating Equipment	25-40	TBD	NA	NA
Payload capability**	100			
SUBTOTAL	505-520	TBD	~68	50.1 Mb/s
25% MARGIN	126-130		17	12.5 Mb/s
TOTAL	631-650	TBD	~85	62.6 Mb/s

*Includes drive train, basic rover structure, communications subsystem, and any autonomous intelligence capability.
**Includes returned samples or additional instruments that can be operated or deployed during a traverse, such as geophysical instruments.

Operational Constraints
TBD: The rover should be robust enough to travel over surfaces similar to those negotiated by the Apollo Lunar Roving Vehicle (maximum slopes negotiated by the Apollo LRV were 19-23°). Obstacle clearance/avoidance capability should be built into any on-board intelligence to account for the 2-3 seconds lag time between receiving teleoperation input and visual feedback returning to the teleoperator.

Crew Interaction
Unloading, set-up, teleoperation when outpost is occupied; routine and non-routine maintenance as required.

Payload Delivery Options
Delivered to the outpost as part of the piloted mission science cargo.

Estimated Set-up Time
TBD (4-8 hrs minimum)

Maintenance Needs
TBD

Technology Assessment
There are a variety of current projects that might be adapted to this rover, but at present, there has been no attempt to develop a rover with these capabilities. Given that situation, the rover is given a Technology Readiness Level of 2.

Infrastructure Interface Requirements
Communications capability with relay orbiter, Earth direct, and lunar outpost.

Resupply Needs
Sample containers and film (if used).

Science/Exploration Community Contact
TBD

References

Budney, D.J., Ionasescu, R., Snyder, G. C., and Wallace, R.A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

SMALL ROBOTIC LUNAR GEOPHYSICAL MONITORING PACKAGE

Date: 8/3/92

PAYLOAD SUMMARY	
Estimated Mass:	**75 kg**
Estimated Volume:	**0.2 m^3**
Estimated Power:	**56 W**
Estimated Data Rate:	**data rates for individual instruments ranges from 0.04 kbps to 1 kbps**

Rationale

The Small Robotic Lunar Geophysical Monitoring Package contains a variety of instruments designed to be landed on a common lunar lander. The instruments will measure the time-variant values of geophysical parameters at a number of locations on the lunar surface. It will provide information on the variation of the moon's magnetic field strength, seismic activity, and the distance between the experiment site and observatories on the Earth.

Description

The Small Robotic Lunar Geophysical Monitoring Package is a collection of geophysical instruments that are designed to measure the temporal variation of several geophysical parameters. The package has a pedigree that extends back to the Apollo Lunar Scientific Experiments Package (ALSEP), and the preliminary concept of the instruments is based on ALSEP designs and the work of the Jet Propulsion Laboratory Science Engineering Analysis Team.

The concept for production and deployment for this package is that the set of instruments described herein will be deployed at a variety of locations on the lunar surface. Widespread deployment of these packages will allow geophysicists to characterize the interior of the moon in detail, and standardizing the instrument sets insures that the same data set is collected at each location. Because these instruments are designed to be landed on a robotic spacecraft, the primary design and operation philosophy is simplicity and high reliability without the need for human interaction.

As with ALSEP, it is likely that many of these packages will be deployed in locations where regular return for maintenance or component change out is unlikely. Therefore, package and instrument designs will need to be rugged, long lasting and self contained with respect to power and communications capability.

The purpose of each of the instruments is as follows:

Central Station	Controls power conditioning and distribution, processing of all commands controlling experiments, and transmittal of data back to Earth.
Magnetometer	Measures the field strength and direction of the lunar magnetic field with a range of ~0 – ±200 γ and a sensitivity of 0.1 γ (based on designs in NASA SP-289, pg. 9-4).

Passive Seismometer	Measures the magnitude and direction to lunar seismic events with a sensitivity of ~10^{-3} to 10^{2} Hz with ground motions on the order of 10^{-1} nm (based on designs in NASA SP-289, pg.8-3).
Laser Ranging Retroreflector	Measures the distance from the Earth to the deployment site on the Moon with centimeter accuracy.

Payload Breakdown

Component	Mass, (kg)	Volume, (m^3)	Power, (W)	Data Rate (Kb/s)
Central Station	25	0.03	25	
Magnetometer	10	0.05	10	0
Passive Seismometer	15	0.01	10	1
Laser Ranging Retroreflector	10	0.06	0	0
PACKAGE SUBTOTAL	60	0.15	45	1
25% MARGIN	15	0.04	11	0
TOTAL	75	0.2	56	1

Power Consumption
Power will be supplied to each instrument after conditioning and distribution by the central station. ALSEP stations successfully used radioisotope thermal generators for power, although some form of advanced solar cell/battery technology may be available. Because geophysical packages will be landed by a robotic spacecraft, the power source selected will have to be maintenance free and provide reliable power for a period of several years without human interaction. Conventional batteries are therefore unlikely to be used.

Planned power consumption on each instrument is as follows:

Central Station	25 W
Magnetometer	10 W
Passive Seismometer	10 W
Laser Ranging Retroreflector	0 W

Data Rate
Each instrument will have its own data rate; present maximum is planned at 1 kbps.

Data Management Strategy
The present configuration calls for data to be processed through a central station, similar to ALSEP designs. Alternatively, it may be possible to provide each instrument with its own data handling and transmission capability. Preliminary design studies should determine the most efficient and feasible method of data handling. Deployment of stations on the lunar farside will require additional communications infrastructure to transmit data to terrestrial ground stations.

Operational Constraints
None.

Payload Delivery Options
The preliminary design discussed here assumes that the payload will be delivered with all four instruments. However, it may be possible to fly combinations of the above payloads as required by the SEI science program and mission requirements.

Maintenance Needs
These instruments should be designed to operate autonomously, without requirements for regular maintenance.

Technology Assessment
Instruments to measure these parameters have been in extensive use both terrestrially and as ALSEP payloads for a significant period of time, suggesting technology readiness level 13. Some development work may be required on power systems if some advanced solar cell/battery power source is desired over radio-isotope thermal generators, suggesting technology readiness level 2.

Resupply Needs
ALSEP stations were considered expendable; that is, no provision was made for replacement or repair of malfunctioning instruments. Whether these stations are considered expendable as well will depend on the cost of production, and the level of transportation infrastructure on the lunar surface.

Science/Exploration Community Contact:
TBD

References
Budney, C. J., Ionasescu, R., Snyder, G. C. and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

Natl. Aeron. Space Admin. (1972), Apollo 15 Preliminary Science Report: NASA SP-289, U. S. Govt. Print. Off., Wash. D.C.

A. Lunar Science Payloads
6. Resource Utilization

IN-SITU RESOURCE UTILIZATION DEMONSTRATION PACKAGE

Date: 8/13/92

PAYLOAD SUMMARY	
Estimated Mass:	**750 kg**
Estimated Volume:	**$0.6 m^3$**
Estimated Power:	**2,900 W peak power; 200 W standby**
Estimated Data Rate:	**TBD**

Rationale

The ability to convert lunar materials to useful products will be a key milestone in determining the long-term viability of any lunar outpost. The first step in this process is determining what, if any, useful products can be produced from in-situ materials. This payload is designed to test three key concepts in lunar resource development: the production of oxygen, the making of building materials from sintered lunar soil, and pneumatic granular material transport and size sorting.

Description

Oxygen Production Pilot Plant: This payload is designed to test the capability for production of lunar oxygen from lunar soil by hydrogen reduction of the mineral ilmenite ($FeTiO_3$), a common component in mature, high-titanium lunar soils. In doing so, it also will evaluate the influence of soil composition on oxygen and water yield, determine the composition of volatiles evolved from the lunar soil, and determine changes in the lunar soil caused by oxygen release. The device will pass hydrogen over a heated soil sample, reducing the ilmenite to produce oxygen which will combine with the hydrogen to form water. The water will then be collected and electrically broken back down to oxygen and hydrogen; the hydrogen will be returned to the reservoir for additional reduction, and the oxygen will be stored for later analysis. The device uses three interconnected modules: a soil hopper, which conducts an initial screening of the soil, rejecting grains above a particular size; a reaction unit, which heats the soil, fluidizes the heated soil bed by passing hydrogen through it, and collects the evolved gases and dumps the spent regolith after the sample has been completely reacted; and a controller module, which runs the experiment.
Brick-making Experiment: This payload will test whether samples of lunar regolith can be sintered using microwave generators to make bricks which can fill for a variety of uses such as radiation protection, and landing pad and road construction. The device is designed to produce a variety of brick sizes and use variations of temperatures to sinter the regolith, thereby determining what is the optimum size, heating rate, and production rate. It consists of three modules: a soil hopper, which is identical to the soil hopper used for the oxygen production pilot plant; a brick press module, in which the soil is heated to varying temperatures with microwave generators and pressed into a mold box to create a brick; and a data acquisition/control module, which runs the experiment.
Gas-Solid Flow Unit: The gas-solid flow unit tests the concept of transport and size-sorting of lunar materials using pneumatic methods.

Power Consumption

Oxygen pilot plant: 2,900 W peak power, 200 W standby.
Brick-making Experiment: TBD W peak power, TBD W standby.
Gas-solid flow unit: 100 W peak power, TBD W standby.

Data Rate

TBD

Data Management Strategy
TBD

Operational Constraints
Since the package consumes a significant amount of power, it may be necessary to run it at times when the outpost power consumption needs are low.

Crew Interaction
EVA crew will be required to initially set up each demonstration module, to periodically load 10 kg of soil sample into the soil hopper, and to recover samples of evolved gases and sintered bricks.

Payload Delivery Options
The payload can be broken into several smaller pieces for ease in packing; however, all pieces are necessary to conduct the full experiment, so it will be necessary to include all pieces on the same flight.

Estimated Set-up Time
TBD

Maintenance Needs
TBD

Technology Assessment
TBD

Infrastructure Interface Requirements
Power hook-up to the habitat. Data link to the habitat and, if necessary, Earth stations.

Resupply Needs
None.

Science/Exploration Community Contact
D. McKay, JSC

References

Altemir, D.A., 1992, Conceptual Design of an ISMU Brickmaking Experiment for a Manned Return to the Moon: unpubl. ms., 10 pp.
McKay, D. S., 1992, Personal Communication.
Sullivan, T.A. and McKay, D. S., 1991, Using Space Resources, NASA/Johnson Space Center, 27 pp.

B. Lunar Scout
Mission Description and Payloads

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Lunar Scout Mission Description and Payloads

Lunar Scout Program: Mission Description

The Lunar Scout Program was developed in late 1991 as two small lunar orbiter satellites to characterize the Moon. It was to be one of the first in a series of low-cost, fast-paced missions that would provide the fundamental science and engineering data needed to prepare the way for follow-on human and robotic exploration of the Moon. The first satellite was to launch separately, its goal to provide a global map of lunar surface elements, acquire high resolution stereo imaging of the Moon's surface, and develop a near-side gravity map. The second mission was to be launched a year later to provide a more comprehensive global map, a global mineralogical map, and extend the gravity map to the far-side of the Moon. The operational life for each orbiter was one year. The data sets obtained from the two missions was to be used to support lunar science objectives as well as site selection determination for future landed missions. The Lunar Scout Program failed to achieve New Start funding in the FY93 and 94 budgets.

Each orbiter includes three main project elements: the spacecraft bus, the instrument module, and the science instruments. The science instruments were selected based on science data requirements, technical maturity, and ability to meet schedule and cost.

Lunar Scout Program: Science Payloads

A Commerce Business Daily announcement was issued in December 1991 calling for ideas for instruments for lunar orbiting missions. The proposals received were discussed and evaluated by a peer group in a workshop held at the Lunar and Planetary Institute (LPI) in February 1992. Proposals were ranked in terms of maturity (i.e., readiness for flight) and science return. The workshop functioned as a market survey and served as the basis for instrument selection.

Over the next few months instruments proposed in the LPI workshop were reviewed that could provide global and local elemental mapping, including a measure of volatiles of which hydrogen was considered to be a key; mineralogical mapping; geodesy; a digital imagery database between 10 and 20 meters/pixel for a global database and less than 10 meters/pixel for a local database and regional imagery; and a means to map the gravity field of the Moon and correlate it with terrain features.

It is this collection of proposed instruments and their payload descriptions that are included in this section of the catalog. Final instrument selection was completed in June 1992 when, out of the set of proposed instruments, six were selected to fly on Scout. They are the first six payloads included in this section: the Hard X-Ray Spectrometer, the Neutron Spectrometer, the High Resolution Stereo Camera, the Ge Gamma Ray Spectrometer, the MinMap Imaging Spectrometer, and the Gravity Map. (Note that of the two gravity experiments proposed, it is the first, more generalized concept that was selected and not the last payload listed, "Lunar Gravity Experiment.")

Lunar Scout Program: Science Payloads (continued)

- * Hard X-Ray Spectrometer
- * Neutron Spectrometer
- * High Resolution Stereo Camera
- * Ge Gamma Ray Spectrometer
- * MinMap Imaging Spectrometer
- * Gravity Experiment
- CompMap
- Geo Map
- Soft X-Ray Fluorescence Imager
- Imaging and Mineralogy Experiment
- Topography and Gravity Experiment
- Global Elemental Composition Package
- Gamma Ray/Neutron Spectrometer
- Secondary Ion Mass Spectrometer
- Lunar Ultraviolet Mapping Interferometric Spectrometer
- Thermal Emission Spectrometer
- Mercator--A Lunar Imaging Mission
- Electrostatic Zoom Digicon Imager
- Lunar Geodetic Mapping Mission
- Lunar Terrain Mapping Mission
- Lunar Resource Mapping Mission
- Si (Li) Gamma Ray Detector
- Small Lunar Information Mission
- Lunar Observer Laser Altimeter
- Lunar Gravity Experiment (second option)

* Selected for Lunar Scout Mission

HARD X-RAY SPECTROMETER

Date: 7/21/92

PAYLOAD SUMMARY	
Estimated Mass	12.0 kg
Estimated Volume	
Estimated Power	22 W
Estimated Data Rate	5 Kb/s

Rationale
The Hard X-Ray Spectrometer provides the elemental abundance data on a 10-20 km footprint scale required to formulate exploration and resource utilization strategies. It measures the abundance of rock-forming elements in the regolith with high precision and at a spatial resolution that is correlative with mineralogic mapping.

Description
The Hard X-Ray Spectrometer provides information on the X-Ray energies produced by Si, Al, Mg, Ca, Fe, and Ti in the lunar soil. Determination of the amounts of these elements allows calculation of the efficacy of mining operations in various locations across the surface. The Al, Ca, and Mg measurements complement and provide a check for the same elements measured over a larger area by the Gamma Ray Spectrometer. In addition, the scale of the measurement footprint (10-20 km) complements imaging spectrometry, allowing a one-to-one correlation of chemical and mineralogic data for geologic units comprising the lunar soil as well as allowing a determination of crustal stratigraphy through the determination of the chemical composition of ejecta blankets from craters large enough to have excavated through the megaregolith to underlying crustal units.

Power Consumption
22 W.

Data Rate
5 Kb/s maximum.

Data Management Strategy
TBD

Operational Constraints

Payload Delivery Options
Selected instrument on the Lunar Scout I mission.

Technology Assessment

Science/Exploration Community Contact
Jack Trombka, Goddard Space Flight Center

References

NEUTRON SPECTROMETER

Date: 7/21/92

PAYLOAD SUMMARY	
Estimated Mass	38.5 kg
Estimated Volume	
Estimated Power	14 W
Estimated Data Rate	50 Kb/s

Rationale
The Neutron Spectrometer provides 100 ppm or better sensitivity for the detection of H and, by inference, other solar wind implanted volatiles such as He. It provides important neutron flux data for interpretation of gamma ray data and is capable of determining H abundances at depths of 2 meters in the regolith for volatile assessment. It is an instrument of choice for investigating the question of water at the poles of the Moon.

Description
The Neutron Spectrometer detects neutrons scattered from elements within the upper several meters of the regolith, providing information on the distribution and abundances of these elements. It is a sensitive indicator of the amount of H (and water) present on the Moon. The Neutron Spectrometer provides a measure of volatile abundances in the lunar regolith over large areas and provides a check on various hypotheses of volatile accumulation. Potential sites of volatile resource utilization can thus be identified with this instrument. Comparing information from the Neutron Spectrometer with results from the Gamma Ray Spectrometer can provide high precision estimates on the abundances of H and other volatile elements.

Power Consumption
14 W.

Data Rate
50 Kb/s maximum.

Data Management Strategy
TBD

Operational Constraints

Payload Delivery Options
Selected instrument on the Lunar Scout I mission.

Technology Assessment
Neutron Spectrometers are in common usage, giving this payload a technology readiness level of 13.

Science/Exploration Community Contact
W. Feldman, Los Alamos National Laboratory

References

HIGH RESOLUTION STEREO CAMERA

Date: 7/21/92

PAYLOAD SUMMARY	
Estimated Mass	49 kg
Estimated Volume	
Estimated Power	67.5 W
Estimated Data Rate	131 Kb/s

Rationale
The High Resolution Stereo Camera provides global imagery in stereo and global geodesy at resolutions that meet SEI requirements for exploration planning and spacecraft navigation. It provides a data set that enables navigation and landing of robotic or piloted spacecraft to any locality on the Moon when combined with gravity data. The geodetic data provide a framework for interpretation of gravity anomalies detected by the Gravity Experiment.

Description
The High Resolution Stereo Camera provides global stereo imagery at 15 m/pixel resolution or higher and regional imagery at about 4 m/pixel resolution with a three camera system that simultaneously provides geodetic data. The camera system includes 4 color bands to provide spectral reflectance data if required for unit discrimination. Geodesy consists of horizontal control at hundreds of meters or better and elevation control of 25 m or better over at least 80% of the Moon. The data complement measurements of the gravity field obtained from the Gravity Experiment for determination of the structure of the lunar crust and mantle.

Power Consumption
67.5 W.

Data Rate
131 Kb/s maximum.

Data Management Strategy
Data sets will be digitized and will allow machine manipulation for data reduction. Contour maps and a geodetic net will be derivable from the digital data.

Operational Constraints

Payload Delivery Options
Selected instrument on Lunar Scout I Mission.

Technology Assessment
New software will need to be developed for the camera system, giving it a technology rating of 2. The stereo camera and geodesy equipment have a technology rating of TBD.

Science/Exploration Community Contact
Gerhard Neukum, German Aerospace Research Establishment.

References

Ge GAMMA RAY SPECTROMETER

Date: 7/21/92

PAYLOAD SUMMARY	
Estimated Mass	84.7 kg
Estimated Volume	
Estimated Power	53 W
Estimated Data Rate	7 Kb/s

Rationale
The Ge Gamma Ray Spectrometer determines the global abundance of an array of key geochemical indicators, including the indigenous radioactive elements, trace elements, volatiles (HO) and major rock-forming elements. The abundances of these elements are determined to very high precision using the Gamma Ray Spectrometer.

Description
The Ge Gamma Ray Spectrometer can determine the abundances of the following elements to the listed precisions: H 0.05%, O 0.68%, Na 0.20%, Mg 0.33%, Al 0.58% (if the housing of the instrument is not Al), Si 0.31%, S 0.5%, Ca 1.3%, Ti 0.11%, Mn 0.12%, Fe 0.26%, K 32ppm, U 0.016ppm, Th 0.043ppm, Sm 12ppm, and Gd 19ppm. Determination of the distribution and abundances of U, Th, and K are necessary for interpreting the current lunar heat flow and for constraining the thermal history of the Moon. In addition, the high precision to which H can be detected provides a check on the volatile distribution information provided by the Neutron Spectrometer.

Power Consumption
53 W.

Data Rate
7 Kb/s maximum.

Data Management Strategy

Operational Constraints

Payload Delivery Options
Selected instrument on the Lunar Scout II Mission.

Technology Assessment
Ge Gamma Ray Spectrometers are used in a variety of applications and thus have a technology rating of 11.

Science/Exploration Community Contact
Cal Moss, Los Alamos National Laboratory.

References

MINMAP IMAGING SPECTROMETER

Date: 9/2/92

PAYLOAD SUMMARY	
Estimated Mass	16 kg
Estimated Volume	18000 cm^3
Estimated Power	35 W (2 W standby)
Estimated Data Rate	2 Mb/s

Rationale
The MinMap Imaging Spectrometer provides identification of major rock-forming minerals with high precision, discrimination of lunar surface units on the basis of their mineral composition on hundreds of meters scale, and determination of the abundances of minerals important for resource assessment.

Description
The MinMap Imaging Spectrometer uses reflectance spectroscopy in the 0.35 to 2.4 μm range to determine mineral type and global abundances of diagnostic minerals at a spatial resolution of 200 m or better, depending on orbit altitude. The data obtained by this instrument will complement the X-ray and gamma ray data by providing the mineral context for interpretation of chemical data. The data also will provide maps showing the variations in lunar soil maturity. The global, regional, and local data obtained from the MinMap Imaging Spectrometer will provide a nested set of data useful for site selection and will allow development of a detailed exploration strategy.

The MinMap system consists of a 240 mm focal length f/8 telescope fitted with an f/8 VIRIS-PIDDP 256 channel imaging spectrometer (0.35 to 2.5 μm). The system is nadir viewing from a 400 km polar orbit (85 to 90° inclination). The camera system consists of a 512x512 CCD maintained at -20°C by passive cooling. Complete coverage of the lunar surface will take at least 90 days since the instrument's 12.8 km footprint requires three cycles for the 33 km orbit-to-orbit trace at the equator.

Power Consumption
35 W.

Data Rate
2 Mb/s maximum

Data Management Strategy
Data collected during nearside operations will be downlinked directly to Earth. Data collected during farside operations will be stored in a 10^9 b memory for later playback. Data will be transmitted at 2 Mb/s using X-band, to be collected by a 10 m antenna on the Earth's surface. A dedicated system on Earth will produce data tapes.

Operational Constraints
Nadir looking system. Current plans based on 400 km altitude circular polar orbit (inclination 85-90°).

Payload Delivery Options
Selected instrument on the Lunar Scout II Mission.

Technology Assessment

Imaging spectrometers have been flown on several NASA missions, indicating a technology readiness level of 13. This specific instrument, however, is in an operating prototype phase, indicating a level of 9.

Science/Exploration Community Contact

James Head, III, Brown University.

References

Head, J., 1992, MinMap - 256 Channel Imaging Spectrometer, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

GRAVITY EXPERIMENT

Date: 7/21/92

PAYLOAD SUMMARY
Estimated Mass
Estimated Volume
Estimated Power
Estimated Data Rate

Rationale
The Gravity Experiment provides data for state vector propagation and orbit stability predictions, predicts gravity perturbations required for precision in navigation and landing of spacecraft on the Moon, and develops gravity field relationships to topography and morphology (in conjunction with geodetic data) that allows modeling of the surface structure of the Moon.

Description
The Gravity Experiment measures gravity field accelerations to better than 0.6 mm/s and probably to near 0.1 mm/s precision by use of ultra-stable oscillators situated on two orbiting spacecraft, one in a high elliptical orbit and one in a low circular orbit. Mutual tracking of the two spacecraft determines the gravity field accelerations. These accelerations are combined with information from the geodetic experiment to obtain surface morphology with approximately 25 m elevation control and 100s of meters positional control. The combined gravity data and geodesy will provide gravity field accelerations and digital terrain models that satisfy SEI navigation requirements.

Power Consumption
TBD

Data Rate
TBD

Data Management Strategy

Operational Constraints
Two orbiting spacecraft are needed for complete field measurements—one spacecraft in a high elliptical orbit and the other in a low circular orbit. Surface topography and morphology information can be obtained only in conjunction with geodesy data.

Payload Delivery Options
Selected experiment for both the Lunar Scout I and II Missions. Nearside gravity field data will be obtained by tracking of Lunar Scout I, while complete field measurements will be obtained by tracking both Lunar Scout I and Lunar Scout II.

Technology Assessment
Gravity accelerations have been measured successfully by numerous spacecraft in the past, giving this experiment a technology rating of 13.

Science/Exploration Community Contact
TBD

COMPMAP

Date: 9/2/92

PAYLOAD SUMMARY	
Estimated Mass:	**6 kg**
Estimated Volume:	**6800 cm^3**
Estimated Power:	**14.2 W (2 W standby)**
Estimated Data Rate:	**275 kb/s**

Rationale
CompMap is a multispectral imaging system designed to produce a global digital data set for high-resolution compositional mapping of lunar surface units and resources assessment. Data will be sensitive to composition and soil maturity and will be used to distinguish and map surface units at high spatial resolution in conjunction with information from Earth-based and Galileo information. CompMap will help address fundamental questions in global lunar and planetary science and will support the lunar exploration strategy, site selection, mission planning, and operations.

Description
The design utilizes the GeoMap Telescope (85 mm focal length, f/10), 512x512 CCD, and Electronics combined with a VIRIS-PIDDP f/10 spectrometer (0.35 to 1.1 µm) to provide co-registered multispectral images of the Moon. The telescope design is a nadir viewing system in a 300 km polar orbit (inclination 85 to 90°). Images have a global resolution of 200 m/pixel over six selectable channels (0.38 to 1.0 µm) at sun angles between 10 and 45°. Signal to noise is high, generally >300:1. The system will take a minimum of 60 days to image the Moon globally since the instrument's 26.5 km footprint required two cycles for a 33 km orbit-to-orbit trace at the equator.

Power Consumption
14.2 W operating power (12 W of which are for operating the camera electronics) and 2 W standby power.

Data Rate
275 kb/s.

Data Management Strategy
Data collected during nearside operations will be downlinked directly to Earth at 275 kb/s. Data taken during farside operations will be stored in memory with later playback.

Operational Constraints
Current scenario calls for a 300 km polar orbit with an 85 to 90° inclination. System is designed for nadir viewing.

Crew Interaction
None

Payload Delivery Options
Orbiter

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
Imaging spectrometer, camera, and electronics have flown on several NASA missions. Actual prototype of CompMap is operating on Earth. This indicates a technology readiness level of 9.

Infrastructure Interface Requirements
System remains attached to orbiter.

Resupply Needs
None

Science/Exploration Community Contact
James Head, Brown University

References
Head, J., 1992, CompMap - Programmable 6 Channel Spectrometer, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

GEOMAP

Date: 9/2/92

PAYLOAD SUMMARY	
Estimated Mass:	**4 kg**
Estimated Volume:	**TBS**
Estimated Power:	**12.2 W (2 W standby)**
Estimated Data Rate:	**400 kb/s**

Rationale

GeoMap, the Lunar Geological Mapper, will provide broadband digital images of the lunar surface with pixels obtained in an accurate fixed reference frame (global, approximately 40m/pixel; sun angle 45-80°). The existing high resolution imaging data for the Moon has been acquired at a wide range of sun angles. Only regions conveniently accessed by the Apollo missions have been photographed at high resolutions. The circular polar orbit will permit GeoMap to obtain a global digital image data set with tightly controlled illumination angles and excellent radiometric precision. In addition, only a very small portion of the Moon is known to a positional accuracy of better than 1 km. The central area on the nearside has an accuracy of 1-2 km from groundbased measurements. Errors as large as 14 km exist on the farside. GeoMap will reduce the errors to less than 100 m globally.

Description

GeoMap is a camera system with a 1024 x 2048 CCD at its core. This CCD has been specially developed for imaging planetary systems from orbit and boasts excellent charge transfer efficiency at very low signal levels, very low noise, low dark current, and is as radiation resistant as practical. It has an unusual split frame transfer which permits image transfer from the imaging area to the storage area in one half the normal time. It can be read out rapidly while preserving the low noise characteristics. The camera head surrounding the CCD consists of 2.5 cm of aluminum which reduces background contamination by proton radiation. During operation the head is cooled by radiation to achieve a CCD temperature of -20°C. Signal to noise ratio of the system is >100:1. The system will take approximately 31 days for complete global coverage.

Power Consumption

Power requirements are 12.2 W, most used by the camera electronics. 2 W of standby power is used by the electronics.

Data Rate

400 kb/s.

Data Management Strategy

During nearside operations, there will be a direct downlink of data to Earth. During farside operations, data will be stored in 10^9 b memory for later playback.

Operational Constraints

Circular polar orbit, 300 km nominal altitude (although 100 to 500 km altitude is acceptable). Orbital inclination between 85 and 90°. Surface sun angle between 45° and 80° with respect to the zenith. System designed for nadir viewing.

Crew Interaction

None

Payload Delivery Options
Orbiter

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
GeoMap is based upon a progressive development of CCD cameras at Ball Aerospace for a number of space programs including the Space Telescope Imaging Spectrograph and both star trackers and cameras for DOD programs, indicating a technology readiness level of 13. The CCD design is new, however, indicating a level of 4. The electronics use existing designs that will be optimized for the new CCD. A new lens design is required but is believed to be a very easy lens to design and fabricate. Nevertheless, the lens has a technology readiness level of 1.

Infrastructure Interface Requirements
System remains attached to the orbiter. Communications infrastructure required.

Resupply Needs
None

Science/Exploration Community Contact
James Head, Brown University

References
Head, J., 1992, GeoMap - Lunar Digital Image Database Generator, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

SOFT X-RAY FLUORESCENCE IMAGER

Date: 9/1/92

PAYLOAD SUMMARY	
Estimated Mass:	**3 kg per telescope**
Estimated Volume:	**TBS**
Estimated Power:	**3 W per telescope**
Estimated Data Rate:	**250 b/s per telescope**

Rationale
Composition of surface materials is one of the most important data sets for understanding the origin, evolution, and present state of the Moon. In addition, in order for humans to utilize local resources while living at a lunar outpost, knowledge of the distribution and inventory of these resources is needed. The interaction of solar and cosmic radiation with lunar surface elements causes fluorescence, with each element fluorescing with a characteristic energy. In addition, the flux of fluorescence energy from the surface is directly proportional to the abundance of that element. A Soft X-ray Fluorescence Imager can measure not only the fluorescence energy but also the flux, providing the desired information about distribution and abundance of specific elements across the lunar surface.

Global 1 km resolution maps of Al, Si, Mg, Na, Ca, Fe, and possibly Ti should be produced within one month with better than 10% accuracy per pixel down to less than 0.1% abundance levels. Al, Si, Fe, Mg, and Ti are important construction materials and define surface geologic types including rocks containing S and K. Studies of crater walls and rims, rilles, stratification, volcanic formations, Mg/(mg+Fe) values, and precise resource location will be possible. Detection of Na is important because of its potential for rocket fuel. Ca is a component of cement, and Ti is an indicator of ilmenite, the preferred material for oxygen extraction.

Description
The Soft X-Ray Fluorescence Imager utilizes proven techniques. The optimal Soft X-Ray Fluorescence Imager mission is nadir pointing with an on-board pointing stability of better than 1° per minute. A normal incidence multilayer mirror 12.8 cm in diameter focuses x-rays and defines the energy band, then a curved microchannel plate is used to image these x-rays. Peak reflectivity for the 93 eV telescope is approximately 50% and field of view is approximately 30°. The energy of each telescope will be tuned to detect a specific element. The events will be binned into a map on-board to reduce the data rate.

Power Consumption
3 W.

Data Rate
250 b/s.

Data Management Strategy
Information will be combined into resource maps on-board to reduce data rate.

Operational Constraints
Orbital mission.

Crew Interaction
None

Payload Delivery Options
Orbital mission only.

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
The Soft X-Ray Fluorescence Imager has a solid technical heritage. Telescopes of the same design have been built and tested for the Los Alamos ALEXIS project and will be flight tested with the launch of ALEXIS. Microchannel plate detectors have been flown on Einstein, EXOSAT, Hubble, ROSAT, and P78-1 SOLEX. Multilayer mirrors have flown on numerous rockets (MIT, Colorado, Osaka, Stanford). These considerations indicate a technology readiness level of 12-13.

Infrastructure Interface Requirements
The imager remains attached to the orbiter throughout its mission. Connection to communications infrastructure needed.

Resupply Needs
None

Science/Exploration Community Contact
Bradley Edwards, Los Alamos National Laboratory

References
Edwards, B., 1992, Soft X-Ray Fluorescence Imager for Lunar Resource Mapper, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

IMAGING AND MINERALOGY EXPERIMENT

Date: 9/1/92

PAYLOAD SUMMARY	
Estimated Mass:	17 kg Visible Imager 30.5 kg Visible and Near IR Spect.
Estimated Volume:	8110 cm^3 Visible Imager 9250 cm^3 Visible and Near IR Spect.
Estimated Power:	30 W Visible Imager 75 W Visible and Near IR Spect.
Estimated Data Rate:	190 kb/s Visible Imager 100 kb/s Visible and Near IR Spect.

Rationale

Detailed information about the surface features and their compositions will be extremely important for EVA activities and resource utilization at a lunar outpost. The imaging and mineralogy experiment will consist of a visible imager and a visible and near infrared (IR) spectrometer to map the mineralogic surface content, generate a digital image database, obtain selected surface coverage in stereo and color, and determine the potential of lunar resources.

Description

The Visible Imager consists of a 15x8x8 cm telescope, a 10x10x4 cm focal plane assembly, and a 15x15x30 cm electronics assembly. The telescope will observe at a 58° to 80° solar zenith angle (morning and afternoon) to take advantage of shadows. It will have a 15-20 m ground resolution at 200 km altitude for the geologic data base and a 75-100 m ground resolution at 200 km altitude for geodetic mapping. Single color or full band photometric capability is possible with the CCD, providing enough sensitivity for an ~1 µm bandpass filter at 0.6 µm. A multicolor option is available with multiple line arrays. At least one full selenographic map should be produced after one year of operation.

The Visible and Near IR Spectrometer consists of a 10x10x10 cm foreoptics assemblage, three 10x10x15 cm spectrometers, and a 15x15x30 electronics assembly. The three spectrometers are each of a Ebert-Fastie design and have no moving parts, thus eliminating any dynamic misalignment. Spectrometer Assembly 1 consists of an 8 cm diameter f/6 telescope with a Ebert-Fastie spectrometer containing a silicon array to observe in the 370 - 970 nm range. Spectrometer Assembly 2 is connected to a 2.4 cm f/3 telescope. This spectrometer also is an Ebert-Fastie design, but uses an InGaAs array in the 800 to 1600 nm range. The telescope with Spectrometer Assembly 3 is again a 2.4 cm f/3 apparatus, but the spectrometer uses an InGaAs array to study the 1600 to 2400 nm range. Therefore, between the three spectrometers, this instrument has a continuous wavelength coverage between 370 and 2410 nm with approximately 10 nm resolution. The assemblage will have a 500 m ground resolution, assuming an altitude of 200 km, and should obtain complete selenographic coverage over one year.

Power Consumption

30 W for the Visible Imager. 75 W for the Visible and Near IR Spectrometer.

Data Rate
190 kb/s for the Visible Imager without compression; 63 kb/s with 3:1 compression (no loss). 100 kb/s for the Visible and Near IR Spectrometer without compression; 33 kb/s with 3:1 compression (no loss).

Data Management Strategy
TBD

Operational Constraints
Instruments remain attached to orbiter.

Crew Interaction
None

Payload Delivery Options
Orbiter

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
TBD

Infrastructure Interface Requirements
Instruments remain attached to orbiter. Communications infrastructure required.

Resupply Needs
None

Science/Exploration Community Contact
Benton Clark, Martin Marietta

References
Clark, B., 1992, Lunar Scout - Mission 3 Imaging and Mineralogy, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

TOPOGRAPHY AND GRAVITY EXPERIMENT

Date: 9/1/92

PAYLOAD SUMMARY	
Estimated Mass:	20 kg
Estimated Volume:	49000 cm^3
Estimated Power:	20 W
Estimated Data Rate:	3.5 kb/s

Rationale
Even with information from Ranger, Surveyor, Lunar Orbiter, and Apollo, a global understanding of lunar topography and gravity does not exist. However, detailed information about topography and gravity will be necessary for landing cargo and piloted missions for a lunar outpost. A combined laser altimeter and gravity measurement system will allow production of a global topographic map of the Moon, provide spatial resolution necessary to resolve individual surface features, and produce a global gravity map of the lunar near and far sides.

Description
The laser altimeter transmitter utilizes a Nd/YLF laser and telescope beam expander (transmitter aperture 10 mm diameter) to send a 25-30 mJ 10 nsec pulse of energy to the lunar surface from an altitude of approximately 100 km. Resolution along the ground track, assuming an altitude of 100 km, is 30-50 m with a vertical resolution of ≤ 1 m. The round trip time-of-flight is 666 μsec. The returned signal is collected by a 30 cm diameter receiver dish on the spacecraft and analyzed by an APD detector.

The gravity experiment will use tracking of the spacecraft as it revolves around the Moon in a circular orbit. Perturbations on the spacecraft's trajectory will be analyzed to map gravity anomalies on the lunar near and far sides.

Power Consumption
20 W continuous.

Data Rate
3.5 kb/s, no compression.

Data Management Strategy
TBD

Operational Constraints
Attached to orbiter; orbiter must be in a circular orbit for the gravity experiment.

Crew Interaction
None

Payload Delivery Options
Orbiter

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
Laser altimeters have been flown on several NASA spacecraft missions and determination of gravity fields from orbit has a substantial flight heritage. Therefore, both experiments for this package have an estimated technology readiness level of 13.

Infrastructure Interface Requirements
Laser altimeter remains attached to orbiter. Communications infrastructure required.

Resupply Needs
None

Science/Exploration Community Contact
Benton Clark, Martin Marietta

References

Clark, B., 1992, Lunar Scout - Mission 2 Topography and Gravity, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

GLOBAL ELEMENTAL COMPOSITION PACKAGE

Date: 9/1/92

PAYLOAD SUMMARY	
Estimated Mass:	**39 kg**
Estimated Volume:	**TBD**
Estimated Power:	**36 W**
Estimated Data Rate:	**12 KB/S**

Rationale

Understanding the abundance and distributions of elements and minerals across the lunar surface is important to our comprehension of the origin and evolution of the lunar crust and to the identification of lunar resources. A package composed of a gamma ray spectrometer with a neutron mode option and/or X-Ray spectrometer option could address many of the questions concerning surface composition and resource location.

Description

The gamma ray spectrometer will consist of a CsI crystal which can detect gamma rays produced by the decay of radioactive elements or by interaction of surface elements with cosmic rays. The crystal will be surrounded by a $Bi_4Ge_3O_{12}$ shield to insure that the detector only picks up gamma rays from the surface. The intensity of the light pulses generated when the gamma ray strikes the crystal is measured by a photomultiplier tube, which converts the light to a voltage pulse proportional to the energy. The pulses are analyzed and counted according to pulse height (= gamma ray energy). A histogram of the number of pulses versus energy results in a spectrum, where variations in amplitudes reflect the abundances of specific elements. Three simultaneous spectra are available in the 200 keV to 10 MeV energy range, each with 2000 energy bins. It is assumed that the spectrometer is thermally isolated at 0°C.

The X-Ray Spectrometer consists of four 25 cm^2 gas-filled (90% Ar, 10% CH_4) proportional counters. Three counters are filtered for the key elements of Al, Mg, and Si, while the fourth is open. These counters measure the X-Ray energies produced by specific elements in the lunar soil, such as Si, Al, Mg, Ca, Fe, and Ti. The Al, Ca, and Mg measurements complement and provide a check for the same elements measured by the gamma ray spectrometer. In addition, a solar monitor provides sun X-Ray burst detection so that such outbursts can be subtracted from the X-Ray data obtained by the counters.

The neutron analyzer utilizes four proportional counters distributed around the instrument with different viewing angles. Each detector provides information about the neutrons scattered from elements within the upper several meters of the regolith. The Neutron Analyzer is a sensitive indicator of the amount of H (and thus water) present on the Moon, thus providing information on potential sites of volatile resources. Combining information from this instrument with that of the gamma ray spectrometer can provide high precision estimates on the abundances of H and other volatile elements.

Power Consumption

16 W for the gamma ray spectrometer, 10 W for the X-Ray spectrometer, and 10 W for the neutron analyzer for a total of 36 W.

Data Rate

2 kb/s for the gamma ray spectrometer, 6 kb/s for the X-Ray spectrometer, and 4 kb/s for the neutron analyzer, for a total of 12 kb/s (uncompressed).

Data Management Strategy
TBD

Operational Constraints
Orbiter

Crew Interaction
None

Payload Delivery Options
TBD

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
All three instruments have substantial heritage on NASA, DOD, and DOE space missions, indicating a technology readiness level of 13.

Infrastructure Interface Requirements
Remains attached to orbiter. Communications infrastructure required.

Resupply Needs
None

Science/Exploration Community Contact
Benton Clark, Martin Marietta

References
Clark, B., 1992, Lunar Scout - Mission 1 Global Elemental Composition, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

GAMMA-RAY/NEUTRON SPECTROMETER (GR/NS)

Date: 9/1/92

PAYLOAD SUMMARY	
Estimated Mass:	**20 kg**
Estimated Volume:	**18000 cm^3**
Estimated Power:	**23 W**
Estimated Data Rate:	**6 Mb/orbit**

Rationale
Composition of surface materials is one of the most important data sets for understanding the origin , evolution, and present state of the Moon. In addition, in order for humans to utilize local resources while living at a lunar outpost, knowledge of the distribution and inventory of these resources is needed. Neutrons and gamma rays, produced by interaction of near surface elements with cosmic rays or by decay of radioactive elements, can be detected by a gamma-ray/neutron spectrometer, providing information on the distribution and abundance of specific elements. In particular, information about major rock types such as the Ti/Fe ratios of mare materials and the Th and K concentrations in KREEP, lunar regolith, and the distribution of lunar resources such as hydrogen (H_2O and solar wind volatiles), Ti, Fe, Si, and O can be determined using the gamma-ray/neutron spectrometer. Results from the spectrometer will allow production of maps showing the abundances of many elements, including certain unique elements such as H, Th, and U, to 20 cm below the lunar surface. Results of the gamma-ray/neutron spectrometer will be complementary with information from other instruments, such as the Soft X-Ray Fluorescence Imager.

Description
The spectrometer will combine a germanium gamma-ray sensor with a ^3He neutron sensor. The gamma-ray spectrometer contains a crystal of Ge into which gamma rays deposit energy. A light pulse is generated by the crystal with an intensity proportional to this energy. A photomultiplier tube converts the light to a voltage pulse proportional to the energy and the pulses are analyzed and counted according to pulse height (= gamma ray energy). A histogram of the number of pulses versus energy results in a spectrum where variations in amplitudes reflect the abundances of specific elements.

The neutron sensor consists of a small tube filled with ^3He. Neutrons interact with the gas, causing ionization. The ionized gas can conduct a current, which is detected by a central wire running through the tube. A detector external to the tube counts the current pulses generated, providing information on the number of neutrons interacting with the ^3He gas. The neutron analyzer will utilize two tubes, one bare and one covered with cadmium. The cadmium serves as a barrier to thermal neutrons, thus allowing only epithermal neutrons to interact with the internal gas. The bare tube allows both thermal and epithermal neutrons to be detected. The ratio of thermal to epithermal neutrons is a reflection of the hydrogen content of the soil.

Power Consumption
23 W.

Data Rate
6 Mb per orbit.

Data Management Strategy
TBD

Operational Constraints
Orbital mission.

Crew Interaction
None

Payload Delivery Options
TBD

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
Gamma-ray/neutron spectrometers have substantial flight experience aboard both NASA and DoD space science and interplanetary missions. Gamma-ray sensors have been flown on Range, ISEE, Pioneer Venus Orbiter, and Ginga and will fly on Mars-94. Neutron sensors have flown on LACE and will fly on Mars Observer. Therefore the gamma-ray/neutron spectrometer has a technology readiness level of 13.

Infrastructure Interface Requirements
Attached to orbiter. Communications link necessary.

Resupply Needs
None

Science/Exploration Community Contact
Cal Moss, Los Alamos National Laboratory

References
Moss, C., 1992, Gamma-Ray/Neutron Spectrometer (GR/NS) for Lunar Resource Mapper, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

SECONDARY ION MASS SPECTROMETER (SIMS)

Date: 9/1/92

PAYLOAD SUMMARY	
Estimated Mass:	**10.5 kg**
Estimated Volume:	**TBS**
Estimated Power:	**12 W**
Estimated Data Rate:	**2.5 kb/s (compressed)**

Rationale
Composition of surface materials is one of the most important data sets for understanding the origin, evolution, and present state of the Moon. In addition, in order for humans to utilize local resources while living at a lunar outpost, knowledge of the distribution and inventory of these resources is needed. Surface composition can be determined through a variety of techniques, including testing of the composition of ions sputtered from the surface by solar wind impacts. The Secondary Ion Mass Spectrometer (SIMS) will acquire secondary ion mass spectra of geochemically important elements such as Mg, Al, Si, K, Ti, and Fe as well as Na, Ca, and Mn for 15-30 km footprint sizes on the lunar surface. In addition, SIMS will allow detection of other possible components, such as S, H_2O, C, and unexpected constituents. Not only does SIMS measure an extensive set of geochemically important elements, but it also provides elemental overlap with other instruments such as the Soft X-Ray Fluorescence Imager (XRFI) and Gamma-Ray/Neutron Spectrometer (GR/NS). SIMS images will have a 15-30 km resolution and will be able to reveal the compositional heterogeneity of the 140 x 140 km footprint of the GR/NS. In addition, SIMS provides an extensive compositional backdrop to the higher resolution XRFI images. SIMS is not tuned to specific elements, therefore it can detect any unexpected elements or compounds that are sputtered from the lunar surface.

Description
The instrument's field of view is approximately 2π steradians about the nadir. Sputtered secondary ions from the lunar surface enter the SIMS aperture and are analyzed for energy/charge. The ions are then passed through an ultrathin carbon foil where secondary electrons are produced--high directional resolution is achieved by imaging these secondary electrons. The ions are passed through a toroidal analyzer for the start of the "time of flight" measurements and continue into a linear electric field region where measurements of their time-of-flight are proportional to the square root of the mass to charge ratio. High mass resolution is achievable with this design. The ion mass is correlated with particular elements and a histogram of secondary ion flux versus ion mass provides information about that element's abundance.

Power Consumption
12 W

Data Rate
2.5 kb/s, compressed.

Data Management Strategy
TBD

Operational Constraints
On orbiter

Crew Interaction
None

Payload Delivery Options
Orbiter

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
More than 25 ion plasma analyzers have been flown by Los Alamos in space aboard NASA and DOE missions. The Los Alamos Linear Electric Field ion mass spectrometer has been selected for flight on Cassini. Thus, SIMS has an estimated technology readiness level of 10.

Infrastructure Interface Requirements
On orbiter. Communications infrastructure required.

Resupply Needs
None

Science/Exploration Community Contact
Richard Elphic, Los Alamos National Laboratory

References
Elphic, R., 1992, Secondary Ion Mass Spectrometer (SIMS) for Lunar Resource Mapper, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

LUNAR ULTRAVIOLET MAPPING INTERFEROMETRIC SPECTROMETER (LUMIS)

Date: 9/2/92

PAYLOAD SUMMARY	
Estimated Mass:	< 10 kg
Estimated Volume:	TBD
Estimated Power:	< 10 W
Estimated Data Rate:	TBD

Rationale

Many different types of feldspar minerals can be identified by their ultraviolet spectra, but UV studies shortward of 0.3 µm cannot be obtained from Earth. In addition, these feldspars are known to be difficult to detect quantitatively in the near-IR. Thus, extension of spectral mapping into the UV from a lunar orbiter will result in superior resource assessments and better determine the mineralogy of the selected sites by quantitatively detecting feldspars and other minerals to which the IR is insensitive. UV studies do not replace, but rather are an extension of and complementary to visible-IR SEI site mapping studies, whether space or ground-based. LUMIS utilizes an UV imaging system to address SEI site resource and structure evaluations and to address the prime science and measurement goal of lunar science: to determine the geochemical nature of the lunar surface.

Description

Lunar reflected solar light passes through an aperture that defines the field of view but not the spectral resolution as does a grating spectrograph. This light is analyzed at 45° polarization, split by a prism, and recombined by a Fourier transform lens that images the interference plane onto array detectors (CCDs with rectangular pixels). The resultant interferogram contains all the spectral information present in the detected incident light. Spatial information is preserved when the slit is imaged onto the detector independently. The Digital Array Scanned Interferometer (DASI) possesses several hundred times the light handling capability of an equal resolving power and equal sized grating spectrograph. Further, the DASI has superior off-axis imaging compared with a grating spectrograph and easily handles large fields of view.

The proposed LUMIS design is a simple solid-state, physically strong and stable instrument, insensitive to environmental variables. In addition, the design is physically small, lightweight, and has low power requirements. Data from LUMIS will be used to produce spectral maps from 180 to 375 nm.

Power Consumption

< 10 W.

Data Rate

TBD; Up to 300 Mb can be returned during high latitude portions of the orbits, but the exact rate is TBD.

Data Management Strategy

TBD

Operational Constraints

Low lunar orbit assumed.

Crew Interaction
None

Payload Delivery Options
Orbiter

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
Detectors are space qualified, indicating a technology readiness level of 13 for the core portion of this instrument.

Infrastructure Interface Requirements
System remains attached to orbiter.

Resupply Needs
None

Science/Exploration Community Contact
William Hayden Smith, Washington University

References
Smith, W. H., 1992, LUMIS Scout, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

THERMAL EMISSION SPECTROMETER (TES)

Date: 9/2/92

PAYLOAD SUMMARY	
Estimated Mass:	**15.3 kg**
Estimated Volume:	**0.3 m^3**
Estimated Power:	**15.6 W**
Estimated Data Rate:	**TBD**

Rationale

The Thermal Emission Spectrometer (TES) provides an excellent means for determining surface mineralogy and petrology using thermal infrared absorption bands. The instrument will obtain high quality thermal infrared spectra (5 to 50 µm wavelength) of the entire lunar surface with 5 and 10 cm^{-1} spectral resolution and 0.5 to 2 km global resolution. TES will determine the global distribution of surface materials, with applications to future landing site selection and resource assessment. It will identify differences in composition based on feldspar, pyroxene, and olivine and use this information to study source composition, depth and degree of fractionation, and evolution of volcanic materials. Spatial and temporal changes in the composition of volcanic materials will be measured and the composition, origin, and evolution of early lunar crustal materials will be studied. In addition, TES will be able to determine the composition of regolith materials and study the particle size and rock abundance using diurnal and eclipse temperature measurements.

Description

The Thermal Emission Spectrometer consists of a FTIR Spectrometer, solar albedo bolometer, thermal emission bolometer, and full on-board processing capability. The spectrometer will cover the 6.25 to 50 µm wavelength region with a resolution of 5 or 10 cm^{-1}. The signal to noise ratio of the spectrometer is greater than 500 at 10 µm (270 K blackbody). The solar albedo bolometer has a 0.3 to 3.0 µm spectral bandpass with signal-to-noise ratio of 2000 (albedo = 1) and the thermal emission bolometer has a spectral bandpass of 4.5 to 100 µm with signal-to-noise ratio of 1000 (270 K blackbody). The system includes an on-board FFT processor with programmable data compression, spectral masks, and spatial masks. The system is a nadir looking design with fore-aft pointable fields-of-view. It requires a 3-axis stabilized platform.

Data products from the TES will include absolute calibrated radiance measurements, global surface maps, emissivity spectra, derived surface compositional maps (mineral occurrence and abundance), and derived thermal inertia, particle size, and rock abundance maps.

Power Consumption

15.6 W average

Data Rate

TBD

Data Management Strategy

TBD

Operational Constraints
Nadir looking design for an orbiting spacecraft (3-axis stabilized platform).

Crew Interaction
None

Payload Delivery Options
Orbiter

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
A similar TES by the same company (Hughes) has been selected for Mars Observer and thus is near a technology readiness level of 13.

Infrastructure Interface Requirements
System remains attached to orbiter. Communications infrastructure required.

Resupply Needs
None

Science/Exploration Community Contact
Philip Christensen, Arizona State University

References
Chase, S. C., 1992, Thermal Emission Spectrometer (TES) for Small Lunar Robotic Missions, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

MERCATOR--A LUNAR IMAGING MISSION

Date: 9/2/92

PAYLOAD SUMMARY	
Estimated Mass:	TBD
Estimated Volume:	TBD
Estimated Power:	TBD
Estimated Data Rate:	2 Mb/s

Rationale
Mercator is designed to obtain a global, cartographic quality digital image database for the Moon to support scientific and engineering investigations. The imaging system will study the morphology and topography of the Moon's features to understand the evolution of lunar surface processes. In addition, the system will allow better determination of the stratigraphy of the Moon which will allow the unraveling of the Moon's geologic history.

Description
Mercator is a nadir looking stereo imaging system designed to be flown on a lunar orbiter at 200 km (±20 km) altitude. The system consists of two 280 mm focal length f/24 cameras and two 2584x128 CCDs. The system will provide global stereo coverage with an accuracy of approximately ±20 m. It will improve areas of uncertainty by comparing values with those obtained by photclinometery, shadow estimates (from terminator imaging), and the laser altimeter. The cameras will operate at a surface sun angle of between 60° and 75° with respect to the zenith. Global coverage will take 14 days minimum.

Power Consumption
TBD

Data Rate
Two camera data rate is 2 Mb/s.

Data Management Strategy
During nearside operations, data return will be continuous with direct downlink at 2 Mb/s. Farside operations will store data in 10^9 b memory for playback at a later time.

Operational Constraints
Nadir pointing system design. Current plans assume a 200 km altitude, but 100 to 500 km altitudes are okay. Orbit is polar circular with an inclination of 85° to 90° and low surface sun angle (60° to 75° with respect to surface zenith).

Crew Interaction
None

Payload Delivery Options
Orbiter

Estimated Set-up Time
None

Maintenance Needs

None

Technology Assessment
TBD

Infrastructure Interface Requirements
System remains attached to orbiter. Communications infrastructure required.

Resupply Needs
None

Science/Exploration Community Contact
Paul Spudis, Lunar and Planetary Institute

References
Spudis P., Davies M., Delamere A., and Reitsema H., 1992, Mercator, A Lunar Imaging Mission, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

ELECTROSTATIC ZOOM DIGICON IMAGER

Date: 9/2/92

PAYLOAD SUMMARY	
Estimated Mass:	347.1 kg
Estimated Volume:	TBS
Estimated Power:	46 W
Estimated Data Rate:	200 - 452 kb/s

Rationale
The Electrostatic Zoom Digicon Imager will provide high resolution (6 - 45 m) of the lunar surface for use in site selection and resource identification.

Description
The Electrostatic Zoom Digicon Imager consists of a 50 mm aperture, 100 mm focal length telescope that has 18 m resolution with a 1:1 zoom lens. The digicon imager utilizes a 50 mm diameter cathode and a 1024x1024 CCD to analyze the photons collected by the telescope. Data products from this instrument will be global stereo monchromatic digital images with selective resolution (zoom to 1 meter).

Power Consumption
46 W per instrument

Data Rate
Data rate varies from 200 kb/s at 45, 18, and 9 m resolutions (data compressions ranging from none to 28:1) to 452 kb/s at 6 m resolution (using 28:1 data compression).

Data Management Strategy
TBD

Operational Constraints
Current plans call for orbiter to have altitude of 100 km in order for reasonable resource and image correlation mapping to be performed.

Crew Interaction
None

Payload Delivery Options
Orbiter

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
TBD

Infrastructure Interface Requirements
System remains attached to orbiter. Communications infrastructure required.

Resupply Needs
None

Science/Exploration Community Contact
Ray Gorski, SAIC Torrance

References

Gorski, R., 1992, Electrostatic Zoom Digicon Imager for Lunar Correlation Mapping, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

LUNAR GEODETIC MAPPING MISSION

Date: 9/2/92

PAYLOAD SUMMARY	
Estimated Mass:	5 kg
Estimated Volume:	4719 cm^3 camera heads
	1180 cm^3 electronics
Estimated Power:	7 W dayside
	3 W nightside
Estimated Data Rate:	2 Mb/s

Rationale

The Lunar Geodetic Mapping Mission will conduct a global photographic lunar mapping mission and provide a global, moderately high resolution (10 m/pixel) uniform imaging data set for science and landing site studies. In addition it will provide an accurate geodetic network for site development and will provide global stereoscopic data for mapping. The mission will simultaneously address several science and exploration objectives and will make the data available for follow-on missions quickly.

Description

The Lunar Geodetic Mapping Mission will utilize a single launch, single spacecraft design. The system consists of two 70 mm focal length f/7 cameras, each with a 3500x3500 array CCD. Realtime data compression capability is available on board. The digital images will have a resolution of 10 m/pixel with a mean signal-to-noise ratio of >50:1. Global coverage will be obtained, limited only by shadows in the polar regions. Stereoscopic coverage will be 100% along the ground track, >10% on the cross-track overlap. The mapping mission will be complete within one month, with an additional six months required for data processing.

Power Consumption

7 W (dayside), 3 W (nightside)

Data Rate

2 Mb/s compressed

Data Management Strategy

Data collected during nearside operations will be downlinked directly to Earth. Data collected during farside operations will be stored in memory for later playback.

Operational Constraints

Mapping camera-head system is nadir pointing. Star camera-head is zenith looking since pointing knowledge is derived from star images.

Crew Interaction

None

Payload Delivery Options

Orbiter

Estimated Set-up Time

None

Maintenance Needs
None

Technology Assessment
TBD

Infrastructure Interface Requirements
System remains attached to orbiter. Communications infrastructure required.

Resupply Needs
None

Science/Exploration Community Contact
Michael Malin, Malin Space Science Systems

References

Malin, M., 1992, Lunar Geodetic Mapping Mission, in Workshop of Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

LUNAR MAGNETICS/GRAVITY MAPPER

Date: 9/2/92

PAYLOAD SUMMARY	
Estimated Mass:	**110 kg**
Estimated Volume:	**TBD**
Estimated Power:	**55 W**
Estimated Data Rate:	**< 200 b/s average; 5 kb/s peak**

Rationale
Many questions remain regarding the geophysical properties of the Moon. Some unresolved issues include the origin of remnant magnetism in lunar rocks, the origin of lunar mascons, the structure of the lunar interior, the detailed gravity field, and the existence and size of a metallic core. The Lunar Magnetics/Gravity Mapper is designed to answer some of these question through a variety of geophysical techniques. The mission will obtain a low-altitude, high-resolution vector magnetic anomaly map of the Moon, obtain a low-altitude, high-resolution Doppler gravity map of the lunar nearside and limbs, obtain a Doppler gravity map of the lunar farside by tracking a pre-existing satellite using the LMG Mapper as a relay, measure the lunar induced magnetic dipole moment in the geomagnetic tail lobes to obtain core size estimates, and obtain a high-resolution electron reflection map of inferred surface magnetic fields covering the entire Moon.

Description
The Lunar Magnetics/Gravity Mapper is a small, spin-stabilized spacecraft containing a fluxgate magnetometer, Doppler Gravity/Transponder Relay, and Electron Reflectometer/Plasma Monitor. The fluxgate magnetometer will measure magnetic anomalies across the lunar surface, producing a vector magnetic field map with an accuracy <0.1 nT at a 30 km spacecraft altitude. In addition, the magnetometer will provide estimates of the lunar induced magnetic dipole moment in the geomagnetic tail lobes. The Doppler Gravity/Transponder Relay will produce a Doppler gravity field map from 30 km altitude for the nearside hemisphere--a farside gravity field map will depend on the existence of a telemetry relay from a second spacecraft. The Electron Reflectometer/Plasma Monitor will produce an electron reflectometer map of the "surface" magnetic field strength as well as determine the plasma energy and mass density versus time. These measurements will improve mapping and induced moment estimates for the Moon.

Power Consumption
Total spacecraft has a 55 W power requirement. The fluxgate magnetometer has a 3 W power need and the electron reflectometer/plasma monitor requires 5 W. The power requirements for the Doppler gravity/transponder relay are TBD.

Data Rate
<200 b/s average, with 5 kb/s peak.

Data Management Strategy
Continuous downlink during nearside operations. Farside operations will depend on the existence of a telemetry relay from a second spacecraft.

Operational Constraints
Spacecraft magnetic fields must be less than 0.01 nT around the fluxgate magnetometer. The electron reflectometer/plasma monitor is sensitive to spacecraft electrostatic charging.

Desired orbit is near-polar with low eccentricity, periapsis altitude of <30 km for field mapping (since magnetic field strength decreases with distance). A circular orbit at <150 km altitude is desired for induced moment estimates.

Crew Interaction
None

Payload Delivery Options
Orbiter

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
TBD

Infrastructure Interface Requirements
Instruments remain attached to orbiting spacecraft. Communications infrastructure required, including telemetry relay from second spacecraft for farside operations.

Resupply Needs
None

Science/Exploration Community Contact
Lon Hood, University of Arizona

References
Hood L., Graf P., Russell C.T., Sjogren W.L., and Lin R.P., 1992, Lunar Magnetics/Gravity Mapper, in Workshop of Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

MAGNETICS-ENVIRONMENT-VOLATILES/GRAVITY-ENVIRONMENT-VOLATILES (MEV/GEV)

Date: 9/2/92

PAYLOAD SUMMARY	
Estimated Mass:	**<175 kg**
Estimated Volume:	**1.2 m diameter x 0.5 m tall cylinder**
Estimated Power:	**100 W**
Estimated Data Rate:	**TBD**

Rationale

The MeV/GeV design will address several key SEI precursor objectives in a relatively short period of time (90 day nominal mission). The MeV payload includes a 3-axis fluxgate magnetometer, electron/ion mass spectrometer, and ultraviolet spectrometer to address various issues about lunar magnetics, environment, and volatile distributions. The magnetometer will document the global lunar magnetic field and its spatial variations down to altitudes of 30 km and will search for evidence of a conducting lunar core. The electron/ion mass spectrometer will determine the full composition of the neutral and charged lunar atmosphere, explore the vertical and horizontal structure of the lunar atmosphere, and search for internal outgassing activity and time variable phenomena associated with the lunar diurnal and orbital cycles. The ultraviolet spectrometer will search for evidence of and will study lunar internal gas release (e.g., Ar, Rn, Po, CO_2, H_2O) and correlate such releases with specific geologic constructs or provinces.

The GeV is a variation of the MeV payload. It differs from the MeV by removing the magnetometer and concentrating the mission plan on precise Earth-based tracking of the spacecraft in a 100 x 100 km orbit. Gravitational field data obtained by GeV will allow for more accurate assessments of orbit maintenance propellant required on future SEI missions. The GeV payload will consist of an electron/ion mass spectrometer, ultraviolet spectrometer, and communications equipment necessary for gravity mapping.

Description

MeV and GeV both employ a single small spin-stabilized spacecraft operating in lunar polar orbit. The MeV payload includes a fluxgate magnetometer, electron/ion mass spectrometer, and an ultraviolet spectrometer. The magnetometer has a sensitivity of 0.5 nT and will be mounted on a 1 m standoff boom. Both the electron/ion mass spectrometer and the ultraviolet spectrometer will be mounted on the body of the spacecraft and have sensitivities of >1 cm^2 sr and 1 Rayleigh (at 1100 - 3200 Å) respectively. The MeV spacecraft is planned to be injected into a highly elliptical (~100 x ~5000 km), near polar (inclination >80°) lunar orbit after a nominal 4-day translunar coast. The science objectives will be met in three stages. During the first 28 days in lunar orbit, the spacecraft will have a ~100 x ~5000 km orbit and will concentrate on an environmental assessment: initial instrument checkout, upper atmosphere observation, solar wind interaction studies, lunar nightside atmosphere observation, and initial magnetic field work. During the next 28 days, the orbit will be circularized at 100 km altitude to concentrate on the search for volatiles. Objectives during this period of time include intensive atmospheric study and search for volatiles, a global lunar magnetic field survey, and electron reflectometry mapping. The final 28 days will be spent with the spacecraft in a 30 x 100 km orbit dedicated to detailed magnetic mapping. During this time, the spacecraft will pursue detailed magnetic field fine structure mapping, detailed electron reflectometery studies, follow-up lunar atmosphere studies, and proof-of-concept surface secondary ion mass spectrometry (SIMS) compositional mapping.

The GeV is a variation of the MeV payload and spacecraft. GeV differs from MeV by removing the magnetometer and concentrating the mission plan on precise Earth-based tracking of the spacecraft in a 100 x 100 km orbit. GeV will map the nearside and polar gravitational fields and will determine the integrated ΔV requirements from the farside gravity perturbations. Detailed farside gravitational mapping is possible if any second spacecraft (could be MeV) is flown in tandem with GeV. GeV is more directly coupled to SEI than MeV. GeV gravitational field data will allow for more accurate assessments of orbit maintenance propellant required on future SEI missions and still accomplishes atmospheric studies and volatile searches. GeV mission operations also are simpler than MeV since they do not require any low (30 km) orbital operations.

Power Consumption
~100 W average, supplied by silicon cell array and NiH_2 battery system.

Data Rate
TBD; ~12.5 Mbytes of science/engineering telemetry will be downlinked twice per day.

Data Management Strategy
TBD

Operational Constraints
TBD

Crew Interaction
None

Payload Delivery Options
Orbiting spacecraft

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
All instruments have a substantial flight heritage on numerous NASA and DOE missions, indicating a technology readiness level of 13.

Infrastructure Interface Requirements
Instruments remain attached to spacecraft.

Resupply Needs
None

Science/Exploration Community Contact
S. Alan Stern, Southwest Research Institute

References
Stern, S. A., 1992, Two Lunar Scout Mission Concepts: Magnetics-Environment-Volatiles (MeV) and Gravity-Environment-Volatiles (GeV), in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

LUNAR TERRAIN MAPPING MISSION

Date: 9/3/92

PAYLOAD SUMMARY	
Estimated Mass:	**453 kg (Total dry spacecraft)**
Estimated Volume:	**TBD**
Estimated Power:	**60 W**
Estimated Data Rate:	**2.5 Mb/s maximum**

Rationale
The Lunar Terrain Mapping Mission will provide imaging, altimetry, and gravity data to address a number of science issues. These issues include information about crustal structure and volcanologic processes, impact processes and their effect on the crust, the lunar gravity field, the internal structure of the Moon, surface morphology, and the distribution of lunar resources. The Lunar Mapping Mission is designed to obtain global topography at <1 m vertical resolution and obtain a global digital image data base at 15 m/pixel resolution, both in monochrome and in 2-color. It will obtain local high resolution (3 m/pixel) resolution images that can be used for site selection and certification as well as characterize possible outpost sites in terms of geology, resource potential, etc. It will obtain early, rapid data for future planning, using existing technology to achieve major science and exploration objectives.

Description
The Lunar Terrain Mapping Mission will contain an imaging system and a laser altimeter. The imaging system will consist of three 4000 element line arrays (broadband green-yellow, blue, and red) with two camera systems mounted at ±25° for stereo viewing. A retractable mirror allows for nadir and stereo viewing. The imaging system will have resolutions sufficient (15 and 3 m/pixel) to resolve major geologic/geomorphic features. Global coverage will be obtained at 15 m/pixel resolution with some local coverage at 3 m/pixel. The system will have the capability to produce stereo images within ±25° of the equator. The laser altimeter will utilize a Nd/YAG laser (1.064 µm) with a pulse energy of 17 mJoule to determine topographic variations on the lunar surface. The system will have a surface spot size of 50 m and utilize a firing rate of 23 Hz. The laser altimeter will provide better than 1 m vertical accuracy of the topography of the lunar surface. Individual topographic profiles will be combined to produce a global topography model.

In addition to the imaging system and laser altimeter, the Lunar Mapping Mission will be used to study variations in the lunar gravity field. A beacon subsatellite will be deployed in a long-period (7 hr) elliptical orbit with a Doppler extractor on the main spacecraft, which will be in a low circular orbit about the Moon. Tracking of the two spacecraft will provide near and far side data for 1 mGal anomaly resolution. Global low resolution data (500 km altitude orbit) will be available during the first 6 months, with high resolution data (100 km orbit) available in the final 3 months of the mission.

Power Consumption
30 W for the imaging system; 29 W for the laser altimeter (includes cooler)

Data Rate
The imaging system will have a data rate of 2.5 Mb/s at 15 m/px mapping and 16 Mb/s at 3 m/px mapping. The laser altimeter will have a rate of 3.5 kb/s.

Data Management Strategy
15 m/px imaging data will be acquired when the nadir point solar elevation angles are between 15° and 30°. A mature data compression technique enhances data return. Compression can occur between the camera and memory or between the memory and the downlink but not both simultaneously. The nearside coverage will be limited by downlink rate. A 10:1 compression from memory to downlink increases the effective data return rate to 1.5 Mb/s. Farside coverage will be limited by the amount of storage memory. With no compression from memory to downlink, the average data rate of 160 kb/s limits the usable memory to 1 Gb, whereas an 8:1 compression from the camera to memory increases the effective size of the data block stored in 1 Gb. 3 m/px imaging will permit coverage of 10 x 12 km sites, producing a relatively low total data volume. A 10:1 data compression scheme is used from memory to transmitter.

The laser altimeter data does not require compression.

Operational Constraints
Both imaging camera and laser altimeter must be nadir pointing. The gravity determination experiment requires spacecraft interaction with a subsatellite. Low, circular orbit for the main spacecraft is needed for the gravity experiment; the subsatellite must be in a 7-hr elliptical orbit.

Crew Interaction
None

Payload Delivery Options
Orbiter

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
TBD

Infrastructure Interface Requirements
Instruments remain attached to spacecraft. Gravity experiment requires spacecraft interaction with a subsatellite. Communications infrastructure required.

Resupply Needs
None

Science/Exploration Community Contact
Phillip Barnett, Jet Propulsion Laboratory

References
Barnett, P., 1992, Lunar Terrain Mapping Mission, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

LUNAR RESOURCE MAPPING MISSION

Date: 9/3/92

PAYLOAD SUMMARY	
Estimated Mass:	447 Kg Total spacecraft 28 kg for gamma ray spectrometer 12 kg for IR spectrometer
Estimated Volume:	21144 cm^3 for gamma ray spect. 1196 cm^3 for IR spectrometer
Estimated Power:	51 W
Estimated Data Rate:	1.2 Mb/s maximum

Rationale
The Lunar Resource Mapping Mission will contain a gamma ray/neutron spectrometer and infrared spectrometer to help provide elemental and mineralogic data about the Moon. Such data will help address questions about the origin of the Moon and its relation to the origin and evolution of the Earth, crustal formation by global magma ocean or serial injection, chemical evolution of crustal formation and evolution, effect of early heavy bombardment on current elemental/mineralogic crustal composition, composition of the lower crust exposed by large impacts, lunar soil maturation, and distribution of lunar resources (especially H, O, H_2O, metals, and regolith).

Description
The gamma ray/neutron spectrometer on the Lunar Resource Mapping Mission will allow detection of major elements such as K, Th, U, O, Si, Al, Mg, Fe, Ca, Na, Mn, Cr, and H in the upper 20 cm of the lunar regolith. It can also detect H (and thus give information on H_2O resources) to depths of 1 m. The gamma ray spectrometer will contain a 5"x5" NaI (Tl doped) detector with 100 km spatial resolution and 0.01 MeV spectral resolution. The instrument will be deployed on a boom which can be deployed and retracted with stops at 1/3 and 2/3 deployed. The mission will require less than 5 deploy/retract cycles.

The infrared (IR) spectrometer will help identify mafic minerals such as olivine, orthopyroxene, and clinopyroxene, as well as the glass content in the lunar regolith. It will contain a HgCdTe 128x128 array with spatial resolution of 300 m, spectral resolution of 13 nm, and a spectral range of 0.8 to 2.5 μm. The IR spectrometer must be nadir pointed and requires a mechanical cooler so that the detector can be cooled to 130 - 150 K. The cooler is designed to be cycled since the detector requires no cooling when it is not in use.

Power Consumption
3 W for the gamma ray spectrometer with an additional 20 W required for the heater. The IR spectrometer requires 28 W of power, which includes the power necessary to run the cooler.

Data Rate
3.5 kb/s for the gamma ray spectrometer and 1.2 Mb/s for the IR spectrometer.

Data Management Strategy
The gamma ray spectrometer will make continuous observation for a total of one year's worth of observations. The IR spectrometer has two possible strategies for data acquisition, depending on the science priorities: single orbit scenario would acquire and

downlink as much data as possible in each orbit (maximum data rate is 100 kb/s over at least a 4300 s Earth view time), whereas the multiple orbit scenario would acquire as much data as possible in one orbit and downlink that information over several successive orbits (6 orbits required to downlink 2.5 Gb if orbit edge-on to Earth). A global map will be assembled by interleaving data blocks and downlink periods. Global coverage will be obtained in 12 months.

Operational Constraints
The IR spectrometer must be nadir pointed. The gamma ray spectrometer must be deployed on a boom.

Crew Interaction
None

Payload Delivery Options
Orbiter

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
Substantial spacecraft heritage for both instruments, indicating a technology readiness level of 13.

Infrastructure Interface Requirements
Both instruments remain fixed to the spacecraft. Communications infrastructure required.

Resupply Needs
None

Science/Exploration Community Contact
Philip Barnett, Jet Propulsion Laboratory

References

Barnett, P.M., 1992, Lunar Resource Mapping Mission, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

SI(LI) GAMMA RAY DETECTOR

Date: 9/3/92

PAYLOAD SUMMARY	
Estimated Mass:	**24 kg**
Estimated Volume:	**TBD**
Estimated Power:	**16 W**
Estimated Data Rate:	**<1 kb/s**

Rationale
Gamma ray spectrometers can help determine the elemental composition of the surface of the Moon through measurements of incident gamma rays and albedo neutrons. They can determine the hydrogen depth dependence in the top tens of centimeters of the lunar regolith, which have implications for the distribution of H_2O reservoirs. In addition, gamma ray spectrometers can determine the arrival time and spectra of gamma ray bursts from solar, stellar, and galactic sources.

Description
Gamma Ray spectroscopy can help determine the distribution of lunar resource reservoirs. Conventional gamma ray detectors are either high purity Ge detectors with a resolution of 2 keV at 1.3 MeV which require cooling to ≤100 K, or scintillators with a resolution of 60 keV at 1.3 MeV which operate at 300 K. Spaceflight instrumentation is always limited in mass and power and the cooling systems required for these conventional detectors account for a substantial amount of the spacecraft mass and power. Recently, gamma ray detectors utilizing Si(Li) detectors has been developed which have a resolution of 5-10 keV at 1.3 MeV and which will operate to 215 K, thus requiring no active cooling. The Si(Li) gamma ray spectrometer will measure primary and secondary gamma rays from the lunar surface, galactic gamma ray bursts, and low energy thermal neutron fluxes from the lunar surface. Gamma rays can be measured between 200 keV and 10 MeV and neutrons up to 10 keV can be detected using the anticoincidence shield plastic scintillators. Predicted energy resolution for this instrument is ~2 keV at 0.122 MeV, ~5 keV at 1.33 MeV, and ~10 keV at 6.13 MeV.

Results from a Si(Li) gamma ray detector will include the production of a resource map of the lunar surface, showing the distribution of elements such as H, O, Na, Mg, Al, Si, S, Cl, K, Ca, Ti, Mn, Fe, Th, U, and C. In addition, data from the gamma ray detector will add to our knowledge base of the lunar and translunar radiation environment.

Power Consumption
~16 W.

Data Rate
<1 kb/s.

Data Management Strategy
TBD

Operational Constraints
TBD

Crew Interaction

None

Payload Delivery Options
Orbiter

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
An experimental stack of Si(Li) detectors has been developed and tested in terrestrial laboratories at Ames. This suggests a technology readiness level of 4.

Infrastructure Interface Requirements
Instrument remains attached to spacecraft. Communications infrastructure required.

Resupply Needs
None

Science/Exploration Community Contact
G. S. Hubbard, Ames Research Center

References
Hubbard, G.S., 1992, A Novel Si(Li) Gamma Ray Detector for Lunar Resource Determination, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

SMALL LUNAR INFORMATION MISSION (SLIM)

Date: 9/3/92

PAYLOAD SUMMARY	
Estimated Mass:	**TBD**
Estimated Dimensions:	**TBD**
Estimated Power:	**TBD**
Estimated Data Rate:	**TBD**

Rationale
The Small Lunar Information Mission (SLIM) is a low cost detailed information gathering mission. The two types of information gathered are detailed topology and subsurface structure. The information gathered by these sensors facilitates further exploration through optimal mission planning, colonization efforts, and lunar resource commercialization. The immediate goal of this mission is to develop an integrated lunar data base to support the cataloging of indigenous resources, to support site selection and local experiment design in preparation for a lunar outpost, and to perform basic solar system research.

Description
SLIM will consist of a LIDAR to provide topographic information, and low and high band imaging RADAR to provide information on subsurface structure. The ground mapper will use a high frequency (X or K band) fully polarimetric SAR. This sensor/processor package will be able to produce 3-D survey maps of the lunar volume with the best available fidelity.

Power Consumption
TBD

Data Rate
TBD

Data Management Strategy
TBD

Operational Constraints
TBD

Crew Interaction
None

Payload Delivery Options
Orbiter

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
TBD

Infrastructure Interface Requirements
Remains attached to orbiter. Communications infrastructure required.

Resupply Needs
None

Science/Exploration Community Contact
Walter Colquitt, Houston Advanced Research Center

References
Colquitt, W. N., 1992, Small Lunar Information Mission, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

LUNAR OBSERVER LASER ALTIMETER (LOLA)

Date: 9/3/92

PAYLOAD SUMMARY	
Estimated Mass:	20 kg
Estimated Volume:	TBD
Estimated Power:	31 W
Estimated Data Rate:	3 kb/s

Rationale

The Lunar Observer Laser Altimeter will utilize a laser altimeter adapted from the Mars Observer Laser Altimeter to make high resolution measurements of lunar topography. Combined with the gravity experiment, the two instruments can measure the global topography and gravity field of the Moon in order to better characterize the figure of the Moon and a center of mass reference frame for all lunar data, the internal density distribution and the variations in crustal and lithospheric thickness, the mechanical properties of the lithosphere and mechanisms of support for major physiographic features, the structure and volume of impact craters and basins (including the thickness of ejecta deposits and crater fill) and the systematic variations in lava flow thickness, scarp height, or graben width and depth across the lunar surface. This information will provide the geodetic control, topographic context, and gravitational knowledge for planning and execution of future orbital and lander missions.

Description

The Lunar Observer Laser Altimeter will make high resolution measurements of lunar topography using a laser altimeter design adapted from that flying aboard Mars Observer. The laser altimeter will have a 2 m precision for slopes less than 4° (20 m accuracy with respect to the center of mass) and a 30-50 m precision along the horizontal. The laser repetition rate will be approximately 40 Hz while the laser pulse energy will be ~10 mJ. Time interval unit resolution is ~3 nsec. A waveform digitizer will be incorporated to improve ranging estimates. LOLA is designed for an ~150 km circular orbit around the Moon.

Power Consumption

31 W.

Data Rate

~ 3 kb/s

Data Management Strategy

TBD

Operational Constraints

TBD

Crew Interaction

None

Payload Delivery Options

Orbiter

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
Substantial flight heritage aboard numerous spacecraft in addition to Mars Observer. Indicates a flight readiness level of 13.

Infrastructure Interface Requirements
Remains attached to spacecraft. Communications infrastructure required.

Resupply Needs
None

Science/Exploration Community Contact
David E. Smith, Goddard Space Flight Center

References
Smith, D. E., 1992, A Topography Experiment for Lunar Geodetic Scout, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

LUNAR GRAVITY EXPERIMENT

Date: 9/3/92

PAYLOAD SUMMARY	
Estimated Mass:	**13 kg**
Estimated Volume:	**36504 CM³**
Estimated Power:	**24 W**
Estimated Data Rate:	**600 b/s**

Rationale
The Lunar Gravity Experiment will utilize a spacecraft and subspacecraft pair to provide a simple, precise instrument to measure the lunar gravity . Combined with the topography experiment, the two instruments can measure the global topography and gravity field of the Moon in order to better characterize the figure of the Moon and a center of mass reference frame for all lunar data, the internal density distribution and the variations in crustal and lithospheric thickness, the mechanical properties of the lithosphere and mechanisms of support for major physiographic features, the structure and volume of impact craters and basins (including the thickness of ejecta deposits and crater fill) and the systematic variations in lava flow thickness, scarp height, or graben width and depth across the lunar surface. This information will provide the geodetic control, topographic context, and gravitational knowledge for planning and execution of future orbital and lander missions.

Description
The Lunar Gravity Experiment will utilize two spacecraft, a main craft and a passive subsatellite, to measure the lunar gravity field to very high precision. Satellite tracking will provide a 0.3 mm/sec range rate (averaged over 1 sec) for both satellite-to-satellite and satellite-to-Earth measurements. The main spacecraft orbits with the subsatellite at ~200 km altitude above the lunar surface. The small passive subsatellite will be equiped with 20 optical retroreflectors while the main craft will have a simple fixed laser terminal mounted on the spacecraft's nadir panel. The transceiver measures ranges and pointing angle to subsatellite. The transmitter consists of 4 small AlGaAs semiconductor lasers, two 800 mW lasers at 830 nm with a 2° beam width and two 100 mW lasers at 810 nm with a 0.3 ° beam width. The receiver is a fixed 20 cm diameter Cassegrain telescope which detects the tracking signal with a 128x128 CCD array and the ranging signal by a GHz bandwidth photomultiplier. Data products resulting from this experiment will include a global gravity field containing information on the harmonic coefficients as well as contour maps.

Power Consumption
24 W: 9W for the transmitter, 7 W for the receiver electronics, 2 W for the computer, 3 W for the power supply, and 3 W for the thermal control.

Data Rate
600 b/s.

Data Management Strategy
TBD

Operational Constraints
TBD

Crew Interaction
None

Payload Delivery Options
Orbiter

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
Substantial flight heritage aboard numerous spacecraft. Indicates a flight readiness level of 13.

Infrastructure Interface Requirements
Remains attached to spacecraft. Communications infrastructure required.

Resupply Needs
None

Science/Exploration Community Contact
David E. Smith, Goddard Space Flight Center

References
Smith, D. E., 1992, A Gravity Experiment for Lunar Geodetic Scout, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

C. Artemis (Common Lunar Lander) Mission Description and Payloads

Artemis (Common Lunar Lander) Mission Description and Payloads

Artemis Program: Mission Description

The purpose of the Artemis Program was to gather vital scientific and engineering data by conducting robotic exploration missions on the lunar surface both prior to and concurrent with human exploration missions. The Artemis Program included rapid, near-term development of a variety of small experimental and operational payloads, a low-cost capability to deliver these payloads to any location on the lunar surface, and the analysis of the data returned. The Artemis Program was to provide opportunities to improve the understanding of lunar geosciences, to demonstrate the Moon's unique capability as an astronomical platform to study the universe, to conduct scientific and technology development experiments, and to prepare for and complement human missions.

A principle goal of Artemis was to safely extend the reach of humans to areas of the lunar surface that would otherwise be inaccessible due to high cost or risk.

The mission consisted of a series of launches that would accommodate two launches per year and deliver 65 kg of experimental payloads using a Delta rocket and 200 kg using an Atlas rocket. The basic concept was to use a common lander that could deliver to the Moon stand-alone science and engineering experiments that are bolted onto the lander with little to no integration between the payload and the lander stage. Multiple trips to the Moon could take a variety of experiments including small telescopes, tiny rovers, a sample return module, and a small resource utilization demonstration package. The common lunar lander, later named Artemis, was to use orbital data from past lunar missions, the most recent being the orbiting Clementine mission, to identify candidate landing sites of geologic interest. Artemis did not survive the FY93 and 94 budget process.

Artemis (Common Lunar Lander) Program: Science Payloads

In July of 1991 NASA/JSC's Exploration Program Office sponsored the "Workshop on the Concept of a Common Lunar Lander" which included discussions on the possibilities for lightweight science payloads that could be delivered by a common lunar lander. Scientists and engineers later designed candidate science payloads to a maximum payload mass of 200 kg. The resulting collection of science experiments are listed below. The respective payload descriptions follow in this section.

- Lunar Lander Geophysics Package
- Lunar Geophysics Network
- In Situ Materials Utilization Module
- Southwest Ultraviolet Astronomical/Atmospheric Telescope
- Laser Induced Breakdown Spectrometer
- Combined X-Ray Fluorescence/X-ray Diffraction Instrument
- Lunar Rover Magnetometer
- Lunar Crater Explorer
- Combined Backscatter Mossbauer Spectrometer and X-Ray Fluorescence Analyzer
- Geophysical Diffraction Tomography
- Radio Frequency Glow Discharge Mass Spectrometer
- MicroRaman Spectrometer
- Integrated Lunar Regolith Analyzer

LUNAR LANDER GEOPHYSICS PACKAGE

Date: 8/28/92

PAYLOAD SUMMARY	
Estimated Mass:	**TBD**
Estimated Volume:	**TBD**
Estimated Power:	**TBD**
Estimated Data Rate:	**TBD**

Rationale

Much still remains unknown about the internal structure and physical state of the Moon and its environment. A geophysics package deployed on a lunar lander such as Artemis can contain numerous instruments which could address questions about the existence and mass of a metallic core, the composition and structure of the crust and mantle, the mean lunar heat flow, the present temperature profile, the origin and nature of the tenuous atmosphere, and the origin of the remnant magnetism in lunar rocks, among other issues.

Description

The geophysics package typically will consist of a seismometer, heat flow experiment, magnetometer, mass spectrometer, and solar wind spectrometer. The package can be deployed by a variety of methods, including on rovers, by humans, on soft landers, or with penetrators. A minimum of three widely separated stations are needed across the Moon to provide constraints on the existence, size, and composition of a lunar core. A maximum of 20 or more stations will permit detailed information to be gathered on the structure of the mantle and crust, global heat flow variations, paleomagnetic changes, etc.

The seismometer and heat flow probe also could be deployed using a penetrator. Penetrator emplacement has some distinct advantages since the instruments are automatically emplaced at depths of 1 to 3 meters in the regolith with no drilling required. In addition, one orbiter can deploy multiple penetrators at various locations across the lunar surface. The proposed penetrators would have a cylindrical shape with a frustrum nose, 82.6 cm long and 12 cm in diameter. Each penetrator would have two spherical solid propellant motors, one for deorbiting and the other for decelerating to <300 m/s just before impact. Power will be provided by lithium batteries, keeping the mass (excluding motors and booms) to about 13 kg. The instrument lifetime would be limited to about 1 year. The 3-axis seismometer proposed for the penetrator is a short-period, electromagnetic seismometer with resonant period of approximately 1 sec. This would be about 10 times more sensitive than the Apollo seismometers. The heat flow probes proposed for the penetrator would consist of 10 temperature sensors along the wall of the penetrator and two thermal conductivity instruments. Detailed analysis of the results is required since the penetrator disturbs the thermal conditions in the surrounding regolith. As such, the estimated measurement error is expected to be about 10% for the heat flow measurements.

Power Consumption

TBD, supplied by either a battery or RTG.

Data Rate

TBD.

Data Management Strategy
Data are expected to be stored with periodic transmission to Earth via an overhead orbiter. An orbital communications satellite is mandatory for any farside stations.

Operational Constraints
Some instruments may need to be isolated from adjacent hardware for proper operation.

Crew Interaction
None required, although the package could be deployed by a human crew.

Payload Delivery Options
Payload can be delivered on a soft lander or on a penetrator (seismometer and heat flow probe would be the major instruments on a penetrator). In addition, the package could be delivered as part of a piloted mission and deployed by a human crew, or it could be attached to a rover and operated in a variety of locations across the Moon.

Estimated Set-up Time
Essentially self-deployable.

Maintenance Needs
None

Technology Assessment
Most instruments have a heritage extending back to ALSEP, thus indicating a technology readiness level of 13.

Infrastructure Interface Requirements
None, unless the package is deployed aboard a rover.

Resupply Needs
None expected.

Science/Exploration Community Contact
Lon Hood, University of Arizona.

References
Hood, L., 1991, Lunar Geophysical Measurements, in Proceedings of the Workshop on the Concept of a Common Lunar Lander, Johnson Space Center, Houston, TX .

LUNAR GEOPHYSICS NETWORK

Date: 8/28/92

PAYLOAD SUMMARY	
Estimated Mass:	**60 kg**
Estimated Volume:	**TBD**
Estimated Power:	**45.5 W**
Estimated Data Rate:	**TBD**

Rationale
Numerous questions still exist about the interior structure and physical state of the Moon and its environment. The instrument payload proposed for the Lunar Geophysics Network will help address a variety of issues, including the composition of the tenuous lunar atmosphere and solar wind, the meteoroid and dust environment on the Moon, etc.

Description
The Lunar Geophysics Network will be composed of the following instruments:

Passive Seismometer	Measures the magnitude and direction to lunar seismic events.
Heat Flow Probes	Measures the rate of heat flow from the lunar interior by temperature and thermal property measurements in the lunar subsurface.
Neutral Gas Mass Spectrometer	Monitors the composition and energy spectrum of neutral atoms and ionic species in the lunar atmosphere.
Dust Detector	Sample the population of dust ejected in meteorite impact, material moving as cosmic dust, and the ambient lunar dust.
Ion Mass Spectrometer	Measure the fluxes of protons, α-particles, and solar flare and cosmic ray nuclei.
Electron Energy Spectrometer	Determine the energy spectrum of electrons in the lunar atmosphere.
Magnetometer	Determine the ambient and solar wind induced magnetic fields.
Electric Field Meter	Determine the magnitude and direction of the lunar surface electric field.
Solar Wind Detector	Monitor the composition and energy of solar wind ions.

Power Consumption
45.5 W, to be supplied by battery or RTG.

Data Rate
TBD

Data Management Strategy
Data will be stored for periodic transmission to Earth.

Operational Constraints
TBD

Crew Interaction
None required.

Payload Delivery Options
Could be deployed as part of either a piloted mission or a soft lander.

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
A number of instruments are similar to those deployed on ALSEP, suggesting a technology readiness level of 13 for those instruments. Instruments flown on other spacecraft (e.g., Space Shuttle) likely will need modifications for deployment in the lunar environment, but should otherwise be level 13 as well. For those instruments not already flown, a technology readiness level of 2 would appear appropriate.

Infrastructure Interface Requirements
Due to the variable locations of proposed deployment, each station should be independent of an outpost communications/data infrastructure and capable of transmitting its own data stream to a terrestrial ground station. Those stations deployed on the lunar farside will need communications satellite relay of data streams.

Resupply Needs
None

Science/Exploration Community Contact
John Freeman, Rice University

References
Freeman, J., 1991, Lunar Geophysics Network, in Proceedings of the Workshop on the Concept of a Common Lunar Lander, Johnson Space Center, Houston, TX.

IN SITU MATERIALS UTILIZATION MODULE

Date: 8/31/92

PAYLOAD SUMMARY	
Estimated Mass:	**TBD**
Estimated Volume:	**TBD**
Estimated Power:	**TBD**
Estimated Data Rate:	**TBD**

Rationale
Outposts on the Moon and Mars could be established by transporting necessary materials from Earth for short mission durations, but extended habitation and full-scale development of lunar and martian outposts will require utilization of local resources. Local derivation of propellants (especially hydrogen and oxygen) will save on transportation costs. In addition, production of metals, ceramics, and composites for construction and other products can and should be produced on the Moon or Mars to reduce the weight and cost of the missions.

Description
A small scale test bed of the ISMU (In-Situ Materials Utilization) module is being developed by the University of Arizona (UA)/NASA Space Engineering Research Center (SERC) to test the concept of resource utilization. The electrical, mechanical, computer, and communication systems of the module will be similar for both the lunar and martian mission plants, although the processing systems will be different for the two cases. The module features limited mobility, a robotic sample-collecting and/or receiving arm, concentrated solar heat for processing, an autonomous battery-powered monitoring and control system, and a communications link with SERC. An automated control and monitoring system featuring distributed intelligence, hierarchical structure, and integral communications is under development and has been implemented for the Small Scale Test Bed. This consists of smart sensors and a local controlling computer connected via an ethernet communication system to a remote commanding computer with appropriate telemetry display and control functions. The final design will employ distributed supervisory control by intelligent agents, advanced artificial intelligence, and human interaction in such a way as to maximize autonomy and fault tolerance while conforming to space mission communication standards.

The lunar system may use carbothermal gas pyrolysis to derive and identify oxygen and other volatiles from a variety of samples, converting the residual melts to glass-ceramic units. The martian system, in addition to solid sample analysis, will make use of the electrolytic cell carbon dioxide reduction process developed by SERC to produce oxygen and methane.

Power Consumption
TBD

Data Rate
TBD

Data Management Strategy
Data will be telemetered to an orbiting communication satellite for transmission to Earth.

Operational Constraints
None

Crew Interaction
Human interaction may be needed for loading and unloading of samples, unless this process can be automated.

Payload Delivery Options
The ISMU Plant can be delivered on either a soft lander or a piloted mission.

Estimated Set-up Time
TBD

Maintenance Needs
TBD

Technology Assessment
The Small Scale Test Bed model of the ISMU Plant is in operations and the structure to house the Large Scale Test Bed for the bench scale demonstration is in place. This suggests a technology readiness level of 4.

Infrastructure Interface Requirements
TBD

Resupply Needs
Sample material will need to be resupplied at periodic intervals.

Science/Exploration Community Contact
Terry Triffet, UA/NASA SERC

References
Triffet, T., 1991, An ISMU/Engineering Test-Bed, in Proceedings of the Workshop on the Concept of a Common Lunar Lander, Johnson Space Center, Houston, TX.

SOUTHWEST ULTRAVIOLET ASTRONOMICAL/ATMOSPHERIC TELESCOPE (SWUAAT)

Date: 8/31/92

PAYLOAD SUMMARY

Estimated Mass:	**40 kg**
Estimated Volume:	**0.2 m^3**
Estimated Power:	**40 W**
Estimated Data Rate:	**64 b/s uplink** **4 kb/s downlink**

Rationale

Astronomical observations from the Moon have several advantages over telescopic usage from Earth. In particular, the extremely low mass and density of the lunar atmosphere allows observation in many frequency ranges invisible from Earth. In addition to astronomical observations, the thin lunar atmosphere itself is important to study since lunar astronomy requires an understanding of the atmospheric background. Atmospheric studies will play an important role in understanding surface modification and weathering, internal outgassing and activity, and the structure and evolution of the lunar interior. In addition, investigations of the lunar atmosphere are likely to be the best way to determine if volatile reservoirs, particularly water, exist. Establishment of a facility to study the lunar atmosphere should be done soon after returning to the Moon since exploration and habitation will destroy the pristine lunar environment.

The SWUAAT will use ultraviolet spectroscopy (λ<3500 Å) to determine the concentrations of various components in the lunar atmosphere as well as atmospheric temperatures, emission mechanisms, and ionization fractions. All known lunar atmospheric species (He, Ar, Na, K) can be observed in the UV and most atmospheric candidate species (e.g., Mg, Ni, Fe, OH, noble gases) fluoresce in the UV. In addition, OH and H UV emissions are the best way to detect H_2O at very low sublimation rates.

Description

The SWUAAT telescope (100 mm focal length) will utilize a variety of mirrors to pass photons through a 250 mm focal length plane grating spectrograph and onto cesium iodide and KCsSb photocathode detectors. Resolution will be on the order of 1 to 3 Å over a field of view of less than 2°.

Power Consumption

40 W maximum power, 40 W setup power. Lunar night power will be low (TBD depending on thermal design) since it will only be used by heaters. Telescope only operates during lunar day.

Data Rate

64 b/s uplink; 4 kb/s downlink.

Data Management Strategy

Data will be transmitted to Earth for distribution through a central control station.

Operational Constraints

Prefer front side location, any latitude.

Crew Interaction
None

Payload Delivery Options
Telescope can be delivered on a soft lander and deployed on top the lander. Telescope should not be set on the lunar surface.

Estimated Set-up Time
TBD

Maintenance Needs
None

Technology Assessment
The SWUAAT payload is based on strong Mariner/Voyager/Spartan/Galileo heritage suggesting a technology readiness level of 13.

Infrastructure Interface Requirements
Telescope should be deployed on top of the lander or on a rover. Telescope should not be in contact with the surface.

Resupply Needs
None

Science/Exploration Community Contact
Alan Stern, Southwest Research Institute

References
Stern, A., 1991, Southwest Ultraviolet Astronomical/Atmospheric Telescope, In Proceedings of the Workshop on the Concept of a Common Lunar Lander, Johnson Space Center, Houston, TX.

LASER INDUCED BREAKDOWN SPECTROMETER (LIBS)

Date: 9/4/92

PAYLOAD SUMMARY	
Estimated Mass:	**30 kg**
Estimated Volume:	**TBD**
Estimated Power:	**7 W**
Estimated Data Rate:	**1 Mb/s**

Rationale
The Laser Induced Breakdown Spectrometer (LIBS) is an instrument for remote atomic emission and UV-visual-IR reflectance spectroscopy analysis of planetary surfaces at distances up to 100 m. The instrument will address issues related to lunar geoscience exploration and lunar resource evaluation.

Description
The LIBS consists of a 2 Joule, Q-switched diode (100 m minimum analytical range) with a 10 ns pulse every 10 s (maximum rate). The laser is passively cooled. After the laser has struck an object, the photons from the event travel back to the optical components, consisting of a light collection lens. The photons are focused onto the spectrograph and detector where the beam is analyzed using combined x-ray fluorescence and X-ray diffraction analysis as well as evolved gas mass spectrometry to determine the chemical constituents.

Power Consumption
7 W, 5 of which are used by the laser.

Data Rate
1 Mb/s

Data Management Strategy
TBD

Operational Constraints
Laser must be operated within about 100 m of the target.

Crew Interaction
None

Payload Delivery Options
Lunar Lander

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
TBD

Infrastructure Interface Requirements
Design calls for attachment of LIBS to a rover.

Resupply Needs
None

Science/Exploration Community Contact
James Blacic, Los Alamos National Laboratory

References
Blacic, J., 1992, Laser-Induced Breakdown Spectrometer (LIBS) for Lunar Lander Mission, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

COMBINED X-RAY FLUORESCENCE/X-RAY DIFFRACTION INSTRUMENT

Date: 9/4/92

PAYLOAD SUMMARY	
Estimated Mass:	**TBD**
Estimated Volume:	**TBD**
Estimated Power:	**TBD**
Estimated Data Rate:	**TBD**

Rationale

X-Ray Flurorescence (XRF) has been used on previous missions such as Viking to test for surface chemistry data. However, the lack of mineralogic data along with the chemistry limits the utility of XRF alone. A combined XRF and X-Ray diffraction (XRD) instrument will provide unambiguous assignment of mineralogy to a given chemistry and the capability to recognize new or unexpected minerals (and hence the ability to explain puzzling chemical data). With quantitative XRD, the accuracy of chemical data can be vastly improved by solving simultaneous equations for chemical and mineral abundances.

Description

In the XRD, a sample of soil is placed in a Be tube and bombarded with Mn Kα radiation from ^{55}Fe source passed through a Cr filter. The resultant fluorescent radiation from the sample is directed to two proportional counters which can measure elements lighter than Cr. The diffracted Mn Kα beam, meanwhile, is sent to a position-sensitive detector.

The XRF uses an unfiltered beam of Mn Kα radiation from the ^{55}Fe source to encounter a sample of soil. An energetic source (e.g., ^{109}Cd or ^{133}Ba) is inserted to fluoresce the heavy elements. The resultant fluorescent radiation is then directed to detectors which can measure a large range of major, minor, and trace elements.

A combined XRF/XRD instrument on a lunar rover significantly increases the ability to analyze regolith samples. The combined quantitative chemical and mineralogic data provide high-accuracy chemical and mineralogic determinations from samples collected along rover traverses. Dependable regolith chemistry and mineralogy determinations have both scientific and resource uses in areas such as determining the chemical/mineralogic stratigraphy from regolith cores, screening samples for return to Earth, measuring the ilmenite concentrations of the regolith, and measuring the percentage of glass in pyroclastic deposits and regolith.

Power Consumption

TBD

Data Rate

TBD

Data Management Strategy

TBD

Operational Constraints

Instrument attached to a rover. Requires regolith sample to be placed in instrument.

Crew Interaction
None

Payload Delivery Options
Lunar Lander

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
TBD

Infrastructure Interface Requirements
Attached to a rover.

Resupply Needs
None

Science/Exploration Community Contact
David Vaniman, Los Alamos National Laboratory

References
Vaniman, D., 1992, Combined X-Ray Fluorescence/X-Ray Diffraction Instrument for Lunar Lander Mission, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

LUNAR ROVER MAGNETOMETER

Date: 9/4/92

PAYLOAD SUMMARY	
Estimated Mass:	**5 kg**
Estimated Volume:	**TBD**
Estimated Power:	**3 W**
Estimated Data Rate:	**TBD**

Rationale
The Lunar Rover Magnetometer is designed to measure the lunar magnetic field at various locations along the rover traverse. Apollo 14 and 16 hand-held magnetometers showed that the surface field can change magnitude by ~400 nT and reverse direction several times over a few km. Close coordination with geological and compositional setting can identify magnetic sources and constrain the origin of lunar paleomagnetism. The results will be combined into a detailed vector gravity field map of the Moon which will be used in cooperation with surface geologic observations and compositional mapping. Results will help constrain the origin of the Moon's paleomagnetism and can determine the distribution of magnetization for possible resource applications.

Description
Two triaxial fluxgate magnetometers are mounted on a telescoping vertical rod attached to the rover. The primary magnetometer is mounted at the top of the rod at a distance of several meters above the rover to minimize rover-associated fields. The second magnetometer is mounted nearer the base to provide a means of estimating the amplitude and time variations of rover-related fields. An electronics box containing a power source and data-recording device is located near the base of the boom. Knowledge of the rover orientation and location is required versus time.

Power Consumption
3 W

Data Rate
TBD

Data Management Strategy
Data recording can be on the rover or via telemetry to a central location via satellite or line-of-sight transmission.

Operational Constraints
Data capture on all rover traverses; non-interfering hands-off operation; direct tape recording or telemetry to base station. Prefer no AC rover magnetic fields >1 nT at primary sensors, but fields as large as 10 nT can be tolerated. Backup station vector magnetometer required for interplanetary reference.

Crew Interaction
None

Payload Delivery Options
Lunar Lander

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
TBD

Infrastructure Interface Requirements
Magnetometer attached to rover via a long dynamically damped sensor boom.

Resupply Needs
None

Science/Exploration Community Contact
Paul Coleman, Jr., University of California at Los Angeles

References
Hood L.L., Sonett C.P., and Coleman P.J., 1992, Lunar Rover Magnetometer, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

LUNAR CRATER EXPLORER

Date: 9/4/92

PAYLOAD SUMMARY	
Estimated Mass:	**TBD**
Estimated Volume:	**TBD**
Estimated Power:	**TBD**
Estimated Data Rate:	**TBD**

Rationale
Impact craters, the dominant geological feature on the Moon, hold great scientific interest concerning a geology and planetary formation, and motivate robotic capabilities for mapping, climbing, and digging. A robotic mission to a lunar crater would achieve scientific, political, and financial goals. Such a mission would set an important precedent in mobile autonomous operation and provide an excellent start for an aggressive interplanetary exploration drive. A robotic mission to a lunar crater would forward the SEI's exploration agenda and provide evidence on the worthiness of the technology to exploit space material and energy resources.

Description
The primary activities of the Lunar Crater Exploration Program will be to demonstrate robotic capabilities in environments inaccessible to humans and dissolve scientific problems concerning the geologic history of the lunar craters. Candidates for locomotion are wheels, tracks, and legs. A wheeled robot is a low risk design with moderate terrain capability, but it may suffer from traction problems and slippage at high angles on the low-cohesion lunar soil. Novel types of wheels need to be designed and developed. Tracked vehicles exhibit fair traction on dry surfaces, have moderate terrainability, and are low risk systems. The leading candidates for the class of machines are legged robots because they possess good traction on all surfaces, have excellent terrain capability, and have high mobility efficiency and good local position estimation, but they are more complex than the other systems.

The perception system will be a technically challenging and unprecedented aspect of this project. The primary goal of the perception system is to permit safe vehicle navigation; obstacles and dangerous terrain conditions must be detected and mapped. The strongest candidate perception strategies include passive stereo vision, laser rangefinding, and tactile sensing.

Power Consumption
TBD; a photovoltaic power source may be able to generate the primary power for this mission. Radioisotope power sources are an alternative for powering the robot. Power storage can use either rechargeable or non-rechargeable batteries.

Data Rate
TBD

Data Management Strategy
TBD

Operational Constraints
The Lunar Crater Explorer will need to be able to navigate highly uneven terrain on the inner walls and floor of the craters.

Crew Interaction
None

Payload Delivery Options
Lunar Lander

Estimated Set-up Time
TBD

Maintenance Needs
None

Technology Assessment
Technology Readiness Level 1.

Infrastructure Interface Requirements
TBD

Resupply Needs
None

Science/Exploration Community Contact
William Whittaker, Carnegie Mellon University

References
Whittaker, W., 1992, Lunar Crater Explorer, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

COMBINED BACKSCATTER MOSSBAUER SPECTROMETER AND X-RAY FLUORESCENCE ANALYZER (BAMS/XRF)

Date: 9/4/92

PAYLOAD SUMMARY	
Estimated Mass:	**500 g**
Estimated Volume:	**300 cm^3**
Estimated Power:	**<2 W**
Estimated Data Rate:	**TBS**

Rationale
The Combined Backscatter Mössbauer Spectrometer and X-Ray Fluorescence Analyzer (BaMS/XRF) will determine, remotely and without sample preparation, the distribution of iron among its oxidation states and mineralogies, and the abundance of selected elements within lunar surface materials. Measurement of elemental abundances and the distribution of iron among its oxidation states and mineralogies provides data for first-order characterization of lunar soils and rocks (iron mineralogy and composition), maturity of lunar soils (derived from Fe(O) content and FeO concentration), prospecting for ilmenite, which is believed to be the best lunar source for oxygen and ^{3}He, and industrial process monitoring (e.g., rate and state of reduction of lunar materials, sintering state during brick formation).

Description
The BaMS/XRF will utilize a common excitation source (^{57}Co) and solid state detectors to do both BaMS and XRF experiments. The combined instrument emits gamma rays to the surface materials and measures the energies of the resulting X-rays to determine iron mineralogy, soil maturity, and composition. No sample preparation is required.

Power Consumption
<2 W.

Data Rate
TBD; 60 kb of data will be produced per spectrum.

Data Management Strategy
Data will be stored by instrument until requested by spacecraft bus.

Operational Constraints
Near surface.

Crew Interaction
None

Payload Delivery Options
Lunar lander--can be deployed on a soft-lander, penetrator, and/or rover.

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
A fully functional BaMS prototype instrument is planned for completion in 1992. Modification to include XRF will require an additional 6 months. This suggests a technology readiness level of 8.

Infrastructure Interface Requirements
Instrument remains attached to lander or deployed on rover.

Resupply Needs
None

Science/Exploration Community Contact
Richard Morris, Johnson Space Center

References
Morris R.V., Agresti D.G., and Clark B.C., 1992, Combined Backscatter Mössbauer Spectrometer and X-Ray Fluorescence Analyzer (BaMS/XRF), in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

GEOPHYSICAL DIFFRACTION TOMOGRAPHY

Date: 9/4/92

PAYLOAD SUMMARY	
Estimated Mass:	**<15 kg**
Estimated Volume:	**TBD**
Estimated Power:	**10 W - 100 W**
Estimated Data Rate:	**100 kb/s**

Rationale

Diffraction tomography (DT) is a method for structure determination from remote measurements. This imaging procedure is similar to more commonly known imaging procedures, namely those of CT scanners used in diagnostic medicine and synthetic aperture radar (SAR) used to map surface features from airborne or orbital platforms. DT, however, offers several advantages that render it more suitable for extraterrestrial resource exploration. As compared to signal processing techniques of CT scanners, the algorithms of DT are a generalization to nonzero wavelength that rigorously account for the diffractions (the redistribution of signal amplitude and phase) which result from the interaction of interrogating waves with inhomogeneities. In addition to greatly improved image quality associated with a more proper representation of the physics of wave propagation and scattering, DT requires no a priori assumption regarding ray paths and, unlike CT type algorithms, is suitable for applications in reflection measurement geometries which are noninvasive and most appropriate for autonomous or remotely controlled extraterrestrial operations. Furthermore, the implicit focusing associated with the mathematical holographic lens offers increased resolution within each unique viewing angle, rendering it more suitable for use in limited view measurement geometries such as reflection.

Description

The concept for extraterrestrial resource exploration is based on a two tiered approach. Initial screening of sites is accomplished from an orbital platform using low frequency radar (1 to 10's MHz range). Using this and other information, candidate sites are identified for more intensive studies using a landed autonomous or remotely operated vehicle (rover). The rover would be equipped with a pair of higher frequency radar antennas (in the hundreds of MHz range) to increase spatial resolution significantly over that derived from orbital measurements. To complement the subsurface electromagnetic properties reconstructed from radar measurements, the rover would contain sensors for probing the subsurface with acoustic waves to characterize subsurface mechanical properties. All rover measurements will be noninvasive multimonostatic pulse/echo type and images of vertical subsurface cross-sections will be reconstructed using the signal processing algorithms of diffraction tomography for both orbital and landed data.

The landed vehicle will contain a pair of antennas (one transmitting and one receiving) which could be either towed or mounted on the undercarriage. For this reason, acoustic measurements require sensors to be well coupled to geology. Acoustic receivers would be piezoelectric ceramics integrated into a number of studs mounted on a wheel or vehicle tread, as appropriate. The acoustic source could be either a spring loaded mass striking a stud or another piezoelectric ceramic within a stud. The use of a spring loaded mass would add at least 5 kg to the weight of the landed vehicle. The weight of the piezoelectric ceramic is negligible; however, the drawback to its use is that the energy output would be quite low requiring multiple pulses at each measurement location to achieve the necessary signal-to-noise ratio. It is estimated that the vehicle would need to remain stationary for at least one second for data acquisition using a piezoelectric ceramic source. The propagation of acoustic waves in the absence of an atmosphere would require sensor coupling to reasonably competent geology which may not exist at the surface of all sites.

Power Consumption
Between 10 and 100 W--performance varies with available power.

Data Rate
<100 kb/s after processing.

Data Management Strategy
TBD

Operational Constraints
TBD

Crew Interaction
None

Payload Delivery Options
Combined orbiter and lunar lander deployed rover.

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
Technology Readiness level 1.

Infrastructure Interface Requirements
Orbital DT instrument remains attached to spacecraft. Landed instrument is deployed on a rover. Communications infrastructure required.

Resupply Needs
None

Science/Exploration Community Contact
S. S. Stevens, Oak Ridge National Laboratory

References
Stevens S.S. and Witten A.J., 1992, A Diffraction Tomography Based Extraterrestrial Resource Exploration System, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

RADIO FREQUENCY GLOW DISCHARGE MASS SPECTROMETRY

Date: 9/4/92

PAYLOAD SUMMARY

Estimated Mass:	TBD
Estimated Volume:	TBD
Estimated Power:	TBD
Estimated Data Rate:	TBD

Rationale
A miniaturized radio frequency (rf) glow discharge mass spectrometer will be adapted for in situ inorganic elemental analysis of lunar samples. The RF Glow Discharge Ionization Source allows direct solids sampling for inorganic elemental analysis, analysis of conducting and nonconducting solids and powders, uniform elemental response (lithium through uranium), and complete qualitative and semi-qualitative analyses.

Description
The miniaturized RF Glow Discharge Ion Trap Mass Spectrometer consists of three primary components: an RF glow discharge ion source, an ion trap mass analyzer, and a detector. The extraction of ions from the RF glow discharge ion source is facilitated through an exit orifice/differential pumping region. Ion optics serve to focus and transport the ions into the miniature ion trap. An ion trap consists of two end cap electrodes, which are typically grounded, and a center ring electrode to which a radio frequency potential is applied. A quadrupole electric field is established, trapping ions. One method of obtaining a mass spectrum is to ramp the rf potential on the ring electrode. A mass spectrum is acquired as successively higher masses are destabilized by the increasing rf potential. The miniature ion trap functions on the same principles as a conventional ion trap with the exception that much smaller concentric cylindrical electrodes replace the much larger ring electrode and end caps. A commercially available detector will be used to provide analog as well as pulse counting detection. Using sensitivity factors that equate variations in elemental response, semi-quantitative analysis will be possible.

Power Consumption
TBD

Data Rate
TBD

Data Management Strategy
TBD

Operational Constraints
TBD

Crew Interaction
None

Payload Delivery Options
Lunar Lander

Estimated Set-up Time

None

Maintenance Needs
None

Technology Assessment
TBD

Infrastructure Interface Requirements
TBD

Resupply Needs
None

Science/Exploration Community Contact
D. H. Smith, Oak Ridge National Laboratory

References
Smith D.H., Buchanan M.V., Bauer M.L., Duckworth D.C., and Barshick C.M., 1992, Elemental Analysis of Lunar Materials by Radio Frequency Glow Discharge Mass Spectrometry, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

MICRORAMEN SPECTROMETER

Date: 9/4/92

PAYLOAD SUMMARY	
Estimated Mass:	**<3 kg**
Estimated Volume:	**3540 cm^3**
Estimated Power:	**milliwatts**
Estimated Data Rate:	**TBD**

Rationale
Laser Raman Spectroscopy is ideally suited for extraterrestrial geochemical analysis since it provides high-resolution spectra of inorganic compounds, direct surface analysis, complete analysis in seconds, and is easily miniaturized. Raman spectroscopy is a light scattering technique and thus requires no sample preparation prior to analysis. A very large advantage of Raman spectroscopy is that it responds to virtually all inorganic compounds, eliminating the need for a different system for every compound or class of compound of interest.

Description
Compact Raman spectrometers are a new development. Key components of these new systems are small diode lasers with low power requirements. The spectrometer detector is composed of a miniature electro-optic filter/photodetector combination. Laser light is focused through the optical window of the instrument onto the sample. Backscattered Raman light is sent to the detector system where it is analyzed. Instrument control, data acquisition, and data processing are all achieved via microcomputer.

Power Consumption
Milliwatts

Data Rate
TBD

Data Management Strategy
TBD

Operational Constraints
Must be operated on surface within a few meters of the material to be sampled.

Crew Interaction
None

Payload Delivery Options
Lunar Lander. Can be deployed at fixed analysis station, on a surface rover, on robotic arms, or through use of fiberoptic probes up to a kilometer from the spectrometer.

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
While largely well developed, compact Raman spectrometers are not 100% ready for extraterrestrial applications, particularly regarding size and weight requirements. This suggests technology readiness level 6.

Infrastructure Interface Requirements
May be attached to fixed lander, on a surface rover, or on robotic arms.

Resupply Needs
None

Science/Exploration Community Contact
John Haas III, Oak Ridge National Laboratory.

References
Haas, J. W., 1992, MicroRaman Spectrometer for Extraterrestrial Geochemical Analysis, in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

INTEGRATED LUNAR REGOLITH ANALYZER (ILRA)

Date: 9/4/92

PAYLOAD SUMMARY	
Estimated Mass:	22 kg
Estimated Volume:	TBD
Estimated Power:	34 W
Estimated Data Rate:	2.5 kb/s

Rationale
The objective of the Integrated Lunar Regolith Analyzer is to provide an instrument for combined X-ray and evolved gas analysis of lunar regolith samples.

Description
The instrument package consists of several science instruments. Elemental analysis will be performed by X-Ray Flurorescence, while mineralogic analysis is performed by grazing incidence X-ray diffraction. The bonding state of Fe is obtained by gamma ray Mössbauer spectroscopy, and evolved solar wind components will be determined by thermal evolved gas analysis. In addition, the interaction of O_2, H_2, CH_4, and CO with the regolith will be determined through use of these instruments.

Power Consumption
34 W

Data Rate
2.5 kb/s

Data Management Strategy
TBD

Operational Constraints
TBD

Crew Interaction
None

Payload Delivery Options
Lunar Lander

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
Substantial flight heritage on numerous NASA missions, indicating a technology readiness level of 13.

Infrastructure Interface Requirements
TBD

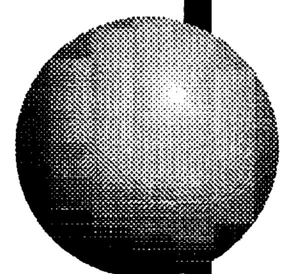
Resupply Needs
None

Science/Exploration Community Contact
Benton Clark, Martin Marietta

References

Clark B., Martin J., Knight T.C.D., Agresti D., and Morris R., 1992, Integrated Lunar Regolith Analyzer (ILRA), in Workshop on Early Robotic Missions to the Moon, Lunar and Planetary Institute, Houston, TX.

Part II: ***Mars***



A. Mars Science Payloads

1. Robotic Mission Payloads

GAMMA-RAY SPECTROMETER AND NEUTRON ANALYZER

Date: 8/19/92

PAYLOAD SUMMARY	
Estimated Mass:	4 kg
Estimated Volume:	2.5 m^3
Estimated Power:	3.5 W
Estimated Data Rate:	TBD

Rationale
Neutrons and gamma rays are produced by a variety of elements through radioactive decay and by interaction of certain surface elements with high energy cosmic rays. The Neutron Analyzer is particularly sensitive to the detection of hydrogen which can provide information about the existence of water. When information from the Neutron Analyzer is combined with data from the Gamma Ray Spectrometer, constraints on the depth of water can be obtained. In addition, the Gamma Ray Spectrometer determines the abundances of other elements, specifically H, O, Mg, Si, Cl, K, Ca, Ti, Fe, Th, and U. Thus, utilization of both instruments in combination can provide important information about elemental abundances constituting planetary surface materials.

Description
Energetic neutrons are produced by interactions of high-energy cosmic rays with surface materials. These neutrons can be slowed to thermal energies by collisions with nuclei in the surface. The resulting thermal neutrons interact with the elements in the surface materials, causing the production of gamma rays. Since both neutrons and gamma rays can travel over a large distance, these instruments are designed to count the numbers of these particles to determine elemental concentrations: thermal and epithermal neutrons are counted to determine the hydrogen content of the surface material and gamma rays provide information on the abundances of a number of elements present in the surficial material.

The Neutron Analyzer consists of a small tube filled with ^{3}He. Neutrons interact with the gas, causing ionization. The ionized gas can conduct a current, which is detected by a central wire running through the tube. A detector external to the tube counts the current pulses generated, providing information on the number of neutrons interacting with the ^{3}He gas. The Neutron Analyzer will utilize two tubes, one bare and one covered with cadmium. The cadmium serves as a barrier to thermal neutrons, thus allowing only epithermal neutrons to interact with the internal gas. The bare tube allows both thermal and epithermal neutrons to be detected. The ratio of thermal to epithermal neutrons is a reflection of the hydrogen content of the soil.

The Gamma Ray Spectrometer contains a large (7.5 cm x 7.5 cm) crystal of NaI into which gamma rays deposit energy. A light pulse is generated by the crystal with an intensity proportional to this energy. A photomultiplier tube converts the light to a voltage pulse proportional to the energy and the pulses are analyzed and counted according to pulse height (= gamma ray energy). A histogram of the number of pulses versus energy results in a spectrum where variations in amplitudes reflect the abundances of specific elements.

Power Consumption
0.5 W for the Neutron Analyzer; 3 W for the Gamma Ray Spectrometer.

Payload Breakdown

Component	Mass (kg)	Volume (cm^3)	Power (W)	Data Rate (kb/s)
Neutron Analyzer	**0.5**	**360**	**0.5**	**TBD**
Detector (each, of 2)	0.1	32		
Electronics	0.3	300		
Gamma Ray Spectrometer	**3.5**	**2100**	**3**	**TBD**
Detector	3	1600		
Electronics	0.5	500		
SUBTOTAL	4	2460	3.5	TBD
25% MARGIN	1	615	0.9	
TOTAL	5	3075	4.4	TBD

Data Rate
TBD

Data Management Strategy
TBD

Operational Constraints
Deployment of both instruments is nearly unconstrained. Neither the Neutron Analyzer nor the Gamma Ray Spectrometer require sample collection or processing. Both are very robust and could be included as payloads on a penetrator or hard lander, although a penetrator is preferable for the Gamma Ray Spectrometer since it has better sensitivity at depth. The Neutron Analyzer is small enough to be included on a microrover; the Gamma Ray Spectrometer, however, is too large for inclusion on such small rovers. For best operation, the Neutron Analyzer must not be located near large amounts of fuel or other hydrogenous material, restricting its location on a lander or rover. The Gamma Ray Spectrometer must avoid being too close to large amounts of the elements it is designed to detect.

Crew Interaction
None required.

Payload Delivery Options
These instruments can be either orbital or lander payloads. Both instruments are rugged enough to be included as payloads on penetrators or hard landers and both could be accommodated as science packages on rovers.

Estimated Set-up Time
None--completely self-contained.

Maintenance Needs
None

Technology Assessment
Both the Neutron Analyzer and the Gamma Ray Spectrometer have proven flight experience and are routinely used in a variety of situations. This indicates a technology readiness level of 13.

Infrastructure Interface Requirements
Communication links to transmit data to Earth.

Resupply Needs
None

Science/Exploration Community Contact
William Boynton, University of Arizona

References
Boynton, W. V., 1992, Neutron and Gamma-Ray Detection, Presentation at Workshop on Mars Robotic Mission Approaches for SEI, Houston, TX.

COMPLEX RESISTIVITY (CR) AND GROUND PENETRATING RADAR (GPR) EXPERIMENTS

Date: 8/19/92

PAYLOAD SUMMARY	
Estimated Mass:	CR: few grams GPR: 1.5 kg
Estimated Volume:	CR: ~1 cm^3 GPR: few 100 cm^3
Estimated Power:	CR: 1 W GPR: few watts
Estimated Data Rate:	TBD for both experiments

Rationale
Electromagnetic investigations conducted from a rover or a lander can provide information about the subsurface region on Mars. The distribution of subsurface hazards (voids, low density soil or dust layers, etc.), the presence and amount of subsurface volatiles, and predications of drilling success are three areas where electromagnetic investigations can provide useful information in support of surface exploration. Complex Resistivity and Ground Penetrating Radar are two EM experiments which have been proposed for various SEI missions.

Description
The Complex Resistivity Experiment generates a current which is transmitted through the near subsurface regions and detected by electrodes on the surface at some distance away. The elapsed time between signal transmission and reception provides information about the resistivity of the soil and the presence of voids, subsurface water, etc. It actively measures chemical reactions within the near surface region and passively measures electrostatic properties of the material.

The Ground Penetrating Radar utilizes an electromagnetic field generated above the surface to penetrate to some depth (penetration depth depends on the wavelength of the EM waves) in the subsurface. Variations in subsurface structure cause upward reflection and scattering of the EM waves, which are detected by electric field antennas on the surface. Inverse techniques are then utilized to obtain the location of the subsurface structures.

Power Consumption
Approximately 1 W for the Complex Resistivity Experiment.
A few watts for the Ground Penetrating Radar.

Data Rate
TBD

Data Management Strategy
TBD

Operational Constraints
The Complex Resistivity Experiment must be operated on the surface since it must be in contact with the soil.

Crew Interaction
None

Payload Delivery Options
Both experiments can be deployed on hard landers, soft landers, or rovers. The Complex Resistivity Experiment also can be deployed on a penetrator. The Ground Penetrating Radar is too large for deployment on a penetrator.

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
Both experiments have substantial terrestrial heritage, giving them an estimated technology readiness level of 9.

Infrastructure Interface Requirements
Communications link for data transmission.

Resupply Needs
None

Science/Exploration Community Contact
Gary Olhoeft, U. S. Geological Survey, Denver, CO.

References
Olhoeft, G. R., 1992, Electromagnetic detection of subsurface hazards and water, Presented at Workshop on Mars Robotic Mission Approaches for SEI, Houston.

THERMAL ANALYZER FOR PLANETARY SOILS (TAPS)

Date: 8/24/92

PAYLOAD SUMMARY	
Estimated Mass:	**1.2 kg**
Estimated Volume:	**850 cm^3**
Estimated Power:	**0.3 W continuous** **5 W peak**
Estimated Data Rate:	**5 kb/s**

Rationale
The Viking Landers performed simple geochemical experiments on the martian soil but many questions remain about the composition of the martian surface materials. In particular, the abundances and forms of water (e.g., adsorbed, ice, bound-mineral, etc.), which are of great interest to SEI, are unknown as are the abundances and types of volatile-bearing minerals and information on surface material hazards, science site selection, and resource utilization.

Description
The Thermal Analyzer for Planetary Soils (TAPS) consists of two parts: the thermodynamic analyzer and the evolved-gas analyzer. The thermodynamic analyzer, containing a differential scanning calorimeter (DSC), heats a sample of martian soil to expel gases. The identity and abundances of the minerals and ices in the soil sample are determined from their thermodynamic responses upon heating, as measured by the DSC. The gases expelled during heating are sent to the evolved-gas analyzer for identification.

Power Consumption
0.3 W continuous power; 5 W peak power.

Data Rate
5 kb/s with 500 kb per analysis.

Data Management Strategy
TBD

Operational Constraints
Must have a soil sample to operate, thus instrument is located on surface.

Crew Interaction
None required

Payload Delivery Options
Can be delivered as a payload on a hard lander, soft lander, rover, or penetrator.

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
Pre-phase A development was completed. Proof of concept was demonstrated at bench-top level, but more engineering studies are needed, indicating a technology readiness level of 3.

Infrastructure Interface Requirements
None

Resupply Needs
None

Science/Exploration Community Contact
James Gooding or Doug Ming, Johnson Space Center

References

Gooding, J. L., 1991, Thermal Analyzer for Planetary Soils (TAPS) experiment: Functions and design options, Lunar Planetary Science XXII, Lunar and Planetary Institute, Houston, TX 457-458.

Gooding, J. L., Kettle, A. J., and Lauer, H. V., Jr., 1991, DSC sensitivity to hydrated minerals in planetary samples, Lunar Planetary Science XXII, Lunar and Planetary Institute, Houston, TX 463-464.

MARS AQUEOUS CHEMISTRY EXPERIMENT (MACE)

Date: 8/24/92

PAYLOAD SUMMARY

Estimated Mass:	**1.7 kg Mini-MACE** **0.8 kg Sub-mini MACE**
Estimated Volume:	**2065 cm^3 Mini-MACE** **983 cm^3 Sub-mini MACE**
Estimated Power:	**2 W Average; 12 W Peak Mini-MACE** **<1 W Average; 12 W Peak Sub-mini MACE**
Estimated Data Rate:	**20 b/s Mini-MACE** **3 b/s Sub-mini MACE**

Rationale

The Viking Landers performed simple chemical analyses on the martian soil, but many questions still remain which are of interest to SEI missions. In particular, information about soil oxidants, excess acidity or basicity, microparticles, and water soluble toxic element concentrations is strongly desired prior to sending humans to Mars. The Mars Aqueous Chemistry Experiment is designed to characterize martian soils through measurement of the chemical reactivity and composition of the soils as well as their physical properties. The resulting data will provide important constraints on questions relating to the fates of atmospheric volatiles, the genetic origin of any salts detected, weathering processes, implications for climatic history, existence of brines, and exobiology.

Description

MACE will determine the chemical and physical properties of martian soils through a series of experiments on 3 to 12 soil samples obtained via miniature coring tubes. Measurement of thermal and electrical conductivity of the samples will provide information about soil properties in the dry state. The samples then will be exposed to water vapor to measure oxygen release and conductivity changes. Full wetting of the soil will provide information on pH, Eh, salts release, particle size distribution, and toxic element concentrations. Chemical stimulation of the soil will cause the release of gases from any carbonates or nitrates which may exist. The primary relevance of this experiment to SEI objectives are in determination of oxygen release, oxidant product detections (using ion or spectro-analysis of solution), pH of wetted soil, Eh of solution, heat of wetting, extractable trace elements (using specific ion electrodes or XRF of extract), electrical conductivity of soil, particle size distribution, salt concentration in martian soil (providing information about the existence of carbonates, nitrates, sulfates, chlorides, bromides, and associated cations), and evidence for clay minerals.

Two versions of the experiment are proposed--the Mini-MACE and the Sub-mini MACE. The two versions have essentially the same design but the Sub-mini version does not incorporate as many sensors or sampling tubes as does the Mini-MACE.

Power Consumption

The Mini-MACE will operate with an average power of 2 W, with peak power (occurring in pulses) approaching 12 W. The Sub-mini MACE has an average operating power consumption of <1 W, with peak operating power (in pulses) of about 12 W. Both versions of MACE operate for 48 hrs per sample.

Data Rate
20 b/s for the Mini-MACE, 3 b/s for the Sub-mini MACE.

Data Management Strategy
TBD

Operational Constraints
The experiment must have soil samples to operate; thus either the instrument is deployed on the surface or the samples must be delivered to the instrument. Temperature must be maintained between 277 K and 311 K during time of measurements.

Crew Interaction
None

Payload Delivery Options
Can be soft landed in one location or deployed on a rover.

Estimated Set-up Time
None

Maintenance Needs
None expected.

Technology Assessment
Several aspects of MACE require further study, including the flight qualification of miniature chemical sensor technology, optimization of porous tubes for samples, miniature low power valves, and methods of fluid transport through small-orifice existing EM latching valves. The technology readiness level is estimated at 2.

Infrastructure Interface Requirements
Current design of both versions of MACE assumes availability of connection to central electronics source and thermal control to keep temperature within the necessary 277-311 K range.

Resupply Needs
None

Science/Exploration Community Contact
Benton Clark, Martin Marietta.

References
Clark, B., 1992, MACE: Mars Aqueous Chemistry Experiment, Presented at Workshop on Mars Robotic Mission Approaches for SEI, Houston, TX.

A. Mars Science Payloads

2. Geosciences/Meteorology Payloads

MARS GEOLOGIC FIELD EQUIPMENT PACKAGE

Date: 8/10/92

PAYLOAD SUMMARY	
Estimated Mass:	**336 kg**
Estimated Volume:	**1.8 m^3**
Estimated Power:	**500 W; supplied by rechargeable batteries in applicable instruments**
Estimated Data Rate:	**all data stored internally in applicable instruments**

Rationale
Proper geologic field work will require hand tools to tackle a variety of tasks, such as removal of samples from larger rocks, emplacing probes in the Martian regolith, recovering drive-type core tubes, and properly documenting the sample environment. This equipment allows the astronauts to properly carry out the necessary tasks to ensure that good samples are taken, properly documented, and stored.

Description
Geologic field tools are the suite of basic tools that will be delivered to the Martian surface for use in collecting, documenting, storing and transporting rock, soil and drive-tube samples. Similar sets of field tools were developed for the Apollo program, and in many cases, identical tools will be used for SEI field activities. Where appropriate, estimates for the mass, volume, etc. were taken from the corresponding Apollo equipment. Each equipment package contains the necessary tools, collection bags, and storage containers to outfit a team of 2 astronauts.

A brief description and the purpose of each component is listed below:

TOOLS	PURPOSE
Regolith Drill	Collect up to 3 meter cores of soil samples; drill holes for emplacement of heat flow and other geophysical experiment probes
Rock Drill	Collect ~2 cm diameter rock cores up to 15 cm deep from surface samples; bits included
Rock Hammer	Remove samples off of boulders; emplace drive tubes
Chisel	Remove samples off of boulders; trim samples
Rake	Collect representative populations of samples >1 cm in size from the lunar regolith.
Rover Soil Sampler	Allows an astronaut to collect a soil sample without getting off an unpressurized rover
Adjustable Angle Scoops	Collect soil samples, trench

Tongs	Pick up rock samples without bending over
Long extension handle	Handle which will fit on any of the above tools through use of a universal fitting. Allows extension of the astronauts reach, and can provide a limited increase in leverage if needed
Drive tube	Collect 4-cm by 40-cm long soil sample; can be mated to produce longer cores. Physically driven in to the soil using the rock hammer to obtain sample
Gnomon	Small folding device used for photodocumentation of sample environment. Allows determination of the local vertical, and also provides a color/grey scale for calibration of photographic images
Orientation/inclinometry tool	Similar to a Brunton compass, this tool will allow determination of orientation of rock units
Sample scale	Allows weighing of samples prior to storage
Tool carrier	Rack for carrying tools on unpressurized rover
Camera equipment	Includes all camera bodies, backs and lenses for adequate photodocumentation of sample environment
CONTAINERS	
Sample collection bag	Soft-sided, non-sealing bag for storage samples that will not be kept in the Martian ambient environment
Sample return container	Aluminum case which has provisions for sealing in the Martian environment; used for samples where it is important to maintain Martian ambient conditions
CONSUMABLES	
Documented sample collection bags	A variety of plastic bags for collecting samples in prior to storage in containers
Photographic film	A variety of types and formats of photographic film to be used to document EVA activities

Power Consumption

Most equipment will not require any electrical power to operate. The following tools will require battery power:

Regolith drill	2150 W-hr @ 430 W
Rock drill	2000 W-hr @ 500 W

Payload Breakdown

	Mass (kg)	Volume (cm^3)	Number/package	Total Mass (kg)	Total Volume (cm^3)
TOOLS					
Regolith drill (includes bits)†	13.9	16704	1	13.9	16704
Rock drill (includes bits)	6	4000	1	6	4000
Geologic hammer	1.3	1200	2	2.6	2400
Chisel	0.2	100	2	0.4	200
Rake	1.5	9100	2	3	18200
Rover soil sampler	0.1	500	1	0-1	500
Small adjustable angle scoop	0.5	1100	2	1	2200
Large adjustable angle scoop	0.6	1200	2	1-2	2400
32-inch tongs	0.2	1600	2	0.4	3200
Long extension handle	0.5	150	2	1.6	300
4-cm drive tube	0.5	11000	45	22.5	495000
Gnomon	0.3	5300	1	0.3	5300
Orientation/inclinometry tool	2	1000	1	2	1000
Sample scale	0.2	900	1	0.2	900
Large tool carrier	5.9	72600	1	5.9	72600
Camera equipment	2.5	10000	1	25	10000
TOOLS SUBTOTAL				86	0.63 m^3
CONTAINERS					
Sample collection bag	0.8	3300	25	20	82500
Mars sample return container	6.6	28000	10	66	280000
Regolith drill stems (per 3-meter hole)	1.2	1267	10	12	12670
CONTAINERS SUBTOTAL				98	0.38 m^3
CONSUMABLES					
Documented sample collection bags*	25		1	25	
Photographic film	25	300000	1	25	300000
CONSUMABLES SUBTOTAL				50	0.30 m^3
COMBINED SUBTOTALS				234 kg	1.31 m^3
25% MARGIN				59 kg	0.33 m^3
TOTAL				293 kg	1.64 m^3

†Tool kit includes sufficient bits and stems to drill ten 3-meter holes.
*Stored in sample return containers during transport to the surface.

Data Rate
Data will not require any data storage/transmittal capability.

Data Management Strategy
TBD.

Operational Constraints
None.

Crew Interaction
Operated by EVA crew. Training and experience as a field geologist will be a necessary prerequisite.

Payload Delivery Options
This payload comes as a single packaged unit, and should not be broken down into smaller components.

Estimated Set-up Time
1 IVA hour, 1 EVA hour.

Maintenance Needs
Inspection, cleaning, repair and replenishment of consumables as needed between EVAs. Battery recharge for rock drill. Estimate <1 hour IVA between EVAs.

Technology Assessment
Most tools were developed for Apollo; a review of designs and operational experience with subsequent changes in design to correct design faults may be necessary. Otherwise, most tools may be considered at Level 13 in NASA's technological readiness scale (see Appendix B). The orientation/inclinometry tool was not developed for Apollo; development should be considered at technology readiness level 1.

Infrastructure Interface Requirements
Rover designs should accommodate tool carriers.
Astronaut support during EVA will require voice and video data links to communications infrastructure.
Rechargeable batteries will require power off of lander/base and power infrastructure.

Resupply Needs
Consumables and replacement batteries as needed on a yearly basis.

Science/Exploration Community Contact
TBD

References
Allton, J. H., 1989, Catalog of Apollo Lunar Surface Geological Sampling Tools and Containers: Johnson Space Center Publication JSC-23454.
Budney, C. I., Ionasescu, R., Snyder, G. C. and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

MARS GEOPHYSICAL/METEOROLOGICAL MONITORING PACKAGE

Date: 8/13/92

PAYLOAD SUMMARY	
Estimated Mass:	**201 kg**
Estimated Volume:	**0.3 m^3**
Estimated Power:	**95 W**
Estimated Data Rate:	**data ranges for individual instruments range from 0.01 kbps to 1 kbps**

Rationale
The Mars Geophysical/Meteorological Monitoring Package contains instruments designed to measure the time-variant values of several geophysical parameters at a range of locations on the Martian surface. This package will provide information on the variation of the Martian magnetic field strength, seismic activity, heat flow, and climate.

Description
The Mars Geophysical/Meteorological Monitoring Package is a collection of geophysical instruments that are designed to measure the temporal variation of a number of geophysical parameters. The package has a pedigree that extends back to the Apollo Lunar Scientific Experiments Package (ALSEP), and the preliminary concept for most of the instrument is based on ALSEP designs.

The concept for production and deployment for this package is that the set of instruments described herein will be deployed at a variety of locations on the Martian surface. Widespread deployment of these packages will allow geophysicians to characterize the interior and climate of Mars in detail, and standardizing the instrument sets insures that the same data set is collected at each location. As in the Apollo program, however, there may be additional instruments that can be deployed on a one-time basis to answer specific geophysical questions. To that end, a placeholder for discretionary principal investigator science is included in the package. This placeholder allows mass-volume-power-data rate planning for the package to be sufficiently robust that additional instrumentation can be added later without perturbing related surface accommodation planning.

As with ALSEP, it is likely that many of these packages will be deployed in locations where regular return for maintenance or component change out is unlikely. Therefore, package and instrument designs will need to be rugged, long lasting and self contained with respect to power and communications capability.

The purpose of each of the instruments is as follows:

Central Station	Controls power conditioning and distribution, processing of all commands controlling experiments, and transmittal of data back to Earth.
Magnetometer	Measures the field strength and direction of Mars' magnetic field with a range of ~0 - $\pm 200\ \gamma$ and a sensitivity of 0.1 γ (based on designs in NASA SP-289, pg. 9-4).

Passive Seismometer	Measures the magnitude and direction to martian seismic events with a sensitivity of ~10^3 to 10^2 Hz with ground motions on the order of 10^{-1} nm (based on designs in NASA SP-289, pg. 8-3).
Heat Flow Probes	Measures the rate of heat flow from the martian interior by temperature and thermal-property measurements in the martian subsurface; sensitivity ranges from ~10^5 to 10^{-3} W/cm-°K and ±0.05 °K (based on designs in NASA SP-289, pp. 11-2–11-3).
Meteorology Sensors	A suite of sensors that continuously measure ambient temperature, atmospheric pressure, wind velocity, humidity and atmospheric opacity
Discretionary PI Science	Placeholder to allow augmentation with additional instruments, based on future experiment designs.

Payload Breakdown

Component	Mass per (kg)	Volume (m^3)	Power (W)	Data Rate (Kb/s)
Central station	25	0.03	25	NA
Magnetometer	10	0.05	10	0.04
Passive Seismometer	15	0.01	10	1
Heat Flow Experiment	10	0.01	5	0.02
Meteorology Sensors	1	0.01	1	0.01
Discretionary PI Science	100	0.1	25	TBS
SUBTOTAL	161	0.21	76	1.07+
25% MARGIN	40	0.05	19	0.27
PAYLOAD TOTAL	201	0.26	95	1.34+

Power Consumption

Power will be supplied to each instrument after conditioning and distribution by the central station. Although ALSEP stations successfully used radioisotope thermal generators for power, some form of advanced solar cell/batter technology may be available now that wasn't available during the Apollo program. Because geophysical packages may be deployed in areas remote from a Mars outpost, the power source selected will have to be maintenance free and provide reliable power for a period of several years without human interaction. Conventional batteries are therefore unlikely to be used.

Planned power consumption on each instrument is as follows:

Central Station	25 W
Magnetometer	10 W
Passive Seismometer	10 W
Heat Flow Experiment	5 W
Meteorology Sensors	5 W
Discretionary PI Science	25 W

Data Rate

Each instrument will have its own data rate; present maximum is planned at 1 Kb/s.

Data Management Strategy
The present configuration calls for data to be processed through a central station, similar to ALSEP designs. Alternatively, it may be possible to provide each instrument with its own data handling and transmission capability. Preliminary design studies should determine the most efficient and feasible method of data handling. Communications satellite infrastructure may be necessary to efficiently transmit data to terrestrial ground stations. Alternatively, the central station may store data in some form, to be dumped periodically when terrestial ground- or space-based communications facilities are above the martian horizon.

Operational Constraints
None.

Crew Interaction
Initial deployment and start-up. Maintenance on those stations close to outposts. Stations deployed at considerable distance may have to be serviced robotically in the event of unscheduled maintenance or repair.

Payload Delivery Options
The payload should be packaged and delivered as a single payload.

Maintenance Needs
These instruments should be designed to operate autonomously without requirements for regular maintenance.

Technology Assessment
Instruments to measure these parameters have been in extensive use both terrestrially and as ALSEP payloads for a significant period of time, suggesting technology readiness level 13. Some development work may be required on power systems if some advanced solar cell/battery power source is desired over radio-isotope thermal generators, suggesting technology readiness level 2.

Infrastructure Interface Requirements
Communication/data links to transmit data to terrestrial stations, including the possible deployment of orbital communications satellites.

Resupply Needs
ALSEP stations were considered expendable; that is, no provision was made for replacement or repair of malfunctioning instruments. Whether these stations are considered expendable as well will depend on the cost of production, and the level of transportation infrastructure on the Martian surface.

Science/Exploration Community Contact
TBD

References

Budney, C. J., Ionasescu, R., Snyder, G. C. and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

Natl. Aeron. Space Admin. (1972), Apollo 15 Preliminary Science Report: NASA SP-289, U. S. Govt. Print. Off., Wash. D.C.

MARS TRAVERSE GEOPHYSICAL PACKAGE

Date: 7/28/92

PAYLOAD SUMMARY	
Estimated Mass:	**401 kg**
Estimated Volume:	**TBD (>0.1 m^3)**
Estimated Power:	**100 W**
Estimated Data Rate:	**data rates for individual experiments ranges up to 1.6 Mbps**

Rationale
The Mars Traverse Geophysical Package contains a variety of experiment packages that will be used by an astronaut crew to determine the subsurface structure of the Mars. These instruments will be deployed as part of a normal traverse operations and will provide successive profiles of the martian subsurface using a variety of measurement parameters.

Description
The Mars Traverse Geophysical Package is a collection of geophysical instruments that are designed to profile the subsurface structure of Mars at a variety of scales and using a number of measurement parameters. The package has a pedigree that extends back to many of the experiments deployed during the Apollo Program.

The concept for deployment of this package is that the set of instruments described herein will be deployed at a variety of locations on the martian surface during geologic traverses. Routine use of these instruments will allow the progressive development of a picture of the subsurface struture in the vicinity of the outpost. Although the complement of instruments planned should cover the variety of potential geophysical techniques, there may be additional instruments that can be deployed to answer specific geophysical questions. To that end, a placeholder for discretionary principal investigator science is included in the package. This placeholder allows mass-volume-power-data rate planning for the package to be sufficiently robust that additional instrumentation can be added later without perturbing related surface accommodation planning.

The purpose and senstitivity of each of the instruments are as follows:

Electromagnetic Sounder	Determination of local structure at various scales; direct detection of water and volatiles; determine the variation in dielectric constant and bulk densities of martian materials; sounding frequencies from 1 to 1,000 Mhz
Active Seismic Experiment	Determine the structure of the subsurface using a combination of geophones and detonation of explosive packages to generate seismic waves in the upper few kilometers of the martian crust
Traverse Gravimeter	Determine the variation in Mars' gravity at selected locations on the martian surface; sensitivity to variations of 0.1 mgal

Electrical Properties Experiment	Determine subsurface structure by detecting variations in electrical current transmitted into the martian crust; direct detection of subsurface water to a depth of 1-2 km
Profiling Magnetometer	Measure the local variation in Mars' magnetic field to 0.5 γ
Discretionary PI Science	Placeholder to allow augmentation with additional instruments, based on future experiment designs.

Power Consumption
Power will be supplied internally to each instrument by means of rechargable batteries. Instruments should be able to go at least 1 month of normal use between charge, which should allow the instrument package to be used on a long pressurized rover traverse without drawing off the internal power of the rover.

Preliminary estimates for power consumption on each instrument is as follows:

Electromagnetic Sounder	10 W
Active Seismic Experiment	10 W
Traverse Gravimeter	10 W
Electrical Properties Experiment	10 W
Profiling Magnetometer	10 W
Discretionary PI Science	25 W

Payload Breakdown

Component	Mass (kg)	Volume (m^3)	Power (W)	Data Rate (Mb/s)
Electromagnetic Sounder	10	0.02	10	1.6
Active Seismic Experiment*	175	0.01	10	1
Traverse Gravimeter	15	0.01	10	
Electrical Properties Experiment	16	0.04	10	
Profiling Magnetometer	5	TBD	10	
Discretionary PI Science	100	0.1	25	
SUBTOTAL	321	0.18	75	2.6
25% MARGIN	80	0.05	19	0.7
TOTAL	401	0.23	94	3.3

*Includes explosive packages for seismic energy source.

Data Rate
Data rate on each instrument will be variable, based on instrument design and the complexity of the signals returned.

Data Management Strategy
Each instrument should store data internally in either a tape cassete, or on a digital disk, to be retrieved later for data reduction.

Operational Constraints
None.

Crew Interaction
Deployment and operation; normal maintenance and repair as necessary.

Payload Delivery Options
The payload should be packaged and delivered as a single payload.

Estimated Set-up Time
These instruments should be operated routinely as part of geology and/or geophysics traverses. Estimates for individual instruments vary. The most labor intensive will be the active seismic experiment, which may take up to several hours to set-up a geophone line. Other packages, such as the traverse gravimeter, should be able to be deployed, operated and then stowed within several minutes. As experiment designs become more mature, time estimates should be determined in order to refine EVA operation planning time.

Maintenance Needs
Routine maintenance as required.

Technology Assessment
Instruments to measure these parameters have been in extensive use both terrestrially and, in some cases, as part of the Apollo Program, suggesting technology readiness level ranging from level 5 to level 13.

Infrastructure Interface Requirements
Data recording should be built into each instrument, so no interface requirements are anticipated.

Resupply Needs
Explosives packages will need to be re-supplied on a regular basis. Also, the data recording medium in each experiment may need resupply, depending on the data volume recorded.

Science/Exploration Community Contact
TBD

References
Budney, C. J., Ionasescu, R., Snyder, G. C. and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

Natl. Aeron. Space Admin. (1972), Apollo 15 Preliminary Science Report: NASA SP-289, U. S. Govt. Print. Off., Wash. D.C.

Natl. Aeron. Space Admin. (1973), Apollo 17 Preliminary Science Report: NASA SP-330, U. S. Govt. Print. Off., Wash. D.C.

GEOSCIENCE LABORATORY INSTRUMENTS

Date: 1/17/92

PAYLOAD SUMMARY

LANDER GEOSCIENCE LABORATORY

Estimated Mass:	**46 kg**
Estimated Volume:	**0.1 m^3**
Estimated Power:	**181 W**
Estimated Data Rate:	**all data stored in lander on appropriate magnetic or optical storage medium; returned to Earth as stored data**

HABITAT GEOSCIENCE LABORATORY

Estimated Mass:	**123 kg**
Estimated Volume:	**0.2 m^3**
Estimated Power:	**396 W**
Estimated Data Rates:	**all data stored in habitat on appropriate magnetic or optical storage medium; returned to Earth as stored data**

Rationale
The volume and mass of samples that will be collected during an extended lander stay on the lunar surface or during establishment of an outpost on either the lunar or Martian surface is likely to be too great to return to Earth. Inclusion of basic laboratory tools for sample analysis allows preliminary investigations of collected samples to take place, and allows "high-grading" of samples and development of suites of samples from a particular traverse, reducing the number of samples to be returned. In addition, sample analysis capability will allow real-time analysis of samples in as close to pristine lunar or Martian conditions as possible.

Description
The instruments for each laboratory set will be built into either the lander or habitat prior to delivery on either the lunar or Martian surface. Each instrument has a specific analysis capability, summarized below:

Instrument	Function
Binocular Microscope	Preliminary, magnified examination of rock and soil samples
Mössbauer Spectrometer	Iron mineralogy (metal and Fe-bearing minerals; soil maturity)
Paleomagnetics magnetometer	Determination of residual rock magnetism
Sample preparation/preservation equipment	Prepare samples for return to Earth
Optical sizing equipment	Grain size analysis
X-ray Fluorescence	Chemical composition
Proton, α-, X-ray spectrometer	Chemical composition
γ-ray spectrometer	Chemical composition
Scanning electron microscope with energy dispersive x-ray analysis	High magnification imaging and chemical composition
Gas chromatograph	Gas analysis
Ferromagnetic resonance spectrometer	Iron metal analysis

PAYLOAD BREAKDOWN

INSTRUMENT	MASS (kg)	POWER (W)	VOLUME (m^3)	BITS/ANALYSIS*
LANDER GEOSCIENCE LABORATORY				
Binocular microscope	5	20	0.01	10 Mb
Mossbauer spectrometer	2	4	0.003	60 kb
Paleomagnetics Magnetometer	10	20	0.02	1 kb
Sample preparation and preservation equipment	20	100	0.05	
SUBTOTAL	37	144	0.08	
25% MARGIN	9	36	0.02	
TOTAL	46	180	0.10	
HABITAT GEOSCIENCE LABORATORY				
Binocular microscope	5	20	0.01	10 Mb
Mossbauer spectrometer	2	4	0.003	60 kb
Paleomagnetics Magnetometer	10	20	0.02	1 kb
Sample preparation and preservation equipment	20	100	0.05	
Optical sizing equipment	2	2	0.002	1 kb
X-ray fluorescence	3	5	0.002	20 kb
Alpha, Proton, X-ray spectrometer	5	30	0.004	320 kb
Scanning electron microscope w/energy dispersive x-ray analysis capability	12	25	0.042	10 Mb
Gas analysis (GCMS)	19	60	0.028	800 kb
Ferromagnetic Reson. Spectrom.	20	50	0.03	50 kb
SUBTOTAL	98	316	0.191	
25% MARGIN	25	79	0.05	
TOTAL	123	395	0.24	

*total data output from each instrument in a single analysis operation.

Power Consumption

Lander geoscience laboratory: 181 W discontinuous
Habitat geoscience laboratory: 396 W discontinuous
All analytical instruments will draw some power in a continuous standby mode; the amount will depend on final instrument design.

Data Rate

The total data output from these instruments depends on the number of samples collected and the number of analyses run per sample. Each instrument should be designed with either an internal data storage capability or the ability to interface with an appropriate data storage device. Although optical storage disks are preferred, due to the large volume of data generated by each analysis, magnetic media can be used as well. It is unlikely that continuous transmission of data to an Earth location would be required; however, it is estimated that data rates of ~100 kbits per second would need to be accommodated. Transmission of processed data would require lower rates.

Operational Constraints
Both sets of instruments operate in a pressurized lander/habitat environment. A vacuum source is required to operate the scanning electron microscope and all spectrometers.

Crew Interactions
These instruments will require a trained crewman to operate, preferably one with a background in geology/geochemistry. Real-time, terrestrially-based assistance is feasible if a communications infrastructure exists to transmit data, but it is not required for normal operations. In addition, at least one crewman should be trained in maintenance and trouble-shooting.

Payload Delivery Options
Each set of instruments will be pre-packaged in a laboratory module or lander prior to launch for the lunar surface. Consequently, payloads may not be broken down into smaller packages.

Estimated Set-up Times
Built into habitat or lander prior to launch

Maintenance Requirements
Periodic maintenance (schedule dependent on instrument design).

Technology Assessment
Working models of all instruments have been constructed, suggesting technology readiness level 4. Some development work adapting the instruments to a lander or habitat will be necessary, based on lander/habitat design.

Infrastructure Interface Requirements
Power to run instrument packages.
Comm/data links if it is necessary to transmit data back to Earth.
Lander laboratory instruments will be an integral part of the lander; therefore, they need to be included in lander design at the begining of the design process.

Resupply Needs
Optical disks or magnetic media, depending on data storage design.

References
Budney, C. J., Ionasescu, R., Snyder, G. C. and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

Morris, R. V., 1992, personal communication.

10-METER DRILL

Date: 8/13/92

PAYLOAD SUMMARY	
Estimated Mass:	**263 kg**
Estimated Volume:	**0.1 m^3**
Estimated Power:	**6120 W (discontinuous)**
Estimated Data Rate:	**NA**

Rationale

A drill of this capability will be a basic research tool for any geological and geotechnical research activities at a lunar or Mars outpost. The 10-meter depth capability should be sufficient to collect a soil core from the surface to the base of the regolith or from crystalline rock units, drill emplacement holes for heat flow or neutron probes, and recover cores that may answer questions on the origin and quantity of volatiles on both planets.

Description

This drill owes its initial pedigree to the Apollo drill, which was limited to drilling in the lunar regolith. The drive unit will be similar to the Apollo drill motor, but has higher power, more torque and improved heat rejection to permit longer operating periods and drilling in consolidated rock units as well as regolith. The unit is designed with a concentric drive so that sections of the drill string can be added and sections of collected core removed from the top of the drill. Bit and string assemblies for two kinds of operations are included: a hollow soil auger capability to take cores of the regolith, and a hardened bit that can take cores through crystalline rock. In each case, the drill should be able to return 10 meters of 2-cm diameter core. Individual drill string segments should be 50-cm long. The drill should be used attached to the back of the rover so as to apply sufficient force (estimated to be ~800 N) to the drill bit during operation. Removal of the drill string and core also may require a significant force. Consequently, a system for removal of the drill string should be developed as part of the drill package.

Payload Breakdown

Component	Mass (kg)	Volume (m^3)	Power (W)
Drill string	4.0	0.2	NA
Sample sleeve	0.1	0.01	0
Drive head	70	0.02	6000
Mount	100	0.03	0
Sample Rack	35	0.03	20
SUBTOTAL	210	0.26	6020
25% MARGIN	53	0.07	1565
TOTAL	263	0.33	7585

Power Consumption

6120 W discontinuous; to reduce the mass of the drill, power should be drawn from the rover power source rather than from integral batteries.

Data Rate

None

Data Management Strategy
None.

Operational Constraints
None.

Crew Interaction
Unpacking, set-up and operation.

Payload Delivery Options
Delivered as a single package; delivery should include drill bits and string as well as drill.

Estimated Set-up Time
10 EVA hours.

Maintenance Needs
Drill bit exchange and replacement; drive unit lubrication as needed.

Technology Assessment
Methods of heat rejection, cuttings removal, soil core retention and basic drill design need to be developed. Estimate Technology Readiness Level 3.

Infrastructure Interface Requirements
Mating and interface with rover designs to provide adequate power and anchoring for drilling and core removal.

Resupply Needs
Drill bits and drill string; initial package includes sufficient drill string to drill ten 10-meter cores.

Science/Exploration Community Contact:
TBD

References

Allton, J. H., 1989, Catalog of Apollo Lunar Surface Geological Sampling Tools and Containers: Johnson Space Center Publication JSC-23454.

Budney, C. J., Ionasescu, R., Snyder, G. C. and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

1-KILOMETER DRILL

Date: 7/21/92

PAYLOAD SUMMARY	
Estimated Mass	**20,000 kg**
Estimated Volume	**200 m^3**
Estimated Power	**500 KW**
Estimated Data Rate	**1 Kb/s**

Rationale
The 1-km Drill will support investigations of lunar materials and their history to depths of the order of one kilometer. It will allow extraction of usable resource materials from these depths and will permit emplacement of down-hole instrumentation for scientific and resource purposes.

Description
This is a partly-automated drill rig similar in concept to Earth-based oil rigs but designed for transport to and use on the Moon. In the expected absence of drilling fluids, the drill bit and string may have to use entirely different technology from that used on Earth. Otherwise conventional but lightweight technology can be used, modified for minimum human operations and EVA demand. Drill string parts must be limited in length (to approximately 20 m each) in order to fit within the transportation system capacity. Therefore assembly and disassembly must be highly automated. Drilling and movement to new hole sites are assumed to be supported by and powered from base systems.

Payload Breakdown

Component	Mass (kg)	Volume (m^3)	Power (kW)	Data Rate (Kb/s)
Drill String	~10,000	100	0	0
Drive Unit	~5,000	10	500	1
Derrick	~5,000	90	0	0
PACKAGE SUBTOTAL	~20,000	200	500	1
25% MARGIN	5000	50	125	0.25
TOTAL	25000	250	625	1.25

Power Consumption
500 kW

Data Rate
1 Kb/s.

Data Management Strategy
TBD

Operational Constraints
Requires monitoring during drilling, probably including drill-bit temperature, depth, and drive-unit power consumption and temperature. Some type of foundation or prepared excavation must exist for erection of derrick. In addition, sufficient anchoring must be provided to keep support stable during drilling operations.

Crew Interaction
Extensive EVA required for setup, breakdown, transport, and re-emplacement. EVA required for examination and selection of extracted cores.

Payload Delivery Options
Delivered (possibly in parts) by large cargo landers. Set up by combination of teleoperations from base and EVA.

Estimated Set-up Time
TBD

Maintenance Needs
Drill bit replacement; drive unit repair and refurbishment; routine inspections; maintenance of power supply and conversion equipment at base to meet drilling demand on shared basis.

Technology Assessment
High mechanical technology will be required throughout because of dry drilling, the strong demand for minimum EVA and best power efficiency, and the difficulty of recovering from stuck, broken, etc. equipment problems. Although the technology exists for terrestrial drilling to this depth, the above uncertainties for operation in the lunar environment give this payload a technology readiness level of 3-4.

Infrastructure Interface Requirements
Drilling and movement to new hole sites are to be supported by and powered from base systems.

Resupply Needs
Drill bits and drill string; initial package includes sufficient drill string to drill one or more 20-cm diameter holes to 1-km depth in lunar mare or polar crater fill materials (depth capability in highland materials is TBD).

Science/Exploration Community Contact
TBD

References

Budney, C. J., Ionasescu, R., Snyder, G. C., and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

Kinney, M. H. and Podnieks, E. R., 1989, Lunar Drill Development Review, PR-T-1241R: U.S. Bureau of Mines, Twin Cities Research Center.

MARS BALLOONS

Date: 7/21/92

PAYLOAD SUMMARY	
Estimated Mass:	**200 kg**
Estimated Volume:	**3.5 m^3**
Estimated Power:	**5 W**
Estimated Data Rate:	**Recorded internally and dumped in bursts to the Orbiter at ~15Kb/s**

Rationale
These balloons would perform close observation of the martian surface and atmospheric phenomena at widely separated sites and would collect geologic, geomorphologic, geochemical, and atmospheric science data. Small balloon payloads provide the possibility of a variety of measurements at and near the martian surface (few km altitude), with flight durations up to a few weeks and flight ranges of thousands of km, depending on winds.

Description
The systems assumed here would be "smart" follow-ons to earlier, uncontrolled systems such as those now in development for the international Mars-94 mission. With automated delivery, the balloon(s) would be inflated during parachute descent. With human-assisted launch, they would be surface launched during calm conditions.

In both the automated-descent and the human-assisted-launch version, the balloon system includes an envelope with a volume of several thousand cubic meters supporting a two-art payload: a meteorology-and-imaging package under the balloon and a surface-instrument package that occasionally contacts the martian surface to make in-situ physical and chemical measurements. The system will measure atmospheric temperature, pressure, humidity, and wind speed. It will perform surface imaging of selected small regions to cm and mm resolution. In addition, through surface contacts, it can perform limited surface chemical analyses, including measurement of near-surface volatiles. Balloon altitude, and hence travel direction and speed, are controlled by on-board "smart" buoyancy control, using the balloon system itself as a probe of temperature and wind profiles. Data are transmitted to Earth and/or to the martian outpost via a relay orbiter.

Power Consumption
5 W for approximately 20 days, supplied by on-board battery.

Data Rate
Data are recorded internally and dumped in bursts to the Orbiter at ~15Kb/s.

Data Management Strategy
Data will be relayed to Earth via a communications orbiter and distributed from a central control station.

Operational Constraints
Automated deorbit at times and places chosen to maximize science yield by selecting target terrains and taking advantage of winds, while minimizing risk, e.g., due to dust storms. Launched by humans at time of zero wind with forecast of rising wind.

Payload Breakdown

Component	Mass (kg)	Volume (m^3)	Power (W)	Data Rate (Kb/s)
Instrumentation				
Meteorology Package	0.2	0.0005	0.5	0.05
Cameras	2	0.001	0.5	10
Surface Sensors	2	0.5	0.003	1
Structure, balloon envelope, data and power systems	TBD	TBD	3.5	TBD
PACKAGE SUBTOTAL	>4.2	>0.5	5	>12*
25% MARGIN	1.05	0.13	1.25	3
TOTAL	>5.25	>0.63	6.25	>15*

*Recorded internally

Crew Interaction
Inflation and launch monitoring for human-assisted launches.

Payload Delivery Options
Automated descent from orbit or human-assisted inflation and launch from surface.

Estimated Set-up Time
TBD

Maintenance Needs
None

Technology Assessment
Balloon technology to be proven in Mars-94 mission. Instrument and "smart" on-board control technology would be new. Thus, the current technology level can be considered to be 1.

Infrastructure Interface Requirements
None

Resupply Needs
None

Science/Exploration Community Contact
TBD

References

Blamont, J., et al., 1989, Martian Aerostats: Planetary Report.

Budney, C. J., Ionasescu, R., Snyder, G. C., and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory Publication JPL D-7955.

A. Mars Science Payloads
3. Space Physics

PARTICLES AND FIELDS CRUISE SCIENCE PACKAGE

Date: 7/24/92

PAYLOAD SUMMARY

Estimated Mass:	**100 kg on main spacecraft** **400 kg as independent spacecraft**
Estimated Volume:	**0.2 m^3 on main spacecraft** **2 m^3 as independent spacecraft**
Estimated Power:	**88 W Average**
Estimated Data Rate:	**10 Kb/s Average** **300 Kb/s Peak**

Rationale

The Particles and Fields Cruise Science Package would form part of the payload on piloted missions to Mars and would take advantage of the science opportunities during the cruise phase and while in Mars orbit. The package could be an integral part of the spacecraft or could be mounted on a detachable probe. The latter option will allow the cruise science instruments to be remote from the main spacecraft in cruise, avoiding electromagnetic contamination and outgassing. The probe also could be left in Mars orbit and communicate with Earth via the main spacecraft. The science package would be used to investigate the environment around the spacecraft and to monitor the solar surface at X-ray wavelengths. Several of the functions of the package would be tailored to provide early warning of solar flares. It is expected that the solar surface also would be monitored from other spacecraft, providing a comprehensive early warning network and allowing an intensive study of solar physics. Investigation of the solar wind and interplanetary magnetic field local to the spacecraft would be a primary science objective.

Description

This payload would provide information on the field and particles environment of interplanetary space and also could supply solar flare warning information to spacecraft crew members. The instrumentation and its functions are as follows:

Magnetometer	Measure interplanetary magnetic field at high resolution and study its structure.
Thermal Plasma Instrument	Measure composition and physical properties of the solar wind.
Energetic Particle Detector	Measure intensity, energy spectrum, and composition of energetic ions and electrons.
Cosmic Ray Detector	Study very high energy particles produced in solar flares and cosmic rays to provide information on radiation hazards.
Plasma Wave Detector	Measure plasma wave electric and magnetic fields in the range 10 Hz to 1 MHz.
Dust Detector	Measure the mass, velocity, and charge on dust particles impacting the instrument to allow determination of interplanetary dust distribution.
X-Ray/Gamma-Ray Instrument	Observe Sun's surface for solar flares and galactic gamma ray bursts.

Payload Breakdown

Component	Mass per (kg)	Volume (m^3)	Power (W)	Data Rate (Kb/s)
Magnetometer	5	TBD	6	1.5
Thermal Plasma Instrument	13	TBD	10	0.5
Energetic Particle Detector	12	TBD	10	1
Cosmic Ray Detector	20	TBD	20	0.5
Plasma Wave Detector	10	TBD	10	<100
Dust Detector	5	TBD	4	0.1
X-ray/Gamma Ray Instrument	10	TBD	10	<200
SUBTOTAL	75	TBD	70	
25% MARGIN	19	TBD	18	
TOTAL	94	0.2	88	Up to 300

Power Consumption
88 W Average.

Data Rate
~10 Kb/s average; ~300 Kb/s peak.

Data Management Strategy
TBD

Operational Constraints
Must be isolated from magnetic fields. Operates continuously during cruise phase.

Crew Interaction
None

Payload Delivery Options
Carried on the exterior of interplanetary transfer vehicles or as a free flyer in association with these vehicles.

Estimated Set-up Time
None

Maintenance Needs
None

Technology Assessment
Significant flight heritage from Ulysses, Galileo, Voyager, EOS, and Giotto exists for all instruments, giving this package a technology readiness level of 13.

Infrastructure Interface Requirements
Carried on exterior of transfer vehicle or flies as a separate spacecraft in communication with main spacecraft.

Resupply Needs
None

Science/Exploration Community Contact
Neil Murphy, Jet Propulsion Laboratory

References
Budney, C. J., Ionasescu, R., Snyder, G. C., and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory publication JPL D-7955.

A. Mars Science Payloads

4. Life Sciences

MARS EXOBIOLOGY PAYLOAD

Date: 7/24/92

PAYLOAD SUMMARY	
Estimated Mass:	51 kg
Estimated Volume:	0.06 m^3
Estimated Power:	155 W Peak
Estimated Data Rate:	1.94 Kb/s

Rationale

Mars could harbor a biosphere because its surface environment resembles Earth's more closely than does any other planet in our solar system. The ancient environments of Earth and Mars probably were even more similar than they are today. The martian regolith therefore harbors a chemical diversity and a historical record whose richness is rivalled only by that of Earth's sedimentary deposits. The Mars Exobiology Payload must not only cope with this chemical complexity but also must be able to detect any evidence of life and/or fossils.

The central task of the Mars Exobiology Payload is to permit the human explorers to elaborate upon the initial exobiological survey begun by robotic missions. Accordingly, a greater variety of surface materials will be examined in a greater range of environments and localities.

Deposits which are aqueous chemical weathering products deserve special attention because these materials have experienced the conditions most suitable for life. The biogenic elements and their oxidized (e.g., CO_3^{2-}, SO_4^{2-}, NO_3^-, PO_4^{3-}) and reduced (e.g., organics, sulfides, etc.) compounds often retain stable isotopic, chemical, or mineralogical evidence of biological activity. Certain transition metals (e.g., Fe and Mn) and their compounds merit study. Clays, zeolites, and other hydrous minerals indicate past or present water activity and perhaps played a role in prebiotic chemical reactions.

The most effective analytical approach coordinates chemical and biochemical analyses of the sample with optical imaging at all size scales from the visual to the microscopic. A key role of this instrument package is to assist in the selection of those particular samples which deserve to be returned to Earth for more comprehensive research.

Description

The Mars Exobiology Payload contains equipment necessary to perform exobiology survey experiments on the martian surface. The equipment is as follows:

Chemical Analysis Package--Surveys for biogenic elements and compounds as well as chemically active compounds relevant to the preservation of biological material. The package contains the following instruments:

Neutron Spectrometer	Neutron scattering analysis for water and organics
Specific Electrode Analyzer	Measures solutes
Thermal/Evolved Gas Analyzer	Detects volatiles and allows general analysis of materials
Mass Spectrometer	Analysis of organics and volatiles

Soil Oxidant Survey Instrument	Chemical detection of oxidants in regolith
Infrared Laser Spectrometer	Analysis of atmospheric trace gases

Biological Analysis Package - Incubates martian soil samples for microorganisms which are then examined by chemical analysis package and microscope.

Imaging Package - Composed of microscopes to allow in-depth inspection of samples.

Optical Microscope	Visual inspection of dust, soil and rock samples, and possible microbes
Electron Microscope	Enhanced imaging and chemical analysis of samples

Sample Collection Bags - For collection and return of samples to Earth.

Payload Breakdown

Component	Mass per (kg)	Volume (m^3)	Power (W)	Data Rate (Kb/s)
Chemical Analysis Package				
Neutron Spectrometer	3	0.00075	3	0.75
Specific Electrode Analyzer	2	0.0015	2	0.1
Thermal/Evolved Gas Analyzer (TA/GC)	1.85	0.0014	14	0.05
Soil Oxidant Survey Instrument	1	0.0005	10	0.05
IR Laser Spectrometer	10	0.005	20	0.075
Mass Spectrometer	6	0.02	8	0.05
Biological Package				
Incubator	1	0.0003	10	0.05
Imaging Package				
Optical Microscope	3	0.002	10	0
Electron Microscope	12.9	0.0129	47	1.1
SUBTOTAL	41	0.045	124	1.55
25% MARGIN	10	0.011	31	0.39
TOTAL	51	0.056	155	1.94

Power Consumption
Approximately 155 W peak power.

Data Rate
Approximately 1.94 Kb/s.

Data Management Strategy
TBD

Operational Constraints
TBD

Crew Interaction
Astronauts required to operate equipment in the field.

Payload Delivery Options
Delivered as standard cargo to the outpost.

Estimated Set-up Time
TBD

Maintenance Needs
Routine maintenance. Sterilization of incubation chamber.

Technology Assessment
All the instrumentation has at least been studied for flight missions. Significant heritage exists for many instruments. This package has a technology readiness level of 9.

Infrastructure Interface Requirements
Assumes some exobiology surveying on precursor missions. Assumes Geologic Field Equipment Package is available to astronauts.

Resupply Needs
TBD

Science/Exploration Community Contact
D. DeVincenzi, NASA Ames Research Center

References

Budney, C. J., Ionasescu, R., Snyder, G. C., and Wallace, R. A. (eds.), 1991, SEI Science Payloads: Descriptions and Delivery Requirements: Jet Propulsion Laboratory publication JPL D-7955.

DeVincenzi, D. L., Marshall, J. R., and Anderson, D. (eds.), 1990, Exobiology on Mars, NASA CP-10055.

BIOMEDICAL LABORATORY I

Date:

PAYLOAD SUMMARY	
Estimated Mass:	2000 kg
Estimated Volume:	50 m^3
Estimated Power:	TBD
Estimated Data Rate:	TBD

Rationale

Description

Power Consumption

Data Rate

Data Management Strategy

Operational Constraints

Crew Interaction

Payload Delivery Options

Estimated Set-up Time

Maintenance Needs

Technology Assessment

Infrastructure Interface Requirements

Resupply Needs

Science/Exploration Community Contact

BIOMEDICAL LABORATORY II

Date:

PAYLOAD SUMMARY	
Estimated Mass:	3000 kg
Estimated Volume:	90 m^3
Estimated Power:	TBD
Estimated Data Rate:	TBD

Rationale

Description

Power Consumption

Data Rate

Data Management Strategy

Operational Constraints

Crew Interaction

Payload Delivery Options

Estimated Set-up Time

Maintenance Needs

Technology Assessment

Infrastructure Interface Requirements

Resupply Needs

Science/Exploration Community Contact

PLANT/ANIMAL LABORATORY I

Date:

PAYLOAD SUMMARY	
Estimated Mass:	2000 kg
Estimated Volume:	65 m^3
Estimated Power:	TBD
Estimated Data Rate:	TBD

Rationale

Description

Power Consumption

Data Rate

Data Management Strategy

Operational Constraints

Crew Interaction

Payload Delivery Options

Estimated Set-up Time

Maintenance Needs

Technology Assessment

Infrastructure Interface Requirements

Resupply Needs

Science/Exploration Community Contact

PLANT/ANIMAL LABORATORY II

Date:

PAYLOAD SUMMARY	
Estimated Mass:	7000 kg
Estimated Volume:	165 m^3
Estimated Power:	TBD
Estimated Data Rate:	TBD

Rationale

Description

Power Consumption

Data Rate

Data Management Strategy

Operational Constraints

Crew Interaction

Payload Delivery Options

Estimated Set-up Time

Maintenance Needs

Technology Assessment

Infrastructure Interface Requirements

Resupply Needs

Science/Exploration Community Contact

Part III: *Applications of Lunar and Mars Science Payloads Catalog*

Appendix A: FIRST LUNAR OUTPOST (FLO) PAYLOADS

First Lunar Outpost Mission Description

The First Lunar Outpost (FLO) is a mission developed by the NASA JSC Exploration Programs Office in 1992-1993. The mission describes the beginning of a human outpost on the Moon which consists of two flights to the Moon, one cargo flight and one piloted flight. The crew remains on the surface for 45 days and then returns to Earth.

The objectives of the mission are to return humans to the Moon in a balanced program of human presence, planetary exploration, and science, laying a pathway for future permanent human presence on the Moon. The mission seeks to enable design and operational experience that will ultimately contribute to Mars exploration.

The FLO science team, headed by David McKay of JSC, selected a complement of science payloads from our unpublished catalog updating JPL's "FY91 Final SEI Science Payloads: Description and Delivery Requirements." The FLO science instruments are listed below. Each of the payloads can be found in this catalog in Part I: The Moon, in the appropriate sections.

First Lunar Outpost Science Payloads

Lunar Geologic Field Equipment Package (Section A-1)
Lunar Geophysical Monitoring Package (Section A-1)
Lunar Traverse Geophysical Package (Section A-1)
Lunar Geoscience Laboratory Equipment (Section A-1)
Lunar Ultraviolet Transit Experiment (Section A-2)
Small Research Telescope (Section A-2)
Solar System Physics Experiment Package (Section A-3)
Small Solar Telescope (Section A-3)
Lunar Robotic Science Rover (Section A-5)
In-Situ Resource Utilization Demonstration Package (Section A-6)

Appendix B: MARS EXPLORATION PROGRAM STUDY PAYLOADS

Mars Exploration Program Study: Mission Description

The Mars Exploration Program Study was undertaken by the Office of Exploration (ExPO) in the summer of 1992. The purpose of the study was to establish a vision for the human exploration of Mars that would serve as a mechanism for understanding program and technical requirements that would be placed on existing and planned NASA programs. In August 1992 the first workshop of the study was held at the Lunar and Planetary Institute to address the whys of Mars exploration (Duke and Budden, 1992.) The attendees identified the major elements of a rationale for a Mars exploration program. Following this ExPO adopted as its technical goal: verify a way that people can inhabit Mars. Derived from this goal are three objectives: (1) conduct human missions to Mars; (2) conduct applied science research to use Mars resources to augment life-sustaining systems; and (3) conduct basic science research to gain new knowledge about the solar system's origin and history. The surface exploration mission envisions approximately equal priority for applied science research (learning about the environment, resources, and operational constraints that would allow humans to eventually inhabit the planet) and basic science research (exploring the planet for insights into the nature of planets, the nature of Mars' atmosphere and its evolution, and the possible past existence of life).

The Mars Exploration mission consists of cargo (including three exploratory rovers) being pre-deployed on the Mars surface on a 2007 launch, followed by three piloted flights during the 2009, 2102 and 2014 opportunities. Science instruments are sent on all four launches.

The three primary science objectives for the Mars reference Mission are to determine

1. Is Mars a home for life—in the past, present, or future?

To answer this question will combine field and laboratory investigations in geology, chemistry, and possibly biology and paleontology. The underlying assumption is that these problems will not have been solved by previous robotic Mars exploration programs, and the optimum manner to solve them is through judicious use of humans on Mars as field geologists and laboratory analysts.

2. What are the origins of the planet Mars and what does it tell us about Earth?

This set of objectives involves geology and geophysics, atmospheric sciences, meteorology and climatology, and chemistry. It will also require iterative sampling of geologic units as well as monitoring of a global network of geophysical/meteorological stations. Elements of any global network would be established by robotic components of the program.

3. What resources are available on Mars?

The location and accessibility of resources on Mars will be determined by the series of robotic missions. To understand the extent and utility of the resources will require the presence of humans. The first missions will require extraction of resources from the atmosphere. Subsequent missions may utilize other resources, including indigenous water if present and accessible. The resource discovery, verification, quantification and quality assessment will require investigations in geology, atmospheric sciences, and chemistry.

The scientific instrumentation to carry out the necessary investigations are listed next.

Mars Exploration Program Study: Science Payloads

The Catalog of Lunar and Mars Science Payloads enables the mission planner to actually manifest the science elements of a mission according to flight (along with other mission elements and equipment). This brings more reality into mission planning because the volumes and masses associated with the payloads must fit within vehicle and launch limitations, i.e., more volume cannot be taken than can physically fit into the space vehicle, or more mass than can be launched into low Earth orbit. To illustrate how this was done, I have shown the Mars Exploration Science payloads here flight by flight as I developed them for the actual Mars Exploration study.

Note that one of the reasons that the Mars mission study was carried out to such detail was so that the cost of this approach could be estimated and compared to other reference missions.

Science Manifest for Mars Exploration Mission

Science Payloads for 2007 Cargo Flight

(3) Robotic Rovers (see note #1)

Science Payloads for 2009 Piloted Flight

Cruise Science (for transit to and from Mars)

- Particles and Fields Cruise Science Package
- Small Solar Telescope
- Astronomy Instruments (TBD)
- Biomedical Instruments (TBD)
- Discretionary P.I. Science (TBD) (see note #2)

Surface Science

- Mars Geologic Field Equipment Package
- Geoscience Laboratory Instruments
- (8) Mars Geophysical/Meteorology Monitoring Package
- Mars Traverse Geophysical Package
- Ten Meter Drill
- Mars Exobiology Payload
- Mars Balloons
- Biomedical Lab I (see note #3)
- Discretionary P.I. Science (TBD)

Science Payloads for 2012 Piloted Flight

Cruise Science (for transit to and from Mars)

- Particles and Fields Cruise Science Package
- Small Solar Telescope
- Astronomy Instruments (TBD)
- Biomedical Instruments (TBD)
- Discretionary P.I. Science (TBD)

Science Payloads for 2012 Piloted Flight (cont.)

Surface Science

Mars Geologic Field Equipment Package
Geoscience Laboratory Instruments
(8) Mars Geophysical/Meteorology Monitoring Package
Mars Traverse Geophysical Package
10 Meter Drill
One Kilometer Drill
Mars Exobiology Payload
Mars Balloons
Biomedical Laboratory II (see note #3)
Plant and Animal Laboratory I (see note #3)
Discretionary P.I. Science (TBD)

Science Payloads for 2014 Piloted Flight

Cruise Science (for transit to and from Mars)

Particles and Fields Cruise Science Package
Small Solar Telescope
Astronomy Instruments (TBD)
Biomedical Instruments (TBD)
Discretionary P.I. Science (TBD)

Surface Science

Mars Geologic Field Equipment Package
Geoscience Laboratory Instruments
(8) Mars Geophysical/Meteorology Monitoring Package
Mars Traverse Geophysical Package
Mars Exobiology Payload
Mars Balloons
Advanced Meteorology Facility (see note #4)
Plant and Animal Laboratory II (see note #2)
Discretionary P.I. Science (TBD)

#1: Use Lunar Science Payloads A-5, Lunar Robotic Science Rover

#2: Discretionary Principal Investigator (P.I.) Science is a placeholder for individual research science experiments that would be competed and awarded to individual P.I.s as the mission could accommodate. For manifesting purposes, the mass for each payload delivery of P.I. science equipment was estimated at 1000 kilograms.

#3: The Life Science payloads have not yet been described, but are listed here as a placeholder for completeness in manifesting the payloads. These payloads include Biomedical Laboratories I and II, and the Plant and Animal Labs I and II.

#4: The Advanced Meteorology Facility is a concept only, and like the Life Sciences payloads, has not been described. It is included as a placeholder for completeness in manifesting the payloads.

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13. ABSTRACT *(Maximum 200 words)*

This catalog collects and describes science payloads considered for future robotic and human exploration missions to the Moon and Mars. The science disciplines included are geosciences, meteorology, space physics, astronomy and astrophysics, life sciences, in-situ resource utilization, and robotic science. Science payload data is helpful for mission scientists and engineers developing reference architectures and detailed descriptions of mission organizations. One early step in advanced planning is formulating the science questions for each mission and identifying the instrumentation required to address these questions. The next critical element is to establish and quantify the supporting infrastructure required to deliver, emplace, operate, and maintain the science experiments with human crews or robots. This requires a comprehensive collection of up-to-date science payload information--hence the birth of this catalog.

Divided into lunar and Mars sections, the catalog describes the physical characteristics of science instruments in terms of mass, volume, power and data requirements, mode of deployment and operation, maintenance needs, and technological readiness. It includes descriptions of science payloads for specific missions that have been studied in the last two years: the Scout Program, the Artemis Program, the First Lunar Outpost, and the Mars Exploration Program.

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