NAS 8-26145 15 MAY 1971 SD 71-477-2

Lunar Base Synthesis Study

FINAL REPORT

VOLUME II
Mission Analysis and Lunar Base Synthesis

Space Division
North American Rockwell

NAS 8-26145

SD 71-477-2

Lunar Base Synthesis Study

FINAL REPORT

VOLUME II

Mission Analysis and Lunar Base Synthesis

15 MAY 1971

APPROVED BY

J.M. MANSFIELD, PROGRAM MANAGER
LUNAR BASE SYNTHESIS

Space Division
North American Rockwell

FOREWORD

The Lunar Base Synthesis Study was conducted by the Space Division of North American Rockwell under Contract NAS8-26145 for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of the Program Development Directorate of the George C. Marshall Space Flight Center.

This document is Volume II, Mission Analysis and Lunar Base Synthesis, which constitutes part of the final report on the study. The following additional documents comprise the entire final report:

Volume I - Executive Summary

Volume III - Shelter Design

Part 1 - Optimized Shelter
Part 2 - Space Station Derivative Shelter
Part 3 - Support Operations and Systems

Volume IV - Cost and Resource Estimates

ACKNOWLEDGMENTS

The Lunar Base Synthesis Study was conducted by the Space Division of North American Rockwell under Contract NAS8-26145 for the George C. Marshall Space Flight Center.

The Study Manager and Contracting Officer Representative (COR) for the National Aeronautics and Space Administration was James B. Brewer of the Program Development Directorate of the George C. Marshall Space Flight Center. Milton A. Page of the same Directorate was the Alternate COR. T. N. V. Karlstrom and R. D. Regan of the United States Geological Survey, Astrogeology Center, provided assistance to the National Aeronautics and Space Administration regarding geological exploration. The Program Manager for the National Aeronautics and Space Administration Headquarters was S. S. DiMaggio of the Manned Space Flight Lunar Exploration Office.

The NR study team was managed by J. M. Mansfield, Advanced Programs. Principal contributors included:

T. J. Dolan, Project Engineer, Mission and Operations Analysis

R. B. Carpenter, Jr., Project Engineer, Configuration and System Analysis

R. G. Johns, Jr., Project Engineer, Cost and Resource Estimates

INTRODUCTION

The objectives of the Lunar Base Synthesis Study were to define and analyze lunar exploration missions in order to establish the role of a semi-permanent lunar surface base (LSB) as an element of an integrated space program, and to prepare conceptual designs for two different lunar surface shelters. One shelter concept was to be optimized for the LSB mission requirements whereas the other represented a potential adaptation of a specified space station module.

The study was oriented towards a lunar surface base which would support a two- to five-year program of scientific and exploration activities in the 1980's by a crew of up to 12 men at any location on the moon which might be selected. The principal program option involved considering the operation of the LSB concurrently with an operational Orbiting Lunar Station (OLS) or without the existence of the OLS. The space station module which was designated as the candidate for adaptation to an LSB shelter configuration was the shuttle-launched Modular Space Station as defined by North American Rockwell, Space Division (NR/SD) under Contract NAS9-9953 for the Manned Spacecraft Center and documented in NR report, SD 70-546-1, January, 1971.

The basic approach adopted for the study involved the identification of scientific and exploration activities appropriate to a single, semi-permanent base on the lunar surface from an examination of the consensus of previous studies of lunar scientific missions. A typical distribution of these activities on the lunar surface was derived from a detailed examination of several potentially desirable areas and operational/design requirements were defined to accomplish the various classes of activities.

The definition of a program encompassing these activities, the associated operational and design requirements, the logistics operational concepts, and the precursor surface and orbit missions comprised study tasks 1 and 2, Mission Analysis and Lunar Base Synthesis, respectively.

A lunar surface base configuration which included a main shelter, major science elements, and surface mobility system elements was conceptually defined. The initial design considered the probable state of the art and the operational and design requirements in arriving at a shelter configuration optimized for the spectrum of lunar surface missions. The subsystem options were identified and tradeoffs performed in arriving at the selected configuration. The potential emergency situations were considered and the implications delineated including a maintenance and repair philosophy. Maintenance, repair and housekeeping functions were described and typical tool requirements identified.

Following the definition of the optimized LSB shelter, a conceptual design of a lunar shelter derived from the specified space station module was developed. The degree of modification required, including specific additions for the lunar mission and environment was identified.

These two conceptual designs and the definition of the characteristics of the mobility concept and its interfaces with the shelter comprised study task 3, Shelter Design.

Cost and resource estimates were prepared for the design and development of each of the shelter configurations and for the science, mobility and power source elements of the LSB program. The shelter development costs were generated utilizing cost estimating relationships from other space programs. Cost estimates for the science, mobility, and power source elements were primarily derived by adjusting prior studies of these elements for the recommended concept modifications and the passage of time. These cost estimates together with program schedules and milestone data comprised task 4, Cost and Resource Estimates.

The study was accomplished and documented in an 11-month period between 15 June 1970 and 15 May 1971. The study results are recorded in four basic volumes. Volume I is an executive summary which briefly outlines the objectives, summarizes the results, conclusions and recommendations; Volume II contains a comprehensive description of the analysis and synthesis results of tasks 1 and 2; Volume III presents the LSB configurations including the conceptual designs of the optimized and derivative shelters which resulted from study task 3; and Volume IV describes the cost estimates derived in task 4.

CONTENTS

ILLUSTRATIONS

PART 1 MISSION ANALYSIS

PART 2 LUNAR BASE SYNTHESIS

TABLES

PART 2 LUNAR BASE SYNTHESIS

ACRONYMS

IVA	Intra-Vehicular Activity, synonomous with shirtsleeve herein
EVA	Extra-Vehicular Activity, in a spacesuit
PLSS	Portable Life Support System, spacesuit backpack
APLSS	Advanced Portable Life Support System
EPS	Electrical Power Subsystem
A&CS	Atmospheric Management and Crew Services
ECLSS	Environmental Control and Life Support Subsystem
LSB	Lunar Surface Base, includes shelter and supporting elements
RAS	Requirement Analysis Sheets
RNS	Reusable Nuclear Shuttle
EOS	Earth Orbit Shuttle
EOSS	Earth Orbital Space Station
MSS	Modular Space Station
CIS	Chemical Inter-orbital Shuttle
JPL	Jet Propulsion Lab
TLI	Translunar Injection
LOI	Lunar Orbit Insertion
TEI	Trans-Earth Injection
EOI	Earth Orbit Insertion
OLS	Orbiting Lunar Station
JD	Julian Date
CS	Cislunar Shuttle
LFV	Lunar Flying Vehicle
MSFN	Manned Space Flight Network
PGA	Pressure Garment Assembly
EMU	Extravehicular Maneuvering Unit
SAS	Space Activity Suit
DRSS	Data Relay Satellite System
RAD	Radiation Absorbed Dose
USGS	Unites States Geological Survey
IITRI	Illinois Institute of Technology Research Institute

1.0 SUMMARY

This volume presents the results of study task 1, Mission Analysis, and study task 2, Lunar Base Synthesis. These tasks culminated in the definition of performance requirements for the Lunar Surface Base including the shelter. These shelter requirements constituted the primary input to study task 3, Shelter Design.

Tasks 1 and 2 encompassed the definition of a wide variety of surface sorties, astronomical equipment, and drilling patterns and depths which would permit observations and measurements directed toward the accomplishment of scientific objectives. These objectives were defined by reference to the previously expressed desires of the scientific community and considered the accomplishment of the Apollo missions. It was assumed that there would be no intervening manned U. S. lunar surface activity until the era of the LSB beginning in the early 1980's.

Concurrent development and operation of earth-orbit shuttles and tugs, cislunar shuttles, and lunar landing tugs was assumed. The influences of a concurrent Orbiting Lunar Station (OLS) were also examined.

In addition, the following guidelines from the contract statement of work were observed:

1. Normal crew complement at a base will be not less than three and not more than twelve men.

2. Shelters associated with different base concepts must be capable of autonomous operation.

3. A lunar surface base must be capable of continuous operation with a full crew for 180 days without resupply.

4. Shelter subsystems must be designed for a lifetime of at least two years; a five-year lifetime is a design goal.

5. The environmental model to be used is contained in the document "Space Environment Criteria Guidelines for Use in Space Vehicle Development," NASA TM X-53798, dated October 31, 1968, or the latest revision thereof.

6. Part of the materials selection criteria to be used in this study are specified in the following documents:

a. "Procedures and Requirements for the Flammability and Offgassing Evaluation of Manned Spacecraft Nonmetallic Materials," NASA Report D-NA-0002, July 1968.

b. "Nonmetallic Materials Design Guidelines and Test Data Handbook," MSC-NA-D-68-1, Revision C, dated February 28, 1969.

7. Radiation protection must be provided to assure that the probability of not exceeding 200 rad to the skin or 100 rad to the blood-forming organs during a crew cycle is at least 0.99.

8. Consideration will be given to the use of lunar soil for radiation shielding and meteoroid protection.

9. The lunar base may be located at any lunar latitude or longitude. The lunar base may be located on the back side of the moon.

2.0 LUNAR PROGRAM OBJECTIVES

The exploration and exploitation of the moon for scientific purposes have been studied extensively during the past ten years, spurred by the prospect and realization of lunar landings. These studies each reflect a consensus of opinion on the objectives of a lunar program but variations occur. These variations are not evident in qualitative terms because most sources agree on the overall goals and objectives of the lunar program. However, significant differences appear when one compares quantitative observation requirements. These differences are of primary importance in the derivation of an LSB where mission parameters and system capabilities that support the science program must be established.

The terms defined below are used throughout the report and indicate the progressive quantitizing of LSB support requirements that evolves in the top-down approach of defining a lunar science program.

Objective	Top-level program goal stated in terms that are independent of specific implementation schemes or disciplinary specialty
Subobjective	A discipline-oriented data requirement expressed in qualitative terms arising from program objectives
Observation requirement (or measurement requirement)	A semiquantitative data requirement relating to a specific phenomenon to be investigated
Experiment	A description of the activities required to obtain data in support of one or more observation requirements
Instrument	The hardware (sensor plus support equipment) required to conduct the experiment
Support requirements	The requirements placed upon the mission, vehicle, and subsystems by the instrument

The lunar program exploration and exploitation objectives are:

1. Improve our understanding of the solar system and its origin through determination of the physical and chemical nature of the moon and its environment.

2. Compare the earth and moon, thereby better understanding the dynamic natural processes that shaped the earth and led to our present environment, including the development of life.

3. Evaluate the natural resources of the moon and utilize its unique environment for scientific research and technological processes.

4. Evaluate and extend man's capability in space and his ability to explore other planetary bodies.

These objectives have been selected to be both all-inclusive and consistent with the definition presented above. Candidate objectives that appear in many data sources but were not included here generally failed to be sufficiently top-level or programmatic in nature, or were too closely tied to a single discipline such as: "Obtain topographic maps of the entire lunar surface" or "Establish a lunar surface observatory". These and others are covered at lower, more detailed, levels of program definition.

The first of our selected objectives expresses perhaps the most fundamental objective, in that improving our understanding of the solar system and its origin is the fundamental goal of all space research and much ground-based research as well.

The moon provides us with another planetological data point--conditions and processes there have apparently been quite different from those on earth. What can we learn from studying the moon which can provide us with greater insight concerning our own planet's evolution?

Clearly, if useful natural resources can be found (particularly water) and efficiently extracted, this would result in an enhanced capability to exploit and eventually colonize the moon. The moon possesses resources that we already know could be scientifically useful: little or no atmosphere, exposure to the interplanetary particle and field environment, little or no intrinsic magnetic field, reduced gravitation, slow earth-synchronous rotation, low levels of seismic disturbance, and no detectable radio noise output.

It can be argued that the last of the previously listed objectives is not purely scientific. It is included to cover, for example, those investigations in aerospace medicine aimed at determining man's reaction to the unique combination of effects found in the lunar environment and casting the role of the earth's environment in the proper light. Do the effects of the lunar environment on man and other living systems make it less or more likely that life exists elsewhere? Can we expect to be able to successfully explore other planets? These are the questions which the LSB can help to answer.

2.1 DISCIPLINARY SUBOBJECTIVES AND OBSERVATION REQUIREMENTS

In this section, the subobjectives and observation requirements are synthesized from standard data sources, condensed to eliminate redundancy, and evaluated including consideration of projected Apollo accomplishments to arrive at an NR-recommended set for the overall lunar program (experiments, instruments, and scientific support requirements are derived in the next section).

2.1.1 Disciplinary Subobjectives

The disciplines for which subobjectives and observation requirements have been defined are as follows (with abbreviations used in this report in parentheses):

Astronomy (AY)
Geology/Geochemistry (GG)
Geophysics (GP)
Bioscience (BI)
Aerospace Medicine (AM)
Lunar Atmosphere (LA)
Particles and Fields (PF)
Geodesy/Cartography (GC)
Engineering, Technology, and Operations (ET)

Subobjectives are grouped by scientific discipline and indicated in Table 2.1-1. Those lunar program subobjectives that will be directly supported by the LSB are indicated by asterisks in the table.

The assignment of subobjectives and observation requirements to disciplines is somewhat arbitrary and some overlap is unavoidable. For example, the determination of the detailed gravitational field of the moon could just as easily be categorized under geodesy/cartography or geophysics. In this case, the geodesy/cartography discipline was restricted to observation requirements relating to map-making and establishing the required controls; gravity measurements were assigned to geophysics. Considerable overlap also exists between particles and fields and astronomy--direct measurements of particle fluxes, energies, etc., were assigned to particles and fields, whereas indirect measurements such as the determination of the electron density in cislunar space by radio techniques were assigned to astronomy.

Table 2.1-1. Disciplinary Subobjectives

Astronomy (AY)	
*AY-1	Investigate weak extended and discrete celestial X-ray sources
AY-2	Investigate celestial gamma ray background and flux anisotropics
*AY-3	Perform radio and optical observations of weak and/or earth obscured galactic and extragalactic sources
*AY-4	Determine lunar surface and near-surface electrical properties
*AY-5	Investigate properties of the cislunar medium
*AY-6	Perform high-resolution radio and optical observations of solar system sources
Geology/Geochemistry (GG)	
*GG-1	Determine the type, form, structure, distribution, and relative age of lunar surface features
*GG-2	Determine the physical, mineralogical, and chemical properties of lunar materials
*GG-3	Deduce the nature and relative importance of dynamic natural processes on the lunar surface
*GG-4	Study the effects of ancient or long-term geologic processes
*GG-5	Compile a geochronology of lunar events from the early stage of formation to the present day
*GG-6	Construct geologic maps of the lunar surface, delineating lithologic contacts, tectonic structures, physiographic, and petrographic provinces
*GG-7	Determine the nature of morphologic differences between the near- and far-side of the moon
*GG-8	Locate geologically favorable sites for advanced lunar exploration/exploitation scientific facilities
Geophysics (GP)	
*GP-1	Determine the mass distribution and figure of the moon
*GP-2	Determine the physical state and composition of the lunar interior
*GP-3	Evaluate the internal dynamics (heat flow, circulation, creep, etc.) of the moon
*GP-4	Determine earth-moon mechanical interactions
Bioscience (BI)	
*BI-1	Determine the existence of viable life forms or dormant spores
*BI-2	Evaluate the lunar environment for survival of terrestrial microorganisms and the amount of forward/backward contamination
*BI-3	Determine effect of lunar environment on the behavior and rhythms of plants and animals
*BI-4	Determine genetic effects of lunar conditions and earth/moon trips on plants and microorganisms
Aerospace Medicine (AM)	
*AM-1	Determine the effect of the reduced magnetism on the body rhythms
*AM-2	Determine the effect of the reduced lunar gravity on man
*AM-3	Determine the effect of the combined isolation and modified gravity and atmosphere on man's psychological health
*AM-4	Verify the effect of the lack of atmosphere on man's vision

Table 2.1-1. Disciplinary Subobjectives (Continued)

Lunar Atmosphere (LA)	
*LA-1	Determine the total quantity and distribution of the component species of the lunar atmosphere
*LA-2	Determine the principal natural atmospheric sources, loss and transport mechanisms, and their rates
*LA-3	Monitor atmospheric contamination resulting from lunar missions, including transport and escape rates
Particles and Fields (PF)	
*PF-1	Study the interaction of the solar wind with the moon
*PF-2	Study the fundamental physics of plasma interactions
*PF-3	Determine the magnetic and electric fields around, on, and within the moon as modified by the relative positions of the earth and sun
*PF-4	Measure the primary and secondary nuclear particles in lunar space and at the surface of the moon
Geodesy/Cartography (GC)	
*GC-1	Establish a three-dimensional geodetic control system over the entire lunar surface in terms of latitude, longitude, and height above the chosen reference figure
*GC-2	Collect photogrammetric data and construct topographic maps for scientific purposes, sortie, and base site evaluation studies
Engineering, Technology, and Operations (ET)	
*ET-1	Support the scientific exploration of planets
*ET-2	Verify performance of a long-duration life support system
*ET-3	Determine effects of long-duration exposure of equipment and materials to the lunar environment
*ET-4	Support the extraction of water and oxygen from lunar materials
ET-5	Support the processing and storage of propellants
*ET-6	Support the deployment and assembly of large structures on the lunar surface
*ET-7	Support the utilization of lunar materials for environmental and structural support purposes

2.1.2 Observation Requirements

Observation requirements are specified in varying degrees of quantitativeness. The more descriptive disciplines, such as geology, bioscience, and aerospace medicine, tend to have their observation requirements specified more qualitatively than geophysics or astronomy. Additionally, coverage of the various disciplines by the standard references varies in depth, with less stress on the life sciences than on physical sciences. The general format utilized in the following lists the subobjectives and the rationale for their selection. Then the observation requirements for each subobjective as described in the standard references are summarized and a consensus opinion is described. In those cases where no constructive purpose would be served by comparing recommended observation requirements, only a consensus requirement is shown. Finally, any contributions from the Apollo missions is indicated and the remaining effort after Apollo shown.

Astronomy

Subobjectives

- AY-1 Investigate weak extended and discrete celestial X-ray sources
- AY-2 Investigate celestial gamma ray background and flux anisotropies
- AY-3 Perform radio and optical observations of weak and/or earth-obscured galactic and extragalactic sources
- AY-4 Determine lunar surface and near-surface electrical properties
- AY-5 Investigate properties of the cislunar medium
- AY-6 Perform high-resolution radio and optical observations of solar system sources

Rationale for Selection

Astronomical observations from earth and earth-orbital satellites have made significant contributions to our knowledge of the solar system, the galaxy, and the universe. In particular, radio astronomy, a comparatively new science, has permitted great advancements to be made in understanding the earth and its environment through ionospheric sounding, radar propagation through the earth's magnetosphere and whistler investigations. The availability of the moon as a base for studying the earth from the outside, the opportunity to study the local solar plasma without earth magnetosphere interference, and the capability to extend the frequency range of radio astronomy investigations will provide an even greater increase of our knowledge of the solar system and the universe. The moon has special advantages for more advanced programs than earth or earth orbit programs; these include large accessible stable areas for long continuous exposures with interferometers and large telescopes, shielding and removal from earth-based interference associated with other large-scale physical experiments, and travel through positions completely free of the magnetosphere. A unique advantage is offered by the ability to study closely the lunar environment per se. An important consideration is the fact that the moon may eventually be the best if not the only suitable base for flexible, precision astronomy over a wide unobstructed frequency spectrum.

The deletion here of some portions of the spectrum, in particular millimeter astronomy and ultraviolet and high-energy gamma rays, results from the promise of future artificial earth satellites. Although atmospheric absorption from earth-based stations in the millimeter region of the spectrum is a nuisance, expected advances in technology will probably eliminate this as a serious problem in the post-Apollo era.

The present and expected earth-orbital astronomy satellite programs are continuing to provide valuable data. These programs and the lunar programs should be highly complementary, particularly for subobjectives AY-3, AY-5, and AY-6.

Observation Requirements

AY-1 - Investigate Weak Extended and Discrete Celestial X-ray Sources

Santa Cruz.

X-rays in the energy band of 1 to 20 keve - Measure intensity distribution as a function of angle - $15^o \times 60^o$ field-of-view collimator

Energy range of 20 to 100 kev - $15^o \times 60^o$ field of view

Falmouth. X-ray - subtended angle 0.5 second of arch, which is equivalent to an occultation angle being covered in two seconds of time. Occultation on the surface observing X-ray sources using the rim of a large crater.

NAS. Precise angular determination (< 1 minute) of X-ray sources. Perform search for weaker discrete sources.

NASA Astronomy Mission Board.

X-rays E < 15 kev

Provide surveys 1 - 8 kev region with 0.5 degree resolution (possible 0.1 degree)

Broadband energy resolution

X-ray imaging telescope
Positions to 1 arc-second

Wavelength to $\frac{\Delta \lambda}{\lambda} = 0.01$

Interchangeable instruments are at focus to provide image detectors, polarization measurements, special studies.

NASA S&T Advisory Committee for Manned Space Flight. Special-purpose less extensive arrays would be useful on the moon for X-ray astronomy to yield finer position determination using the lunar horizon as an occulting edge.

Energy range = 2 to 10 kev

Consensus. The energy band is from 1 to 10 kev. The lunar surface (for example, the rim of a large crater) is utilized as the occulting edge to perform a search for these weak discrete sources. Resolution is at possibly 0.1 degree. X-ray imaging telescope to yield position accuracies of 0.5 arc-second.

No reference states that X-ray observations should be made from lunar orbit. The lunar surface based program for X-ray observation is more promising, particularly near the lunar equator. The reasons for a lunar based program in X-ray astronomy are the availability of an extremely stable platform and very long exposure times and the occulting edges of the horizon and craters.

Apollo Accomplishments. None of the planned Apollo era experiments contribute significantly to this subobjective.

Remaining Requirements. Same as consensus.

AY-2 - Investigate Celestial Gamma Ray Background and Flux Anisotropies

Santa Cruz. Omnidirectional measurements for the gamma ray energy region of 0.1 to 10 Mev. Integration time of about one second.

Directional measurements for gamma ray observation greater than 50 Mev. Observation will be made to detect the electron-position pair produced by a gamma ray photon conversion in a crystal. Rotation through 180 degrees from zenith to nadir in six steps to measure angular distribution of the background radiation.

NAS. Directional and spectral characteristics in the 1 Mev region and $>$ 100 Mev.

NASA Astronomy Mission Board. Extend the energy spectrum of the background radiation to energies above 1 Mev. From 1 Mev to 10.0 Mev.

Study the energy spectrum and departures from isotropy in order to separate galactic and extragalactic components and to determine their production mechanisms.

Study background radiation with angular resolution of 1 degree to separate background from weak sources and a true diffuse background. Study nuclear transition gamma rays coming from supernova remnants or other gaseous region to determine if the high gamma rays are diffuse or discrete.

Sensitivities of discrete sources should be 10^{-6} to 10^{-7} photons/cm^2/sec, and angular resolution equal to 0.5 degree. Observations require pointing to within 2 degrees for days. High energy gamma ray detectors best suited for semi-automatic to automatic operation.

Consensus. No reference states that gamma ray observations are needed from lunar orbit. No requirement for lunar surface to be used for gamma ray astronomy.

Balloon and low earth orbit satellites fulfill the astronomical observatory site requirements better in the gamma ray region because of the reduced background radiation as compared to that resulting from lunar surface backscattering and the natural lunar radiation background. Also, the high energy gamma rays are observable from earth orbit as well as from lunar orbit. Therefore, this subobjective is deleted from any further consideration.

AY-3 - Perform Radio and Optical Observations of Weak and/or Earth-Obscured Galactic and Extragalactic Sources

Santa Cruz. Measurement of ambient noise levels and position, intensity and motion of sporadic radio signals. Frequency range, 500 kHz - 15 MHz.

NASA Astronomy Mission Board. Measure flux densities of 50 to 100 extragalactic and galactic sources at a number of frequencies around 1 MHz. In the area of self-absorption and plasma effects, map the cosmic background noise level of the entire sky from 0.5 to 10 MHz to yield information on the distribution of free electrons in the galaxy and later the extragalactic component. This would determine the large scale structure of the universe.

Measure brightness distribution across radio sources which are occulted by the moon. Obtain angular information as well as spectral descriptions which relate directly to the mechanisms of radio emission.

NASA S&T Advisory Committee for Manned Space Flight. Long wavelength radio astronomy could use the moon as a support for extremely large-filled-aperture radio telescope many kilometers in extent.

Millimeter astronomy - Very large fixed dish with a movable feed and operated only during lunar night.

North American Rockwell (SID 66-381). Measurements of certain galactic and extragalactic sources utilizing directive elements. These measurements include low-frequency spectra of supernova remnants, gaseous nebulae, and extragalactic radio sources and determination of the spatial distribution of hydrogen clouds in the galactic medium and determination of the energy spectrum and density of relativistic electrons emitting by the synchroton process with the assumed galactic halo. Frequency region from 300 kHz to 20 MHz.

Measurements of the scintillation of quasistellar radio sources and Jupiter radiation to infer the structure of the interplanetary medium. Galactic radiation at frequencies near the interplanetary plasma frequency to determine the medium, including the spatial and temporal variations injected into it by the sun and earth.

The frequency range confined to the interplanetary plasma frequency. Also, 21-cm radiation from neutral hydrogen.

Directivity is very important (less than 1 degree) and can be accomplished with occultation. Wide bandwidth phenomena predominate which implies no need to adapt bandwidth or to sweep frequencies. Both the front and backside of the moon used for sites.

Optical Astronomy. The projected (optimistic) capability in earth orbit for achieving attitude stability (0.1 arc-sec) can support diffraction-limited performance from a 1 meter diameter optical telescope. The moon provides a much more stable platform with additional advantages of a very dark sky and long (2 weeks) lunar nights (exposures could be indefinite at the poles). Additional sites could be used to permit several concurrent exposures.

Consensus. Radio astronomical observations covering the frequency range of 300 kHz to 15 MHz to a high degree of angular resolution (1 degree). One antenna array with an operating bandwidth from 300 to 1000 kHz. Another antenna system covering the range from 1.0 MHz to 15 MHz which would correlate with earth observations. The angular extent bounds should be 2 π steradians with the angular position known to appromixately one degree. The polarization sensed could be right- or left-hand or circular polarization.

These measurements made from the lunar surface at one or more sites, with the possibility of one site on the far side of the moon. The measurements will include flux densities of galactic and extragalactic sources. These sources are supernova remnants, quasistellar radio sources, gaseous nebulae, hydrogen clouds in the galaxy, and relativistic electrons emitted by the synchroton process from the assumed galactic halo. The parameters to be measured include angular position, angular extent, intensity, polarization (both degree and sense), and temporal variation.

Initial telescopes (12-inch) could be positioned for environmental effects on the surface and with favorable results could be extended to 60 inches or more. Optical astronomy on the lunar surface has the advantage of minimum background light and noise for faint signal discrimination. The moon's surface relieves the earth orbit or lunar orbit difficulties of deployment, storing, and stabilizing the large structures and antenna arrays (kilometers) required to obtain adequate resolution for the study of galactic and extragalactic sources.

Apollo Accomplishments. None of the planned Apollo era experiments contribute significantly to this objective.

Remaining Requirements. Same as consensus.

AY-4 - Determine Lunar Surface and Near-Surface Electrical Properties

Santa Cruz. Measure the complex impedance of an antenna in the vicinity of the lunar surface as a function of frequency and height above the lunar surface up to heights of six feet. Frequency range will be 50 kHz to 10 MHz. Measure the local ionosphere and/or photoemission clouds.

Falmouth. Measure the conductivity and dielectric constant of the lunar soil at frequencies on the order of 10 MHz. After the cosmic noise and impedance properties have been determined, the electron density in the lunar environment could be determined, but at lower frequencies.

IITRI. Obtain measurements concerning the subsurface structure.

North American Rockwell (SID 66-381). Basic investigations include a spectral noise survey, spatial variation of plasma cutoff frequency, collision frequency, electron gyro frequency, particle velocity, and flux measurements.

The observables are the constituents of the solar wind, lunar ionosphere, and the earth's magnetic tail. Their interactions and separate characteristics can be determined through a careful choice of the observation times and locations of the surface or orbital station.

The noise survey defining the gross characteristics of the local plasma environment. The upper frequency is determined by the lunar plasma frequency, ~ 200 kHz, and the lower frequency is determined by proton resonance effects, ~ 0.1 Hz.

After the noise is located, the problem is to determine intensity, source (which source is predominant--local noise or extralunar noise), and in what form the noise exists (traveling electromagnetic wave, an induction magnetic field), and in what direction. If the extralunar noise is greater than the lunar noise, then a swept receiver could sweep the range of cutoff frequencies. If the extralunar noise is equal to the lunar noise, then a lunar orbiter could carry a swept frequency beacon with the receiver on the lunar surface. If the lunar noise is greater than the extralunar noise, the lunar orbiter could carry a swept frequency beacon alongside the receiver. Wave polarization measurements could be made to determine the direction of arrival. Measurement of the magnetic field strength, magnitude, and direction as a function of time and position could be made at frequencies between 0.01 and 10 Hz (see Particles and Fields discipline). Ionospheric measurements could be made by receiving extralunar noise signals at a frequency above the plasma cutoff frequency (30 kHz). The degree of absorption of waves passing through an ionized medium yields information on the collision frequency of the ions and electrons in the ionosphere.

The signal intensity varies exponentially with the distance and with the attenuation factor which, in turn, is a function of the electron density, magnetic field, and collision frequency. The measurement could be made on a single frequency with an expansion to a multifrequency measurement and then to a multistation setup.

An electron-density profile of the lunar environment could be determined. Transmitted signals less than the plasma cutoff frequency could be swept over the expected range to measure height as a function of frequency.

Supplemental measurements can be made on the amount of dust particles (charged or neutral) that accumulate on or near the surface of the antenna. There are additional advantages in lunar surface communications--optimum frequencies can be determined for communications between stations and between stations and an orbiting station within line of sight and beyond line of sight.

Consensus. The lower frequency is determined by proton resonance effects, ~ 0.1 Hz, and the upper frequency is determined by the lunar plasma frequency, slightly above ~ 300 kHz. Therefore, the frequency region of interest will be 0.1 Hz to 300 kHz.

Measurement of the complex impedance of an antenna (whips, dipoles, wires) in the vicinity of the lunar surface over the frequency range of 10 Hz to 10 MHz will provide data on the subsurface material (permittivity, conductivity, and depth of penetration) and on the near-surface plasma (electron density and conductivity).

Detection of any lunar plasma or ionospheres near and above the surface and measurement of the electrical potential versus time and the electric field gradient above the surface up to 10 meters. Measurements of naturally occurring electromagnetic signals in the frequency range 10.0 Hz to 300 kHz and detection of signals (low-frequency plasma waves) in the frequency range of 0.1 to 10 Hz.

A surface radio wave propagation experiment over the lunar surface for distances of 10 to 1000 kilometers. Several broad frequency bands from 1 kHz to 30 MHz could be used.

Measurements of the moon's electromagnetic environment. Fundamental lunar plasma parameters include plasma cutoff frequencies, local plasma frequencies and electron densities which can be measured as a function of time and position. Also, waves that originate inside the local plasma should be sensed for magnitude, frequency spectra, direction-of-arrival, and polarization. Measurements of extralunar noise at frequencies near the local plasma frequency. The observables will be the constituents of the solar wind, lunar ionosphere, and earth's magnetic tail and their interactions. Their interactions and separate characteristics can be determined through a careful choice of frequencies, observation times, and location of the surface stations along with coordinated observations from satellite and earth-based observations.

Apollo Accomplishments. Static magnetic field measurements; static electrical field measurements (± 0.2 to 500 V/m, uncertainty ± 2 percent or ± 10 V/m); multifrequency radiometer -50 kHz to 50 MHz to study background.

Remaining Requirements. Same as consensus.

AY-5 - Investigate Properties of the Cislunar Medium

Falmouth. Utilize a radio transponder (CW or pulse). Utilize an optical corner reflector.

North American Rockwell (SID 66-381). Investigations of the cislunar wave propagation environment (electron density) include an explicit description of the propagation properties of cislunar space and the direct geometric measurement of the earth-moon system and its absolute dimension and their temporal and spatial variations.

The measurements to be performed by a transponder system include (1) more sensitive and precise measurements to explore the cislunar medium (both average and time-varying shapes and densities), the earth's ionosphere, the earth's magnetosphere, the sheath between the magnetospheric boundary and the bow shock formed by the solar wind, magnetospheric wake of the earth, interplanetary medium, and possible shock and wake around the moon; and (2) precise measurements of range and range rate ($\pm$ 0.3 meters).

A number of parameters that are affected by the wave propagation characteristics of the cislunar media are phase path (delay or advance), group path (delay or advance), phase change, frequency change, Faraday (polarization) rotation, attenuation (absorption), refraction angle of wave, and differential absorption.

The lunar-based system would receive earth-based transmitted signals (50 MHz, 400 MHz, 2300 MHz and, possibly 5000 MHz and 10,000 MHz) and retransmit them after a harmonically related translation in frequency (51 MHz, 408 MHz, and 2340 MHz). The frequencies are chosen so that the low frequency is low enough to show effects of planetary electrons but high enough so that refractive effects of the ionosphere are not applicable. The 200 to 300 MHz region is in the passband of the deep space net antenna feeds and is not affected by ionospheric refraction. Beamwidths of 7.5 degrees in the plane of its naroow dimension are needed to retain the earth within its half power points. The Doppler shift and rotation of the plane of polarization is determined from the carrier frequency. These measurements can be made (0.1 degree or better) continuously. The integrated electron density should be measured to an accuracy of one percent. To resolve range ambiguities, a number of modulation frequencies will be required at each carrier frequency depending upon the accuracy to which the lunar range and its variation is known. All data analysis and interpretation will be performed on earth.

VLF and LF measurements could be made between lunar surface and an earth orbiter to obtain phase and group path measurements. These frequencies would be above the ambient plasma frequency. The advantage for substituting a high satellite for a station on the earth's surface is two-fold. The effects of the ionosphere and inner magnetosphere are largely eliminated when earth, satellite, and moon are in line, and a much lower frequency can be used that increases the sensitivity of the experiment.

Consensus. The parameters that are effected by the wave propagation through the cislunar media are phase path (a delay or advance), group path (a delay or advance), phase change, frequency change, Faraday (polarization) rotation, attenuation (absorption), refraction of wave, and differential absorption. The measurement of the total cislunar integrated electron density (accuracy, 1 percent) by the continuous wave dispersion technique should have accuracy of 2×10^{-2} cycles. Also, the extramagnetospheric integrated electron density accuracy is 1 percent utilizing Faraday rotation. The continuous wave dispersion technique should have an accuracy of 5 percent. To determine the range rate (integration time, 10 seconds), the Doppler frequency shift (accuracy of 3×10^{-3} cycles) should be measured (corrected for plasma-induced frequency shifts). The earth-lunar range (accuracy of $\pm$ 30 cm) can be determined by group-path delay and phase-path advance techniques (an accuracy of 1×10^{-2} percent). Beamwidth and gain of HVF equipment 46 degrees and 10 db, respectively, and 30 degrees and 15 db for the higher frequencies (L- and S-band).

Measurement of the cislunar medium includes those of electron densities in the magnetospheric and extramagnetospheric region, and the measurement of the range to the moon and accompanying range rate. The Doppler radar technique used for the range rate, a cislunar ranging technique for absolute range, continuous wave dispersion technique for total cislunar integrated electron density, and a Faraday rotation technique to determine the magnetospheric electron density.

Apollo Accomplishments. Good coverage at S-band frequency on communication channel; ruby laser reflector in conjunction with MacDonald Observatory obtained earth-moon distance to $\pm$ 0.3 meter, $\pm$ 0.15 meter accuracy expected later in program.

Remaining Requirements. More than one site for the transponder con-configuration (three or more) is required, in addition to measurements described in consensus.

AY-6 - Perform High-Resolution Radio and Optical Observations of Solar System Sources

North American Rockwell (SID 66-381). The radio emission is monitored from discrete sources in the time domain. Jupiter decameter burst and solar meter-wave burst are of importance plus searches for low frequency emissions from other objects in the solar system. The frequency range will be from 300 kHz to 20 MHz. The investigations will cover a wide variety of temporal singals from the sun, Jupiter, earth, and possibly other planets at low frequency. The useful investigation will include the time occurrence, details of time variations, the dynamic spectra and polarization, all measured with low directivity (5 degrees). The narrow-band phenomena will predominate. Observations of the sun, Jupiter, and the background will be made at 10 to 20 MHz. Phase-switching can be incorporated to eliminate the dc background. The advantages of using the moon as a radio astronomy base is the moon's stable position and attitude, a large rigid base area, a large mass for shielding earth, location outside the magnetosphere, and man's capability for checkout and modification.

The investigations particularly slanted toward the sun are the slowly varying component, which comes and goes with sunspots, burst activities at millimeter wavelength and at low frequencies including the time-dependence and spectral and spatial characteristics and occultations of radio stars by the corona.

Santa Cruz.

Nonsolar optical astronomy

Wide field photometry of sky brightness (1-degree resolution)

Map sky brightness near the sun after sunset and before sunrise to one-arc-minute resolution

Obtain coronagrams of the sun

Jupiter - high resolution imagery of near polar object at 100-kilometer resolution

NAS.

Jupiter bursts below 10 MHz

NASA S&T Advisory Committee for Manned Space Flight. The moon used as a solid base for an optical interferometer. The Starlight Deflection Experiment will study the outer corona and optical nonsolar astronomy. Infrared astronomy used to study outer layers of the sun, especially the corona.

The planetary atmospheres analyzed to determine the chemical compositions and heat balance.

NASA Astronomy Mission Board. For frequencies from 5 MHz to 500 MHz, the far side of the moon is recommended in order to block out interference from earth.

Dynamic radio phenomena, location of strong sources, including variable sources at low frequencies as well as at high frequencies. Permanence of a baseline makes radio direction finding easier. Baselines with distances of 50 to 100 kilometers deployed from a manned lunar exploratory vehicle.

Data obtained on the statistical parameters of cosmic background noise fluctuations at several frequencies near 1 MHz.

Studies made of variable interplanetary absorption and interplanetary scintillation effects that are in the inaccessible region beyond the earth's orbit.

Consensus. Investigation should be made of strong discrete sources exhibiting temporal variations such as Jupiter and solar radiation in the range of 0.6 MHz to 1.5 MHz. Since Jupiter and the sun emit signals that are partly polarized, polarization density receptions should be made to measure the degree and sense of polarization. To achieve a 1.7-degree beamwidth at 1 MHz, the separation distance shall be 9 kilometers (0.17 degree at 90-kilometer separation).

Radio interferences from earth could be monitored in the range of 100 kHz to 3 GHz. The emissions would be from reflected energy, man-made emissions, ionospheric emissions, etc.

For frequencies from 5 MHz to 500 MHz, observation should be taken from the far side of the moon. Optical astronomy measurements or infrared measurements could be taken from sites near the poles because of the long viewing times afforded by darkness.

Most of the time-variable signals in the low-frequency, nonthermal radio emission region would corresponde to sources lying within the solar system. Sources outside the solar system seldom show any significant time dependence. Therefore, when the temporal variations in a received signal are detected by a lunar-based system, then identification of the source can be made through correlation of this temporal behavior with that of more directional radio astronomy telescopes (operating perhaps at higher frequencies) deployed on earth. Utilizing this rationale, simpler antennas would be employed that would allow polarization measurements and would provide for measuring calibrated intensity, whereby the cosmic background could be determined. Solar astronomy can be achieved as well from high earth orbit.

Apollo Accomplishments. Multifrequency radiometer; 50 kHz to 15 MHz to study background; expected results from the RAE satellite experiment from 400 kHz to 10 MHz.

Remaining Requirements. Same as consensus.

Geology/Geochemisty

Subobjectives

GG-1 Determine the type, form, structure, distribution, and relative age of lunar surface features

GG-2 Determine the physical, mineralogical, and chemical properties of lunar materials

GG-3 Deduce the nature and relative importance of dynamic natural processes on the lunar surface

GG-4 Study the effects of ancient or long-term geologic processes

GG-5 Compile a geochronology of lunar events from the early stage of formation to the present day

GG-6 Construct geologic maps of the lunar surface, delineating lithologic contacts, tectonic structures, physiographic, and petrographic provinces

GG-7 Determine the nature of morphologic differences between the near and far side of the moon

GG-8 Locate geologically favorable sites for advanced lunar exploration/exploitation scientific facilities

Rationale for Selection

Geological exploration of the moon, including its subdisciplines, petrology, stratigraphy, mineralogy and geochemistry, has received and will probably continue to receive the major emphasis in the lunar exploration program. This is a result of several influences, among which are the necessity to be on the lunar surface to obtain definitive answers to fundamental questions and the major impact on crew time which such investigations have. The subobjectives listed above have been selected to assure that adequate emphasis is placed both on the acquisition of geologic data and on its interpretation and use. Thus, many of the listed subobjectives will be accomplished to a major extent by the careful preparation of geologic maps, but the large variety of uses for such maps, each with its own requirements for data type and scale, is reflected in the large number of listed subobjectives and observation requirements. The selected subobjectives represent a distillation or summary of the goals of lunar geological exploration as expressed in the referenced documents.

Observation Requirements

GG-1 - Determine the Type, Form, Structure, Distribution, and Relative Age of Lunar Surface Features

Falmouth 1965.

Surface mobility: 15 kilometers, 600-pound payload

Flying mobility: 15 kilometers, 300-pound payload

Subsurface exploration: > 300 meters

Laboratory mobility: 800 kilometers, 2 months operation

Topo maps: 1:250,000, 20 to 30-meter contours.
Special purpose at 1:100,000

Orbital sensing: X-ray, gamma ray, particle spectroscopy, high-resolution panoramic photography, multiband, and ultra-high resolution photography (1-m resolution)

La Jolla 1968.

Extended traverse measurements, especially of mascons

Three-dimensional network of seismic measurements

Subsurface exploration at least several hundred meters

Woods Hole 1965.

Systematic orbital remote sensing followed by detailed surface studies

Topo maps of 1:1,000,000, 1:250,000, and 1:100,000

USGS Astrogeology Interagency Report No. 19, 1970.

Remote sensing: bistatic radar probing, passive microwave, and X-ray spectrometry

Surface analytical sensing: alpha backscatter, X-ray fluorescence, and neutron activation

Santa Cruz 1967.

Orbital sensing: High resolution photography (resolution, 20 cm), Infrared (IR) radiometry, passive microwave, imaging radar, bi-static low frequency radar, ultraviolet (UV), visible-IR scanning (imaging)

Surface: Traverse with visual and analytic investigations

Subsurface and geophysical probing

Sample return and remote in situ analysis

LESA 1965.

Orbital sensing of gamma ray spectra

Borehole logging for self-potential, resistivity, sonic, and nuclear logging

Neutron activation chemical analysis

IITRI.

Orbital sensing:

Metric photographs, 2-m resolution
Panoramic 1/2-m resolution
Radar probing, 25 percent of surface
Gravity gradient
Magnetometry, 0.5-degree resolution or 0.01
IR-UV imagery, 100-m resolution

Consensus.

Orbital sensing:

High-resolution photography, resolution 20-cm (specific areas)
Front and backside gravity survey
IR-UV imagery and passive microwave
Gamma ray spectroscopy, 1 km^2 resolution
X-ray fluorescence, 1 km^2 resolution
LF bistatic radar

Surface: visual, inspection/analysis geologic mapping; local and traverse geophysics; subsurface sampling and logging

Mobility: 100 kilometers radius, 10-day

Flying mobility: 100 kilometers, 300 pounds

Apollo Accomplishments.

Four landings: sample return and site geology at two Mare sites; one near-highland site; one Mare/volcanic (?) site; magnetometry at two sites

Orbital sensing: photography - local coverage, high resolution and low resolution

Gamma ray spectra, omnidirectional

Frontside gravity map

Remaining Requirements.

Orbital sensing:

High resolution photography, 20-cm resolution locally
Backside gravity map
IR and UV imaging at 100-meter resolution
Gamma ray and X-ray fluorescence from polar orbit, 1 or 10 km^2 resolution
LF bistatic radar

Surface: Visual, inspection/analysis, geologic mapping, and sample return. Local geophysics and geochemistry analysis. Subsurface sampling and logging.

Mobility: 100-kilometer surface radius, 10 days

Flying mobility: 100 kilometers

Natural continuation and extension of Apollo exploration will be accomplished. Investigation of lunar features (e.g., basins, highlands, craters, rilles, ridges, volcanic land forms, ejecta blankets, etc.) will be affected by Apollo accomplishments to the extent that individual sites or features similar to those already visited need not be reinvestigated. In general, however, such scientific investigations spawn more interest and deeper questions as the studies progress. All Apollo investigations are of low-latitude regions, whereas OLS/LSB programs are concerned with global coverage. Apollo X-rays and gamma ray orbital experiments are omnidirectional. Better resolution from 1 to 10 km^2 will be more meaningful.

GG-2 - *Determine the Physical, Mineralogical, and Chemical Properties of Lunar Materials*

Falmouth 1965.

Orbital sensing: microwave spectra, electromagnetic pulse probing, radar scatterometry, low-frequency radar imaging, microwave imaging, X-ray fluorescence spectra, gamma ray spectra, UV reflectance and luminescence multispectral photography and IR imager.

Surface investigation: sample return. In situ analysis by petrographic microscope, X-ray diffraction, X-ray spectra, mass spectra, natural radiation measurements, and physical measurements.

La Jolla 1968.

Sample analysis; composition data; isotopic ratios; resource prospecting

Woods Hole 1965.

Emphasis will be placed on search for ancient rocks for clues to lunar origin

Petrographic examination

X-ray spectra

Measurement of atomic masses 12 to 200, and gas pressures to 10^{-14} torr

USGS No. 19, 1970.

Mineralogic analysis emphasized, X-ray diffraction

Remote chemical analysis by alpha backscatter, X-ray fluorescence neutron activation, and optical emission spectroscopy

Santa Cruz 1967.

Orbital sensing: (same as GG-1, plus gamma ray and X-ray fluorescence spectra, and mass spectrometry)

Surface: sample return and in situ petrologic investigations by microscope, X-ray diffraction, gas chromatography, solids mass spectrometry, and neutron activation device

LESA 1965.

Water search using vertical and horizontal nuclear logging

Bellcomm 1969.

Orbital geochemistry:

Gamma ray spectra:
Natural: K, Th, U --- Induced: Na, Mg, Al
X-ray spectra: O, Mg, Si, Fe
Mineralogy by IR emission and spectral reflectance

IITRI 1966, 1970.

Orbital (polar) geochemistry

Visual - UV spectral signatures, 100 - 7000 A, 100-meter resolution

IR spectra: 7 - 40 μ

Passive microwave, 30 μ to 30 cm (~150k temp) at 10 km^2

Consensus.

Orbital sensing: polar orbit

High resolution sensing of gamma ray and X-ray spectra, 10 km^2 or 1 km^2

IR and UV spectra and imagery

Passive microwave

Low-frequency radar probing

Surface investigation: Sample return, petrographic micrography, X-ray diffraction, X-ray spectra. Mass spectrometry, neutron activation. Auger spectrometry.

Subsurface sampling, electric and nuclear logging

Apollo Accomplishments.

Orbital: omnidirectional gamma ray and X-ray spectrography S-band bistatic radar, Apollo 16, also Explorer 35 and Lunar Orbiter

Surface: sample return from two Mare sites, one near-highland, and one volcanic (?) site

Subsurface: soil cores 70-cm depth, auger-percussion drill to 3 meters

Remaining Requirements.

Orbital sensing in polar orbits:

High-resolution gamma ray and X-ray spectrography at 10 or 1 km^2 resolution

IR and UV spectra and imagery

Passive microwave

Low-frequency radar probing

Surface:

Sample return

In situ petrographic micrography, X-ray diffraction and spectrometry, mass spectrometry, neutron activation, or auger spectrometry

Subsurface sampling and logging, electrical and nuclear. Sounding for velocity measurement. Depths of order of 300-m desirable.

Mass distribution of lunar differentiated materials is best determined by orbital sensing. Apollo gamma ray and X-ray spectra experiments have practically no resolution and are restricted to equatorial region. Good resolution and global coverage are required and sensitivity of instrumentation can be calibrated according to results of Apollo experiments.

Passive microwave and IR imagery will indicate regional heat flow and locate anomalies and possible tectonically active zones and areas for surface exploitation. UV imagery will assist geologic mapping and identify some areas of mineralization.

In situ petrographic and geochemical measurements will screen samples for earth return and assist geologists in mapping and exploration tasks. More work is required in highland areas of the moon and at sites of reported transient activity. Mass spectrometer experiments are especially useful for studying outgassing (see section under "Atmosphere").

Subsurface sampling and investigation has been very limited in the Apollo program. Deep samples and probing are required to obtain oldest rocks and to detect fossil life and possible permafrost.

GG-3 - Deduce the Nature and Relative Importance of Dynamic Natural Processes on the Lunar Surface

Falmouth 1965.

Atmospheric measurements; seismometry

La Jolla 1968.

Heat flow measurements in hole some tens of meters deep

Woods Hole 1965.

Broad recommendation for the investigation of interior and exterior processes--coordinated with geologic mappin

Santa Cruz 1967.

Orbital geochemistry measurement

- Gamma ray spectra, 0.3 - 10 Mev
- Alpha particle measurement
- Mass spectrometry and IR spectra
- Neutron albedo

LESA 1965.

Gas composition

Thermoluminescence

Isotopic geochemistry:

Pb/U, C, S, H/He, I^{129}, Xn

Erosion study by stero microscopy

Bellcomm 1969.

Geomorphic procurement studies

Field analysis. Landforms, ash flows, solifluction, rille formation, mass wasting, etc. Atmospheric isotope determination. Heat flow anomalies.

IITRI 1966, 1970.

Lyman - alpha radiation

Charged particles 1 ev - 500 Mev

$0 - 10^3$ cm^{-2} sec^{-1}

Cosmic ray electrons, 0.05 - 50 Mev. 0.3 - 500 Mev protons

$1 - 10^{10}$ $cm^{-2} sec^{-1}$ omnidirectional

Consensus. General and varied.

Apollo Accomplishments. Local site investigations will be made of effects of solar and cosmic bombardment, micrometeoroite bombardment, and impact effects. A qualitative study of erosion phenomena will be made. Passive seismometry at as many as three sites will be conducted. Identification of widespread phenomena; e.g., glass spherules and regolith breccia, glass blobs, and surface mounds remain puzzling.

Remaining Requirements. High-resolution photography, 20 cm, at selected sites. Determination of atmospheric variations, density and composition. Geologic mapping and geophysical traverses. Subsurface sampling and logging to 300 meters. Mobility up to 100 kilometers. Extensive passive seismometry.

Dynamic natural processes on the moon include degassing, thermal activity, mass wasting phenomenon such as slumping, micrometeorite erosion, formation and "gardening" of the regolith, various impact phenomena, including the formation of rays, glass spherules, blebs and blobs. Also included is seismic activity due to impacts or tectonic activity and bleaching/darkening effects of material caused by solar/cosmic radiation.

Interpretation of these require in situ field analysis assisted by high-resolution (HR) photography and laboratory support. In some cases, subsurface sampling and geophysical exploration will be required.

Apollo missions are answering many questions, but also raise new questions. Dynamic process studies of post Apollo will probably be more detailed and deal with unexpected anomalies and large-scale or isolated volcanic phenomena.

GG-4 - Study the Effects of Ancient or Long-Term Geologic Processes

Falmouth 1965.

Gravity and geological surface mapping of the Appenines

Woods Hole 1965.

Search for history of cosmic radiation variations

USGS No. 19, 1970.

Stratigraphic and structural determinations by remote sensing studies

Santa Cruz 1967.

Gravity anomalies; Magnetic anomalies

LESA 1965.

Differentiation effects (gamma ray spectra); Isotopic ages

Bellcomm 1969.

Deep-seated material, excavations, ejecta blankets, and central peaks

IITRI 1966, 1970.

Outcrop and structural patters, local and regional

IR anomalies

Differential masses (gamma spectra 0.01 - 100 photons per cm^2-sec, 0.1 - 10 Mev); (X-ray fluorescence of 0.01 - 100 photons per cm^2-sec, 0.1 - 10 Mev, 100-meter resolution)

Consensus.

Crustal differentiation by gamma ray spectrography and gravity anomalies

Apollo Accomplishments. Mare and semi-highland areas will have been sampled and briefly studied in situ. Also, remote geochemical analysis (gamma ray, X-ray, alpha emission) will be performed for limited durations from lunar orbit on Apollo J missions.

Remaining Requirements.

Orbital:

High-resolution photography (1 meter) of key areas

Global coverage from polar orbit with resolution better than 1 km^2 of gamma radiation, 0.1 - 10 Mev, 0.01 - 100 photons per cm^2-sec; X-ray fluorescence spectra, 0.1 - 10 kev, 0.01 -100 photons cm^2-sec

IR (3 - 25 micron spectral range) imagery and UV imagery at 100-meter resolution

Surface: geologic mapping on topographic base maps

Subsurface sampling and logging to 30-meter depth. Mobility 10 to 500 kilometers. Active seismic, gravity, and magnetic traverses

Ancient or long-term geologic processes to be studied include chemical and mineralogical differentiation of the lunar crust, magmatic intrusion, volcanism, mountain building and basin subsidence, isostatic readjustment to major bolide impacts, formation of fracture nets and lineations, faulting, convection, hydrothermal or pneumatolytic activity, and cosmic and solar bombardment.

The recommended measurement objectives are an extension of Apollo investigations and generally are in agreement with the Santa Cruz study. The gamma and X-ray spectral sensing will delineate areas of silicic or felsic concentrations in the crust. UV imagery may indicate areas of zones of mineralization. High-resolution photography will assist elucidation of border and structural features, also stratigraphic relations. Impact or endogenic processes which caused crustal anomalies will be discovered by gravity and magnetic surveys and active seismic surveys.

The Apollo program will leave many questions unanswered, especially in highland areas and for large features; e.g., mascons. Its gamma rays will indicate the levels at which radiation needs to be measured, but resolution may be insufficient for other than intelligent planning purposes.

GG-5 - Compile a Geochronology of Lunar Events From the Early Stage of Formation to the Present Day

Falmouth 1965.

Subsurface exploration, > 300 meters

Woods Hole 1965.

Unraveling of the stratigraphic sequence for the "exploration of time" as well as space

Santa Cruz 1967.

Determine solar and cosmic radiation history by subsurface exploration, petrographic analysis for radiation damage indicators

Isotopic age dating of returned samples

LESA 1965.

Isotopic age dating best done by earth laboratories

Bellcomm 1969.

Isotopic age dating techniques

Zircon, Pb^{207} - Pb^{206}
Zircon, U^{238} - Pb^{206}
Hornblende, K - Ar
Biotite, Rb - Sr
Biotite, K - Ar

Consensus.

Isotopic dating of surface and subsurface samples, Mare and highland

Apollo Accomplishments. Obtained isotopic ages of major lunar events: eastern and western Mare formation, Mare Imbrium impact data, and crystallization of some highland rocks. Better understanding of lunar evolution.

Remaining Requirements. Synthesis of orbital and surface studies with emphasis on stratigraphic investigations and collection of meaningful specimens representing major and typical lunar events. Requires geologic mapping and field stratigraphy combined with intensive interpretation of orbital remote sensing data.

Dating will be done in earth-based laboratories until suitable portable instrumentation can be developed.

Determination of the evolution or geologic history of the moon is not a singular task, but will develop as a synthesis of all lunar geoscience investigations. Isotopic dating is simply the mechanical processes of assigning an absolute age to specimens affected by lunar events, indicated by study of field and microscopic study of other phenomena caused by the event and preserved in lunar rocks.

GG-6 - Construct Geologic Maps of the Lunar Surface, Delineating Lithologic Contacts, Tectonic Structures, Physiographic, and Petrographic Provinces

Falmouth 1965.

Systematic geologic mapping at 1:25,000,000; 1:1,000,000; and 1:250,000

Mapping of key areas at 1:25,000 and 1:100,000

Orbital remote sensing with ground truth landings

Rover mobility and flying mobility

Woods Hole 1965.

Geological plotting on topo base maps of scales: 1:1,000,000; 1:250,000; and 1:100,000

USGS No. 19, 1970.

Orbital remote sensing aided by bistatic radar sounding and passive microwave

Santa Cruz 1967.

Orbital remote sensing:

> Global geologic mapping by photointerpretation and remote sensing data

Ground truth at scattered strategic sites, using geologic and geochemical methods, and lunar surveying system and electromechanical line scanner.

IITRI.

Orbital: Low-frequency radar probing. Radar imagery, 100-meter resolution. Gravity gradiometer surveys, microwave (passive) surveys, IR mapping, and 25 percent coverage.

Surface: surface mapping, long and short traverses

Consensus.

Orbital: photography, high-resolution (1 meter), IR and UV imagery at 10-meter resolution. Gravity gradient surveys and low-frequency radar sounding

Surface: Geological, geochemical, and geophysical surveys and traverses. Subsurface sampling and logging. Traverses from 10 to 500 kilometers.

Apollo Accomplishments. Provide useful ground truth information at four sites (two of which are in key areas) important for extrapolation of remote sensing data. Subsurface data minimal.

Remaining Requirements.

Orbital: Photograph, high-resolution (1 meter). IR and UV imagery, 10-meter resolution. Gravity gradient and low-frequency radar sounding.

Surface: Geologic/geochemical/geophysical traverses and surveys with subsurface sampling and logging. Laboratory and mobility support.

The tasks consist of plotting geologic data on topographic maps constructed photogrammetrically. Method is the same as used on earth in remote, undeveloped terrain: (1) reconnaissance of area using photographic and other remotely sensed data, (2) spot (ground) investigations at strategic or problem areas, and (3) continuation of interpretation of remote sensing data using and extrapolating knowledge gained by the surface investigations.

Apollo has provided four such spot investigations, two of which were very limited in scope and were in relatively homogeneous geologic areas. Further landing must obtain more subsurface (stratigraphic) field investigations and geophysical traverses.

GG-7 - Determine the Nature of Morphologic Differences Between the Near and Farside of the Moon

USGS No. 19, 1970.

Exploit color characteristics with multiband photography and photometry

Santa Cruz 1967.

Recommends polar but no far side investigations except Mare Orientale

LESA 1965.

Remote areas probed by unmanned experiment packages

Bellcomm 1969.

Far side and highland areas best sources of oldest possible material

IITRI 1966, 1970.

Radar imagery of far side, 100-meter resolution

Ideal base site in Mare Orientale

Consensus.

Same procedures used on front side to be applied to far side

Apollo Accomplishments. Near-side information is indispensible for planning far-side investigations and comparing results.

Remaining Requirements.

Orbital:

> High-resolution (1 meter) photography from polar orbit. Gravity gradient of entire surface with high resolution magnetic field measurement. Low frequency radar probing, 50 to 150 meters deep, IR and UV imagery, 10-meter resolution.

Surface: visual analytical fields survey, local geological mapping and subsurface sampling and geophysics.

Utilization of orbital and surface investigations for comparing the near and far side geomorphology of the moon and to assist in determining the reasons for the differences of the two sides with respect to the presence or absence of maria and mare concentrations.

Apollo contributions to far side geology have been minimal, but their near side accomplishments will be essential to carrying out this subobjective.

GG-8 - Locate Geologically Favorable Sites for Advanced Lunar Exploration/ Exploitation Scientific Facilities

Falmouth 1965.

Historical interest

La Jolla 1968.

Select sites on basis of self-sufficiency for colonization, refueling capability and quarantine for planetary missions.

USGS No. 19, 1970.

Unmanned landers determine lithology, texture and mineralogy of area. Representative quality of site is important.

Santa Cruz 1967.

Unmanned probes and high resolution photography

LESA 1965.

Recommends three sites accessible by 1500-kilometer range vehicle

Bellcomm 1969.

Selection based upon proximity to: significant geologic formations, rilles, elongate craters, mare ridges, impact crater with fresh rays, central peaks, highland volcanic features, mare volcanic domes, and major mountain range.

IITRI 1966, 1970.

Utilize virtually all sensors. Concept of feature clusters.

Consensus. Utilize remote sensors and unmanned lander or short landing mission to check out site after consideration of feature cluster and general significance of the area.

Apollo Accomplishments. Apollo will obtain high-resolution photography of low latitude candidate. Surface conditions encountered may be extrapolated for mobility planning.

Remaining Requirements.

Orbital:

High-resolution (1 meter) photography from polar orbit. Low-frequency radar probing, 50 to 150 meters. IR and UV scanning at 10-meter resolution.

Surface: Preliminary landing for engineering purposes; e.g., nature of surface and underlying regolith, trafficability analysis.

Selection of sites for advanced lunar exploration activities can be approached from a feature-cluster concept; that is, utilizing sites with numerous features of interest within range of available mobility aids. All applicable sensors will be employed to locate or begin detailed studies of known features of interest before a surface visit.

Geophysics

Subobjectives

GP-1 Determine the mass distribution and figure of the moon

GP-2 Determine the physical state and composition of the lunar interior

GP-3 Evaluate the internal dynamics (heat flow, circulation, creep, etc.) of the moon

GP-4 Determine earth-moon mechanical interactions

Rationale for Selection

GP-1 - Distribution of Mass and Figure of the Moon

There will be a continuing requirement to refine the measurements of the mass distribution of the lunar interior and establish more precisely the overall physical shape of the moon. Better knowledge of the gravitational potential of the moon is required to determine the degree of departure of the moon from an equilibrium configuration. The presently available representation of the gravitational potential to the fifth degree harmonics must be extended through the 10th or 15th degree to adequately test the hypothesis of isostasy. More precise determination of the moment of inertia is required. The present relation among the three unequal axial moments of inertia of the moon contributes to the understanding of the evolution of the moon and the establishment of the time at which the figure of the moon was stabilized.

GP-2 - Physical State and Composition of Interior

There is presently much less information on the seismicity of the moon than on its magnetic or gravitational fields and this may well still be the situation at the end of the pre-OLS/LSB period. Seismic measurements are considered to have the very highest priority in future lunar missions because they represent a powerful probe for inferring structure and composition of the interior from a remote station on the surface. Ideally, a network of many short period seismic stations over the entire lunar surface with communication links to the LSB would be desirable. A long wavelength network is also desirable and would provide surface wave data inferring structure and anelastic properties of the interior.

GP-3 - Internal Dynamics of the Moon

A direct measurement of the heat escaping from the lunar interior is an important goal of lunar science. The net heat flow outward is derived from energy generated from internal processes and energy retained from the initial formation of the moon. In the case of the moon, the surface heat results from heat sources distributed throughout a larger fraction of the lunar volume and, therefore, is more revealing of internal processes than in the case of larger bodies such as the earth and other planets. The internal sources presently contributing to the surface heat are believed to be the long-lived decaying radioisotopes of uranium, thorium and potassium.

By the time of the OLS/LSB period, heat flow experiments at the lunar surface should be extendible from shallow holes to deep holes down to 100 meters or more.

Infrared radiometer orbital sensing should continue with higher resolution to record anomalous hot spots and cold spots in previously undiscovered locations; e.g., spotted from polar or high inclination orbits.

GP-4 - Earth-Moon Mechanical Interactions

The use of the moon as an astronomical platform will require a continual refinement of the calibrated position and motion of this platform. The determination of lunar librations in longitude, including their excitation and decay, is of considerable interest. There may also be a lunar libration in latitude analogous to the Chandler wobble of the earth.

Observation Requirements

GP-1 - Determine the Mass Distribution and Figure of the Moon

Santa Cruz. More detailed gravity measurements to establish gravitational potential out to the 10th or 15th harmonics to test theory of isostasy. Map figure of moon to ± 100 meters. Determine moment of inertia more accurately.

IITRI. Mascons revealed by Doppler shift of lunar orbiter signals; i.e., velocity components along earth-moon line. More accurate method is to measure spacecraft total velocity and position versus time laser ranging and photographs.

NAS. Produce gravity map of far side of moon. Measure large scale variations in elevations of topography to ± 100 meters at 2-degree intervals.

Other. Medium resolution general topographic mapping with 100-meter resolution with metric camera system capable of 10-meter positional accuracy. Determine spacecraft orbit pertubations to 10-meter accuracy--radar altimetry and laser ranging (with surface reflectors).

Consensus. Make gravitmetry measurements to allow field representation to 15th harmonic on both sides of moon. Photographic mapping of moon to 100-meter resolution. Determine camera position to ± 10 meters. Use radar altimetry and laser ranging with surface reflectors.

Apollo Accomplishments. Present Lunar Orbiter provides data to determine harmonics through 5th. Photographic mapping on Apollo 17, 18, and 19. Laser altimetry, Apollo 17, 18, and 19. Apollo 12 found small mascons under Ptolemaeus and Albategnius.

Remaining Requirements. Conduct more extensive measurements of far side gravity anomalies. Extend field representation to 15th harmonic on both sides of moon. Photographically map moon to 100-meter resolution. Define camera position in orbit to ± 10 meters.

GP-2 - Determine the Physical State and Composition of the Lunar Interior

Santa Cruz. Measure seismic data from propagation of elastic waves from: moonquakes, meteor impacts and artificial missiles (e.g., S-IVB shells). Measure short wave periods, 0.01 to 20 Hz. Measure long wave periods:

Free oscillations: 0.1 mm, T $<$ 15 minutes/cycle

Tides: T ~ 28 days/cycle
1 milligal $\pm$ 0.1 percent

Secular strains: $10^{-8} \pm 0.1$ percent

Tilts: 0.1 second of arc $\pm$ 0.1 percent

IITRI. Passive seismic measurements are judged to satisfy more scientific objectives than any other surface experiment.

NAS. Active seismic energy source: define source location (e.g., impact of S-IVB shell) to $\pm$ 1 kilometer, time to $\pm$ 0.1 second.

Other.

Dynamic range: 1.0 millimicron to 10 microns

Short-period interval: 0.2 - 25 Hz

Long-period interval: 0.004 - 3.3 Hz

Consensus. Make seismic measurements with dynamic range of 0.1 millimicron to 10 microns. Measure moonquakes, meteor impacts, and artificial impacts. Determine artificial impact point location to $\pm$ 1 kilometer.

Apollo Accomplishments. Active seismic measurements on lunar surface on Apollo 14 and 16. Passive seismic measurements on lunar surface on Apollo 15, 16, 17, 18, and 19.

Remaining Requirements. Provide for simultaneous measurements from an array of seismic sensors on the lunar surface. Measure long and short period waves at representatively different locations.

GP-3 - Evaluate the Internal Dynamics (Heat Flow, Circulation, Creep, etc.) of the Moon

Santa Cruz. Measure the energy budget (mechanical and thermal) and response of the moon to internal and external stresses. Measure heat flow, creep, movement of magma, seismicity, tectonic activity and electrical properties. Measure thermal conductivity for which temperature fluctuations of 0.015 C for which sensor resolution of $\pm$ 0.001 C is desirable. Conduct polar orbit radiometry measurements 30 to 300 microns $\pm$ 100 meters.

IITRI. Not discussed except that heat flow probes are second only to passive seismometers in satisfying scientific objectives for lunar surface measurements.

NAS. Measure heat flow in hole 1 to 10 meters deep in both typical and atypical locations to obtain conductivity. Measure microwave emissions from lunar surface from orbit for different sun elevations to obtain average temperature profile versus depth.

Other. Measure thermal anomalies with 100-meter resolution with IR (5 to 300 microns) to find anomalously hot or cold areas and determine mineralogical characteristics and composition variations. Measure gamma rays from orbit to infer radiogenic elements on surface to aid in interpreting heat flow measurements. Accuracy of heat flow measurements: $\pm$ 0.05 microcal per cm^2 -sec over a range of 0 to 5 microcal per cm^2-sec.

Consensus. Make IR measurements of thermal anomalies with 100-meter resolution for wavelengths of 5 to 300 microns from lunar orbit. Extend measurements into microwave region. Arrange for high latitude (including polar) orbits. Measure heat flow in deep drilled holes 1 to 10 meters. Require temperature resolution of 0.001 C to measure fluctuations on the order of $\pm$ 0.01 C. Obtain net outward heat flux from surface of moon. Compare with earth's. Heat flow measurements together with seismic measurements will provide information on composition and physical state of lunar interior.

Apollo Accomplishments. IR scanning radiometry measurements had been scheduled on Apollo 18 and 19. Heat flow measurements of vertical conductivity in shallow (3-meter) holes had been scheduledon Apollo 13 and 16.

Remaining Requirements. Measure heat flow in holes 10 to 100 meters deep in both typical and atypical locations. Measure radiometrically from polar and other high-latitude orbits the total heat flux as a function of position and deduce lateral thermal gradients. Require resolution of 100 meters.

GP-4 - Determine Earth-Moon Mechanical Interactions

Santa Cruz. Measure orbital perturbations, librations, and lunar moment of inertia.

Other. Measure librations.

Consensus. Determine spacecraft orbit perturbations to 10-meter accuracy. Make microwave radar measurements. Make laser altimeter and retroreflector measurements.

Apollo Accomplishments. S-band transponder measurements had been scheduled on Apollo 17, 18, and 19. Earth transmitter, 2106 MHz, transponder, 2287 MHz measure librations, variations in earth rotation rate, and earth-moon distance.

Remaining Requirements. Measure perturbations in lunar motion at lunar surface sites for purpose of selecting location for large radiotelescope.

Bioscience

Subobjectives

- BI-1 Determine the existence of viable life forms or dormant spores
- BI-2 Evaluate the lunar environment for survival of terrestrial micro-organisms and the amount of forward/backward contamination
- BI-3 Determine the effect of lunar environment on the behavior and rhythms of plants and animals
- BI-4 Determine genetic effects of lunar conditions and earth/moon trips of plants and micro-organisms

Rationale for Selection

The subobjectives selected for implementation in this discipline are those which compare the effects of the lunar environment with those of the terrestrial environment on imported typical terrestrial life forms. In addition, a search for viable intrinsically lunar life forms has been retained although early results from Apollo 11 and 12 have been negative. The former type of study (comparison of terrestrial versus lunar effects) is far more likely to produce positive results and will clearly establish a new data point in the study of processes which are known to be of interest. The selected subobjectives represent a summary of the recommendation of the referenced studies.

Observation Requirements

BI-1 - Determine the Existence of Viable Life Forms or Dormant Spores

This topic was suggested by NAS, Woods Hole, Falmouth, Extended Lunar Exploration (ELE), Santa Cruz, and IITRI.

Although the lunar samples to date have not yield any life forms, samples have not been taken from deep within the moon, and samples remain to be taken from high latitudes (above and below the ± 20-degree latitude covered by Apollo). IITRI identifies the measurements as CO at 200, N_2 at 150, H_2 at 40 to 50, Alkane at 0.1, and Porphyrin at 0.1. All of the values are in parts per million except Porphyrin which is per billion.

Falmouth estimates that the physical presence of 10^{-6} grams in 1 kilogram of lunar samples can be detected. Falmouth also identifies nucleosides, bases, sugars, liquids, and hydrocarbons as candidate observables. All of the previously mentioned constituents require surface samples.

Each sample area will basically be performed from the viewpoint of a unique, initial sampling. The areas to be sampled will have been selected for their distinguishing characteristics; therefore, each sample will be examined and will require examination for such constituents.

Corliss identifies three observables that should be monitored to aid the definition of life; namely, metabolism, reproduction, and isolation (mutation).

BI-2 - Evaluate the Lunar Environment for Survival of Terrestrial Micro-Organisms and the Amount of Forward/Backward Contamination

Contamination of the moon by man or his effects will be a continuing problem during lunar exploration. The influence of propulsion combustion of the orbiting/arriving/departing spacecraft is presented in the atmosphere section. Propulsive combustion due to the tug (lunar logistics tug) will certainly modify the immediate vicinity of the tug. Microbial contamination will follow man on the moon to some degree. Determination of the modification of the lunar surface by both types of contamination is required, on a continuing basis, to enable positive identification of the true lunar material. Santa Cruz recommends the use of the optical rotary dispersion and stable isotope ratio for contamination measurement. Apollo contamination measurements are performed through the ALSEP Mass Spectrometer and primarily indicate the rate of loss of the contamination in the landing area. Distribution of the contamination will enable selection of the correct samples. Apollo also evaluates a common astronaut strain and the effect of the lunar environment on spores of bacteria, fungi, higher plant forms, and their progeny. Apollo does not evaluate on the basis of exposure to one full day; therefore, this experiment should be continued to perform that evaluation.

BI-3 - Determine the Effect of Lunar Environment on the Behavior and Rhythms of Plants and Animals

Suggested by the ELE/LESA to determine the effect of the longer duration day-night cycle on plants and animals. Apollo is not conducting any experiments along this line. LESA recommends such studies to support the aspect of growing plants on the moon for the purpose of growing food during later expeditions. The overall purpose is to identify the effect of the light/dark cycles in combinations with the associated environmental factors. Requires plant cultivation for evaluation. The response of mice and owls to the lunar environment is measured by comparison with earth-bound control group to identify any subtle change induced by their presence on the moon.

BI-4 - Determine Genetic Effects of Lunar Conditions and Earth-Moon Trips on Plants and Micro-organisms

Suggested by ELE/LESA to investigate the effects of additional ionizing radiation received, and the possible genetic effects of the vibration/acceleration to which the cells will be exposed during the trip. The search is for chromosome changes which have occurred in the earlier phases of the plant life; and gene mutation, which is generally evidenced by a shortcoming of chlorophy development. LESA recommends these comparison tests be performed on earth. It is necessary to establish a procedure for identifying the forward/backward mutations, but eliminating the mutation similating phenomena. Apollo is not experimenting along this line; thus the entire area remains open.

Aerospace Medicine

Subobjectives

AM-1 Determine the effect of the reduced magnetism on the body rhythms

AM-2 Determine the effect of the reduced gravity on man

AM-3 Determine the effect of the combined isolation and modified gravity and atmosphere on man's psychological health

AM-4 Verify the effect of the lack of atmosphere on man's vision

Rationale for Selection

The primary objective supported by the Aerospace Medicine discipline is AM-4, evaluating and extending man's capability in space and his ability to explore other planetary bodies.

Selection criteria were based upon the differences between the moon environment and that of earth. Gravity and atmosphere are apparent differences; the reaction of man to them is understood for short durations, but leaving the question of the extrapolation of these results to the longer durations of later planetary studies unanswered. Readjustment of man to those environments on earth after being elsewhere (the moon) also is not answered. The effect of magnetic differences (earth and moon) has not been determined and is amplified below as the first subobjective. The effect of the differences in atmospheres requires evaluation of vision effects in addition to the physiological effects mentioned earlier. Therefore, the combination of the environmental differences (between moon and earth), with the primary objective of man's capability, generate the subobjectives previously listed.

Differences in radiation levels have not been included since it is agreed that effects due to combination of radiation and weightlessness can be investigated in single environment levels--radiation or weightlessness and then combined. Rules for combination do not seem to be available.

Observation Requirements

AM-1 - Determine the Effect of the Reduced Magnetism on Body Rhythms

Physiological and psychological observations of man in the reduced magnetic field of the moon is required to verify or qualify the Larmar

Theorem which suggests that motion of the human body within the earth's magnetic field imparts a precession of 2000 cps to all H_2 nuclei in the human body, thereby providing spatial clues which the human has become accustomed to physiologically and psychologically.

The "Compendium" continues to mention a study wherein six men in a reduced magnetic field, less than 50 gammas, five incurred significant alterations in scotopia (vision in dim light, dark adaptation) critical flicker fusion and lightness discrimination. However, another study (14 days) of two men in a field of about 50 gammas showed no abnormal responses in physiological or pscyhological effects.

Thus, no definite trends may be concluded from such sparse data and investigations. The lack of an atmosphere in space presents adaptation difficulty to the eye; since there is no atmosphere to diffuse light, the shift from light to shade and shade to light is more pronounced. If the trend of "scoptopia" were to persist toward degradation, then rapid changes from light to dark would have to be avoided to prevent disorientation of the individual.

Critical flicker fusion level is measurable in the individual by monitoring physiological data.

1. The flicker fusion effects should be investigated for its relationship to low magentic fields.

2. The duration of any changes should be determined.

3. The relationship of flicker fusion (if any) to dark adaptation should be determined.

4. Combined effects of partial g - low magnetic field on flicker fusion should be determined.

Vision protection is being evaluated during the Apollo program by experiments in biomedicine in the area of surface reflections (IR and UV ranges).

AM-2 - Determine the Effect of Reduced Gravity on Man

The effect of the reduced gravity on man requires definition to evaluate man's adaptiveness to the partial g of the moon for application to the Mars and planetary programs. The rationale is to assure that the projected plans for long-duration manned planetary missions will not induce unknown disability. The rationale takes advantage of the presence of man in the shorter missions to accumulate data which will assure his capacity or identify protective means.

Apollo is contributing to this objective for short staytimes on the moon or in its locale by television monitoring of the surface crew to observe agility/dexterity, metabolic rate assessment, inflight aerosol analysis, pre- and post-flight and biomedical operational measurements.

The division of investigation falls into the duration categories of the OLS and LSB. Man's adaptability to intermediate length missions on the surface will certainly be established prior to the activation of a surface base program. This will lead to the inference that man's responses will lie between zero-g and 1-g. Man's recovery is a logical supplement to this area.

AM-3 - *Determine the Effect of the Combined Isolation and Modified Gravity Atmosphere on Man's Psychological Health*

This area has been selected because of the combination of isolation and a foreign environment. Data observations will be directed toward correlation of the observed data with the isolation data acquired during earthbound tests. Tests will be paper and pencil, supplemented by television observation from earth.

Apollo has and will have performed observation of the astronauts during the lunar surface activities. Crew sizes up to 5 or more present situations as follows:

Crew size 2 - limited social interaction combined with interpersonal overexposure in irritability and friction

Crew size 3 - problem of two versus one split, minority is isolated but majority is not sufficient to dominate

Crew size 4 - no problem if authoritarian structure is maintained; otherwise, two versus two, three-to-one brings high pressure on the minority

Crew size 5 or greater - acceptable except with increased size the management roles, communications, and structure assume importance

AM-4 - *Verify the Effect of the Lack of Atmosphere on Man's Vision*

This study is selected because of dark adaptation and object discrimination difficulties in atmosphereless environment. Dark adaptation requires 30 to 45 minutes while light adaptation requires only 3 or 4 minutes. Their shadows will complicate the individual tasks required outside the surface base. Discrimination is aggravated; for example, the sun view of the astronauts can appear as a point in the lunar environment.

Apollo is investigating vision effects for the purposes of protection from the IR-UV reflected radiation. Additional evaluation of discrimination per se is being performed in simulation tests within vacuum chambers in the earth's environment.

The validity of the earth tests is to be verified by lunar testing.

Lunar Atmosphere

Subobjectives

LA-1 Determine the total quantity and distribution of the component species of the lunar atmosphere

LA-2 Determine the principal natural atmosphere source, loss and transport mechanisms, and their rates

LA-3 Monitor atmospheric contamination resulting from lunar missions, including transport and escape rates

Rationale for Selection

There are several areas of lunar study to which data concerning the lunar atmosphere would be applicable. It is important in investigating the suggestion that noble gases, carbon dioxide, carbon monoxide, hydrogen sulfide, ammonia, sulphur dioxide and water vapor may be released by lunar volcanism and from rocks and magma. Other proposed mechanisms of release of gases from the surface; e.g., solar wind bombardment, perhaps can be affirmed knowing what the effluent gases are. Likewise, data on released gases will certainly afford some knowledge of the chemical processes underlying the lunar surface. Location of areas of released gases are related to the selenological structures in these areas.

The firing of tug engines would be a good example of a known point source of gas on the lunar surface. The rate of spreading of this gas cloud from the source around the moon can be studied from surface and orbit and diffusion rates for the various gases calculated. Also, the escape rates of gases of various molecular weight can be determined. Some of the gases from the rocket will be absorbed on the lunar surface materials, so the outgassing rates of these absorbed gases can be measured. From this information, the amount of contamination of the lunar atmosphere caused by the firing of rocket motors, both past and future, near the surface could be estimated.

Another significant problem is related to transport processes in planetary exospheres. The exosphere of the earth, and that of almost any other planet, is bounded by a dense atmosphere, in which hydrodynamic wind systems complicate the problem of specifying appropriate boundary conditions for exospheric transport. This contrasts sharply with the situation in the lunar atmosphere, which is entirely a classical exosphere, with its base the surface of the moon. Therefore, the lunar exosphere should be amenable to accurate, analytical study, and experimental determination of the global distributions of lunar gases can provide a reasonable check on theory, giving confidence to the application of theoretical techniques to transport problems in the terrestrial exosphere.

There is some evidence for the release of gases, at least sporadically, from the lunar interior. Middlehurst (1967) has summarized the visual evidence for color changes at specific locations on the lunar surface. These are interpreted as luminescence associated with gas release. About 400 cases have been observed, with maximum activity in the vicinity of Aristarchus. The best presumption is probably that the composition of the released gases is similar to volcanic gas on earth.

Although not much gas can be expected on the moon, any identifiable gases of internal origin will be important from a geochemical viewpoint. They should provide clues to the internal composition of the moon and, hence, possibly to its origin.

Observation Requirements

LA-1 - *Determine the Total Qunatity and Distribution of the Component Species of the Lunar Atmosphere*

Santa Cruz.

Total pressure--sensitivity to 10^{-15} torr, surface up to altitudes of 60 kilometers

Neutral mass spectra - mass range 1 -- 150 atomic mass units (amu), resolution 1 amu, sensitivity 10 particles per cm^3

IITRI. Mass spectra and total pressure (not quantitatively defined)

Falmouth. Total pressure and mass spectrum of neutrals; sensitivity of 10^{-15} torr.

LA-2 - *Determine the Principal Natural Atmosphere Source, Loss and Transport Mechanisms, and Their Rates*

Santa Cruz. Concentration, flux, and mass spectrum of low energy ions, mass range 1 to 150 amu, resolution 1 amu, sensitivity 10 particles per cm^3, surface to altitudes of 100 kilometers. Provide triangulation capability to locate sources. Measure directed flux of neutral species. Detect and analyze subsurface gas up to molecular weight 150.

IITRI. Neutral particle fluxes, sensitivity one particle per cm^2-sec, energy range 0 to 10 kev, resolution 10 percent in flux and energy.

Falmouth. Total concentration, mass spectrum and directed flux of ions; instruments must be capable of operating with concentrations as low as 10 particles per cm^3.

National Academy of Sciences (in "Lunar Exploration, Strategy for Research, 1969-1975"). Detect transient gas releases of such species as H_2O, NH_3, CH_4, N_2, H_2, O_2, and CO (no quantitative requirements).

LA-3 - Monitor Atmospheric Contamination Resulting from Lunar Missions, Including Transport and Escape Rates

Santa Cruz. Monitor vicinity of landing site up to 10 days after landing. Species of interest are H_2O, CO, CO_2, N_2, H_2, OH, and NO. Monitor controlled releases of specific volatiles with sensitivity to 10 particles per cm^3.

Falmouth. Contamination monitoring for several months. Measure diffusion and retention times for rocket exhaust gases in lunar surface.

Since the consensus observation requirements, Apollo accomplishments and remaining (post-Apollo) requirements are closely related in this discipline, they are listed below undifferentiated by subobjectives. All measurements listed support each of the Lunar Atmosphere subobjectives.

Consensus Observation Requirements.

Total pressure of neutrals with sensitivity sufficient to detect total pressures down to 10^{-15} torr.

Mass spectra of neutrals whose concentration exceeds 10 particles per cm^3, with capability for isotopic abundance detection to atomic mass 150.

Directed flux of neutrals with capability of detecting direction of motion to ± 10 percent for fluxes of 1 particle/cm^2-sec.

Variation of above parameters to be detected on global and local scales as a function of height above surface, absolute surface position and position relative to sun.

Concentration, mass spectrum, and flux of low energy ($<$ 1 ev) ions (higher energy ions included under Particles and Fields discipline).

Apollo Accomplishments.

Mass spectra of neutral particles will be obtained from 60-kilometer circular orbit on Apollo missions 16 and 17 (Experiment S-165).

Total pressure will be measured at the landing site with a cold cathode gauge on Apollo missions 14 and 16 (Experiment S-058). Mass spectra of neutrals will be obtained at the landing sites of Apollo missions 18 and 19 (Experiment unnumbered). Flux, number density, and mass and energy per unit charge of positive ions will be measured at the landing sites of Apollo 12, 14 and 15 (Experiment S-036).

The orbit experiment, S-165, obtains data in the mass range of 12 - 66 amu with an ultimate sensitivity of 10^{-13} torr.

The total pressure gauge, S-058, was to be emplaced at the sites Frau Mauro and Davy Crater Chain. Its dynamic range is 10^{-6} to 10^{-12} torr.

The mass spectrometer was a candidate for emplacement at two sites to be selected from Mairus Hills, Descartes, Copernicus, and Hadley-Apennine. (These were the prime sites for Apollo missions 16 through 19.) The mass range is 1 to 150 amu with resolution capable of detecting isotropic abundances thro throughout this range. It is sensitive to partial pressures as low as 10^{-14} torr. The suprathermal ion detector, S-036, detects nearly thermal positive ions (0.2 to 48.6 ev) and analyzes their masses to 120 amu (higher energy particles are also detected).

Remaining Requirements.

Apollo measurements do not meet the consensus observation requirements in the following areas:

1. Neutral Atmosphere

   a. Measurement sensitivity - Apollo surface total pressure gauge sensitivity limit is 10^{-12} torr. Consensus requirement is 10^{-15} torr (approximately 40 particles per cm^3).

      Orbit mass spectrometer sensitivity is 10^{-13} torr; surface mass spectrometer sensitivity is 10^{-14} torr.

      Consensus requirement is 10^{-15} torr in both cases.

   b. Mass spectrum range and resolution - Apollo surface experiment adequate. Orbit experiment range 12 to 66 amu falls short of the required range of 1 to 150 amu. Orbit experiment resolution is adequate.

   c. Coverage and duration - Orbit experiment coverage marginally adequate to detect day-night variations at low latitudes with fair statistics. Range of altitudes and inclinations must be expanded. Surface experiment very inadequate for mointoring natural transient gas sources.

   d. Other - All orbital experiments will be concluded before emplacement of surface mass spectrometers; therefore, no correlated surface and orbital measurements of the mass spectra can be made. No directional measurements are planned.

2. Ions

The capability of the suprathermal ion detector seems adequate for most applications. Direct ionospheric sensing from low orbit remains to be performed as does coordinated simultaneous measurement for several sites. Directionality of the ionic flux also remains to be determined.

Particles and Fields

Subobjectives

PF-1 Study the interaction of the solar wind with the moon

PF-2 Study the fundamental physics of plasma interactions

PF-3 Determine the magnetic and electric fields around, on, and within the moon as modified by the relative positions of the earth and the sun

PF-4 Measure the primary and secondary nuclear particles in lunar space and at the surface of the moon

Rationale for Selection

PF-1 - Interaction of Solar Wind with the Moon

There has been considerable speculation as to whether or not the interaction of the solar wind with a lunar magnetosphere would be observable just as is the interaction of the solar wind with the geomagnetosphere, in which the latter is compressed toward the earth in the solar direction and elongated into a tail in the anti-solar direction. Because the lunar magnetic field is so much smaller than that of the earth, a similar bow shock and magnetosheath region may not be observable. Estimates of the position of this lunar magnetosheath in the solar direction have ranged from standoff distances at the surface to 600 kilometers above the surface. The evaluation will require both orbital and surface measurements.

The passage of the moon through the tail of the geomagnetosphere and the modification of the solar wind flux and magnetic field in the vicinity of the moon during this event is also of considerable interest. Also, there has been some conjecture as to whether a few charged particles originally associated with the moon become trapped in the geomagnetosphere and find their way eventually to the vicinity of the earth.

The solar wind radiation damage effects on natural lunar surface materials, as well as on artificially introduced samples in the ambient lunar vacuum, is of continuing scientific and technological interest and will shed light on lunar evolution and space radiation effects on engineering materials.

PF-2 - Fundamental Physics of Plasma Interactions

Observations of the interplanetary plasma from the surface of the moon have advantages over those made from a moving spacecraft, wherein the latter there is difficulty separating the spatial from the temporal effects. So far, limited measurements near the lunar surface have not revealed a bow shock caused by the interaction of the solar wind with the lunar magnetosphere. Thus far, measurements of the lunar magnetic field have yielded only extremely small values (the order of a few gammas).

The moon provides a unique place from which to study a collisionless plasma; i.e., one in which the collision-mean-free path (approximately 10^7 kilometers) is much greater than the cyclotron radious (approximately 10^3 kilometers), and the collision period (approximately 10 hours) is large compared to the time scale for phenomena of interest. No such plasma experiments can be formed in a laboratory on earth because the dimensions of the vacuum chambers would not be large enough.

Of further interest will be a comparison of the properties of the relatively slow moving plasma within the geomagnetic tail as the moon swings through it compared to the properties of the solar wind which moves at least an order of magnitude faster with respect to the moon.

PF-3 - Magnetic and Electric Fields

Because the magnetic fields in interplanetary space are quire small and expected to vary, particularly at times during which interesting phenomena are occurring (such as during periods of high solar activity or passage of the moon through the geomagnetic tail), there is an obvious advantage to having simultaneous measurements from numerous symmetrically placed points in lunar space and on the lunar surface. The measurement of magnetic fields is essential to the understanding of the propagation of charged particles in the vicinity of the moon, and to the composition and past history of the lunar interior

The electric field measurements in the vicinity of the moon are essential for the understanding of the interaction of the solar wind with the moon, the conductivity of the interplanetary plasma and acceleration processes occurring within the plasma. Electric fields as large as 1 volt/meter may arise in connection with the shock front formed by the encounter of the interplanetary plasma and the moon. In the cases where a shock is not formed, electric field data would help explain the rapid convection of magnetic fields through the moon.

PF-4 - Primary and Secondary Nuclear Particles

Solar particles above solar wind energies, primarily in the 10's of kev range up to 1 Mev, are of interest because they may also participate, as well as the solar wind, in the formation of the as yet unobserved bow shock at the moon. Such a shock might arise for conditions not prevailing thus far; e.g., during Explorer 34 measurements.

Higher energy solar particles may be measured at the lunar surface and compared with partially geomagnetically shielded fluxes arriving simultaneously in the vicinity of the earth. These measurements would give some insight into the spatial distribution of solar flare particles. The directionality of these particles will be of continuing interest in the explanation of propagation mechanisms. A comparison of fluxes on the solar and antisolar sides of the moon would be of interest.

Secondary nuclear particle detection and analysis near the lunar surface or beneath the surface may provide insight into lunar interior composition and evolution.

Simultaneous front and backside measurements of galactic flux would yield information on departures from isotropy of fluxes and effects of the interplanetary magnetic field on the low-energy end of the spectrum.

Observation Requirements

PF-1 - *Study the Interaction of the Solar Wind With the Moon*

Santa Cruz. Collect data concerning the lunar magnetic field, gross conductivity, distribution of conductivity, and interior temperature.

IITRI.

Differential energy flux: 10^5 - 10^{11} particles per cm^2-sec-steradian kev

Energy range: 1.2×10^2 - 5×10^3 ev/protons

$3 - 3 \times 10^2$ ev/electrons

Measurement accuracy: $\pm$ 2 percent in flux and energy

NAS.

2.5×10^8 per cm^2-sec

From propagation of solar wind magnetic field transient through moon, lunar interior temperature inferred to be 800 C

Measure Kr and Xe content of surface materials

Analyze precise photography of topography shaded from solar wind

Other.

Analyze erosion of surface layer by solar wind and compare with lower layer

10^8 - 10^9 per cm^2-sec

$0 - 2 \times 10^4$ ev

Consensus.

Measure solar wind distribution in space and on surface around moon simultaneously

$10^7 - 10^{10}$ per cm^2-sec

$10^2 - 2 \times 10^4$ ev

Measure directionality

Compare properties of their lunar surface layers eroded by solar wind and lower layers.

Apollo Accomplishments. Heavier ion content of the solar wind determined on Apollo 11 and 12 on the lunar surface. Solar wind proton and electron spectral ($1 \leq E \leq 40$ kev), direction, and time variation on surface on Apollo 12 and 15.

Remaining Requirements. Simultaneous high and low altitude and surface measurements of solar wind flux in energy and direction as moon passes through geomagnetic tail at symmetric points in space and on lunar surface (e.g., at pairs of equatorial stations located at ± 60 degrees to the earth-moon line).

PF-2 - Study the Fundamental Physics of Plasma Interactions

Santa Cruz. Measure plasma angular distribution in two orthogonal planes and energy distributions in 1 to 5 seconds.

NAS. Measurement of large scale MHD flow in solar system (e.g., around moon) may cast light on early solar system evolution.

Other. Search for formation of bow shock at the moon (thus far not observed; may be none).

Compare fluxes in plasma sheets behind earth and moon with incident solar plasma.

Consensus. Same as for PF-1.

Apollo Accomplishments. Plasma angular distribution measured in one plane and energy distribution measured in 10 to 20 seconds on Apollo 20. Pioneer and AIMP recommended for F1, F2, Fe and F4 in early 1970's.

Remaining Requirements. Provide resolution times of 1 to 5 seconds for energy and angular distribution in two orthogonal planes.

PF-3 - Determine the Magnetic and Electric Fields Around, On, and Within the Moon as Modified by the Relative Positions of the Earth and the Sun

Santa Cruz. Measure magnetic fields simultaneously at two equatorial stations at ± 60 degrees to earth-moon line and subsequent at three equatorial stations 120 degrees apart and at one high latitude station with simultaneous orbital measurements.

Magnetic fields: 0 to 100 gammas ± 0.1 gamma

Frequency response: 0 to 20 kHz

Sample frequency: >1 per second

Electric fields: 10 to 10^2 volts/meter

Frequency response: 1 to 10^4 Hz

Sensitivity: <1 millivolt/meter

IITRI. Relate measured magnetic anomalies with mascons revealed by gravity measurements P.1.

0.01 - 100 gammas ± 0.01 gamma or 0.5 percent

0 - 20 kHz

NAS. 2 - 8 gammas

Consensus.

0.5 - 1000 gammas ± 0.1 gamma

0 - 20 kHz

Sampled at 1 per second

Apollo Accomplishments. Magnetic field measurements on the lunar surface on Apollo 12, 15, and 16. Electric field measurement on lunar surface on Apollo 19.

Remaining Requirements. Measure magnetic fields simultaneously on lunar surface at equator on earth-moon line at ± 60 degrees, and subsequently at three equatorial stations 120 degrees apart and at one or more high latituddes with nearly simultaneous orbital measurements; e.g., one equatorial and one polar orbit. Measure electric fields in the range of 0.5 to 100 ± 0.1 gammas, 10 - 10^2 volts/meter.

PF-4 - Measure the Primary and Secondary Nuclear Particles in Lunar Space and at Surface of the Moon

Santa Cruz.

Low-energy solar particles (above plasma energies) 10^4 - 10^6 ev
Particles may be accelerated by shock waves
High-energy solar particles
High-energy galactic particles

IITRI.

Secondary charged particles from lunar surface: 0 - 10^3 per cm^2-sec
All directions
Resolution: ± 10 percent in energy and flux
1 ev - 500 Mev

Other.

10^2 - 10^5 per cm^2-sec

5 x 10^6 - 5 x 10^8 ev protons

10^7 - 10^{10} ev electrons

Consensus. Surface measurements and orbital measurements should be made of primary particles and surface measurements of secondary particles in the 10^4 - 10^6 ev range. Primary particle fluxes up to 10^{10} per cm^2-sec, and secondary fluxes up to 10^4 per cm^2-sec should be measurable.

Measure protons 3 x 10^5 - 5 x 10^8 ev, electrons 5 x 10^4 - 5 x 10^7 ev as a function of direction with ± 10 percent resolution in energy and flux.

Measure galactic nuclei flux 1 - 20 per cm^2-sec, 5 x 10^8 - 10^{10} ev ±20 percent resolution. Discriminate from solar flux.

Apollo Accomplishments. Particles and fields subsatellite on Apollo 19 will measure 2.5 x 10^4 - 2 x 10^6 ev protons and 2.4 x 10^4 - 3.2 x 10^5 ev electrons. Will search for boundary layer at low altitude (approximately 100 kilometers).

Lunar surface measurements of solar protons and electrons are to be made on Apollo 17 and 19.

Cosmic ray detector will be operated at lunar surface on Apollo 16 and 18.

Remaining Requirements. Search for boundary layer of interaction of low-energy particles and moon (or lunar magnetosphere) with subsatellite probes measuring fluxes as on Apollo 19 and lower energies at low altitudes from 10 kilometers to 300 kilometers.

Make lunar surface measurements in antisolar and solar direction of incident charged particles during solar particle event and compare.

Conduct galactic particle flux measurements at antisolar location on lunar surface. Discriminate from solar particle influence.

Geodesy/Cartography

Subobjectives

GC-1 Establishment of a three-dimensional geodetic control system over the entire lunar surface in terms of latitude, longitude, and height above the chosen reference figure

GC-2 Collection of photogrammetric data and construction of topographic maps for scientific purposes and base site evaluation studies

Rationale for Selection

The selected Geodesy/Cartography subobjectives reflect the limited scope assigned arbitrarily to this discipline. Most physical geodesy (e.g., the determination of the large-scale lunar gravity field) was assigned to the geophysics discipline. However, the activities required to implement these subobjectives are amon the most important and most universally recognized in the lunar exploration program. They result in the basic matrix against which most other physical data will be displayed for the determination of geographical trends. In addition, the scale of activity being considered for the lunar surface base, coupled with unique communication and navigation problems to be encountered on the lunar surface, makes top quality maps of such areas indispensible.

Observation Requirements

GC-1 - Establishment of a Three-Dimensional Geodetic Control System Over Entire Lunar Surface in Terms of Latitude, Longitude, and Height Above Chosen Reference Figure

Falmouth 1965.

Metric photography (6-inch focal length 9 x 9 format)
(For 10-meter tolerance) precision = 1 part in 200K

Radar or laser altimetry, stellar observation from ground stations, absolute gravity measurements, control grid

3D accuracy of ±100-meter, vertical accuracy of ± 10-meter (1 sigma)

Photogrammetric triangulation orbital dynamic supplemental control

Woods Hole 1965.

Lunar orbiter metric photography, controlled from orbit parameters, and orientation and radar altimetry

USGS No. 19, 1970.

Film return, wide angle (60 degrees to 90 degrees) metric photography

Time and stellar photography coupled, radar altimetry

Santa Cruz 1967.

Stellar observation/photography from ground stations

Absolute gravity measurement

Metric with stellar photography: 6-inch focal length resolution 10-meter or 12-inch resolution 6-meter

Laser altimetry

IITRI 1966, 1970.

Metric photography - resolution 2 meters

Consensus. Metric photography, 6-inch focal length in conjunction with stellar photography and precise timing and radar or laser altimetry.

Apollo Accomplishments. Three-inch focal length Fairchild metric camera to fly on Apollo 16 through 19. Includes simultaneous stellar photography and altimetry.

Remaining Requirements. Metric photography with simultaneous stellar photography, precise timing, and laser altimetry. Polar orbit; ground observations to include absolute gravity measurements, stellar photo, and surface triangulations to 1-inch accuracy. Geodetic grid accuracy of ± 100 meters, ± 10 meters vertically.

In response to Santa Cruz recommendations, Apollo accomplishments will not significant affect overall geodetic program for they will be limited to equatorial zone, whereas synoptic mapping should be from polar orbit.

Absolute gravity measurements are important in establishing the geodetic grid. Ground-based measurements should be performed with an absolute gravimeter.

GC-2 - Collection of Photogrammetric Data and Construction of Topographic Maps for Scientific Purposes and Base Site Evaluation Studies

Falmouth 1965.

Base maps for geology, 1:250,000 entire surface, locally at 1:25,000

Accuracy ± 10 to ± 100 meters

Woods Hole 1965.

Topo base maps of scales of 1:1,000,000, 1:250,000, and locally 1:100,000

USGS No. 19, 1970.

Adopts Santa Cruz requirements

Santa Cruz 1967.

Base maps for geologic mapping:

1:5,000,000; 1:1,000,000 complete coverage
Special areas at 1:250,000; 50,000; and 5,000

HR photography, 1-meter resolution

Orthographic, mercator and polar stereographic projection

IITRI 1966, 1970.

Metric photography - resolution 2 meters
High-resolution photography - resolution 0.5 meter

Consensus. Metric photography as previously mentioned. Maps required scales of 1:1,000,000; 1:250,000 and 50,000 of special areas.

Apollo Accomplishments. Three-inch metric photography (previously mentioned). Nonmetric high-resolution photography, 24-inch focal length to photograph selected sites on Apollo 16 through 19 missions.

Remaining Requirements. Metric photography as previously mentioned. Photogrammetric construction of base maps, complete surface coverage at 1:5,000,000 and 1:1,000,000. Local coverage at 1:250,000, 1:50,000 and 1:5,000. Supplementary 24-inch photography required for feature interpretation.

Consistent and metrically accurate mapping program will await determination of geodetic grid with ± 100-meter accuracy and ± 10-meter vertical accuracy of stations.

Engineering, Technology, and Operations

Subobjectives

- ET-1 Support the scientific exploration of the planets
- ET-2 Verify performance of a long duration life support system
- ET-3 Determine effects of long term exposure of equipment and materials to the lunar environment
- ET-4 Support the extraction of water and oxygen from lunar materials
- ET-5 Support the processing and storage of propellants
- ET-6 Support the deployment and assembly of large structures on the lunar surface
- ET-7 Support the utilization of lunar materials for environmental and structural support purposes

Rationale for Selection

Successful scientific exploration of the moon depends, among other things, upon a sound technological base to assure reliable operation of equipment, steady flow of supplies, trained support personnel, accurate navigation systems, and dependable environmental protection. In addition, operations at the lunar base must be performed as efficiently as possible to minimize program costs. Personnel must be used effectively and, wherever possible, lunar materials should be substituted for earth materials. An example of this kind of savings would be to use lunar rocks and soils to form a cement which could provide foundation support to the many structures to be assembled. Many of these subobjectives, which must be accomplished during lunar exploration, will provide data which may be applicable to planetary exploration, such as development of a life support system. No experiments are performed exclusively for planetary exploration purposes.

Consensus Observation Requirements

ET-1 - Support the Scientific Exploration of Planets

Calibration of remote sensing techniques
Sampling survey techniques
Stereophotogrammetry
Dangerous-terrain warning techniques
Visual techniques in land navigation

ET-2 - Verify Performance of a Long-Duration Life Support System

Biological monitor and eco-system prototype
Evaluation of hydrocarbons-utilizing organisms
Growth, development, production, and survival of plants
Growth, development, reproduction, and survival of animals

ET-3 - Effect of Long-Duration Exposure of Equipment and Materials to the Lunar Environment

Corrosive action of lunar surface material
Lunar surface dust environment
Solid state materials
Damage to lunar base equipment
Early materials-dynamic tests - thin film bearings

ET-4 - Support the Extraction of Water or Oxygen from Lunar Materials

Water discovery techniques
Assay methods and equipment development
Materials mining and transportation equipment and processes
Water extraction processes
Water reduction process equipment
Heat transfer in liquids through natural convection
Heat transfer in film and drop condensation processes

ET-5 - Support the Processing or Storage of Propellants

Storage equipment development (water, GOX, GH_2, LOX, and LH_2)

ET-6 - Support the Construction of a Lunar Observatory

Earth and RFI noise background
Lunar optical astronomy test program
Remote occulting disk as solar observatory
Engineering properties of the lunar surface
Lunar seismic environment
Shielding and construction support properties of lunar soils
Lunar surface and subsurface electrical parameters
Lunar strata electromagnetic propagation parameters
Lunar RF noise
Lunar surface transmission line interaction
Electrical transmission line routes
Electrical systems grounding
RF groundwave propagation

ET-7 - Support the Utilization of Lunar Materials

Explosive techniques for surface modification
Digging and cutting tool assessments
Metals joining techniques on lunar surface
Differential thermal analysis of potentially castable materials
Self-welding characteristics of lunar ores
Particle adhesion in mechanical processing
Lunar dry cement and concrete applications

Several subobjectives have observation requirements which support the engineering design and development of the lunar science equipment. As the results of these observations can significantly affect the cost and reliability of the equipment, they have been added as engineering experiments to the precursor LSB site selection missions to the moon in the pre-1985 era. The precursor experiment list is given in Section 3, Part 3. Of the ETO subobjectives only the lunar cement experiment is a precursor.

3.0 MISSION SCIENCE EQUIPMENT

The measurement requirements identified in the previous section define the range and accuracy of the sensors and other science equipment necessary to accomplish the LSB mission objectives.

The scientific equipment selected for the LSB is classified as major or minor equipment depending on its weight which, in turn, is an indicator of complexity, size, cost, and manpower requirements. Equipment weighing less than 100 pounds is treated as minor equipment. Major equipment such as telescopes and drills have been selected from an assortment of preliminary designs in various NR, NASA, and other studies. Minor equipment has been selected from existing space-rated components or based on extrapolations into the lunar environment of existing components by the manufacturer.

The objective here was not to define exact equipment configurations for use in the 1985 period, which is not felt to be realistic, but to conservatively size the logistics and surface mission payload requirements assuming the aggregate will not change appreciably. A complete list of all the science equipment is given in Appendix A. Also included are the individual weight, power, volume, and data rates of the equipment items.

3.1 MAJOR SCIENCE EQUIPMENT

The configurations of the 1000-foot drill, the 100-inch optical telescope, the 50-inch telescope and all four radio telescopes have been extensively modified from those in the referenced lunar surface studies in order to integrate more effectively with the LSB mission requirements. The X-ray telescope and the 100-foot drill configurations were used directly.

3.1.1 Drills

Lunar surface drilling is required to determine the composition of the moon's shallow subsurface. Three types of drills are planned for the LSB -- a manual 10-foot drill and two semiautomatic drills, one for the 100- and one for the 1000-foot holes.

Drilling is a necessary step in the exploration of the moon because it provides the key to subsurface geology. All drills being developed for this purpose are core drills, that is, they cut a solid cylindrical core which can be transported back to earth for subsequent analysis. The extraction of this core sample, however, is not the sole objective of the lunar drills, for after the core is taken the hole will be available for the emplacement of geophysical instruments such as heat probes, radiation detectors, and seismic devices.

Holes have been mechanically drilled in rock on earth for more than a century, although the greatest advances in equipment did not occur until the last 20 years (tungsten-carbide insert bits for percussive drilling and the wire-line system for diamond drilling). When all factors of lunar drilling are considered, however, they combine into an intricate and complex problem involving the environmental effects of high vacuum, reduced gravity, and temperature extremes not encountered on earth.

To drill a hole on earth to a predetermined depth within a rigid time schedule, while collecting good samples, requires a certain amount of skill. The earth driller uses a machine which has been thoroughly tested, and, in addition, he has relatively easy access to an unlimited supply of replacement parts. Although the components of the lunar drills will have been rigorously tested, it is extremely difficult to test-run the complete drilling system in the temperature-vacuum-gravity environment to be encountered on the moon.

The lunar environment will have a significant effect on the design and operation of a drill. Systems for drilling deep holes on earth depend on water or air as the flushing medium to remove cuttings and cool the bit. Normally, the flushing medium flows down through the hollow drill rods across the face of the bit, and then out of the hole in the annular space between the drill rod and hole wall. A liquid flushing medium probably accounts for some lubricating action at the bit-rock interface; soap or glycerine additives are sometimes used to enhance this action.

Lack of readily available water and the ultrahigh vacuum indicate that drilling on the moon be accomplished dry; that is, without any flushing medium. Although liquids could be used in lunar drilling, spacecraft weight limitations limit transport of the required quantity from earth. The possibility that earth-produced media used on the moon may contaminate lunar samples also restricts their use. Consequently, all lunar-drill systems under current development use an augering action to remove cuttings from the bottom of the hole mechanically.

Cooling the drill bit without a flushing medium is a significant problem, especially in rotary systems which convert a high percent of the available energy into heat at the bit. One approach to the problem is an internally cooled diamond bit that uses a closed-loop cooling system and a highly conductive matrix material that will conduct bit heat through the drill string rapidly. Removal of heat through the cuttings which serve as a heat sink is another possibility.

Another possible difficulty in lunar drilling is that lunar vacuum may cause rock cuttings to adhere to each other or to the drill steel. Drilling tests have been conducted in vacuum chambers in the range of 10^{-6} to 10^{-7} torr and, at these pressures, there do not appear to be any adhesion problems with the proposed cutting-removal systems. No drilling under simulated lunar vacuum conditions has been performed. Bottom-hole pressures caused by outgassing of rock as it is being drilled may also inhibit particle adhesion or welding in these tests. Whether outgassing will occur in lunar rocks is not known, although information on the outgassing characteristics of simulated lunar rocks being investigated by the Bureau of Mines may help to answer this question.

The other difficulties that lunar temperature and gravity impose on drilling systems and techniques can probably be overcome by our present technology. Suitable design criteria should be adequate to cope with the temperature range of -250 F to +250 F to be encountered on the moon. Thrust, an important parameter in drilling, will be affected by lunar gravity, which is approximately one-sixth that of earth. For example, the 10-foot drill, which will be hand-held by the astronaut, must operate under an axial thrust of somewhat less than 20 pounds. This thrust will be adequate for unconsolidated material or soft rock, but will be insufficient for drilling harder rock. The deepest drill will require anchoring to the lunar surface to provide adequate thrust for drilling hard rock.

Other constraints that are placed on lunar-drill systems are total weight and available power. Since the volume of rock removed is directly proportional to power input, the energy source powering the drill becomes a critical factor in its performance.

Shallow Drill

The 10-foot drill considered for the LSB is the existing flight-qualified Apollo Lunar Surface Drill (ALSD), Figure 3.1-1, scheduled for first use on Apollo 15. The ALSD is designed to be able to drill and core two 10-foot holes within 66.4 minutes. The drill is powered with a self-contained battery, and the entire system weighs approximately 25 pounds. The drill utilizes a 5-tungsten-carbide-tooth rotary percussive bit rotating at 280 rpm with a blow frequency of 2250 bpm. The drill drills at a rate of 1 inch per minute in dense basalt and 5 inches per minute in vesicular basalt. The cuttings are carried to the surface by helical auger flights on the outside of the drill string (Reference 1).

Intermediate Drill

The 100-foot drill concept selected for the LSB is based on a Westinghouse design, Figure 3.1-2, which is like a conventional wire-line rotary diamond drill except for the cuttings-removal mechanism. The above hole portion consists of a drill drive mechanism and a structural support frame to react the static and dynamic drill loads. The design static load is a steady 1600-2000 pounds axial force on the drill bit and the primary dynamic load of 800-1200 pounds occurs when the cores are broken via tensile failure prior to recovery. The drive mechanism rotates the drill stem and, through a ball drive system, maintains the steady axial load while advancing the bit. A winch and wire drum automatically raises and lowers the chip basket. The rotary diamond drilling has been found to be superior by Westinghouse to the rotary percussive drilling in simulated lunar bedrock. Rotary percussive results in faster drilling when the materials are unconsolidated and in vesicular basalts, which is considered to be more typical of the physical composition of the surface regolith.

The downhole portion consists of a surface-set diamond coring bit, a core barrel system, and a cutting container. The outer core barrel has auger flights on the outside diameter which transport the cuttings to a point

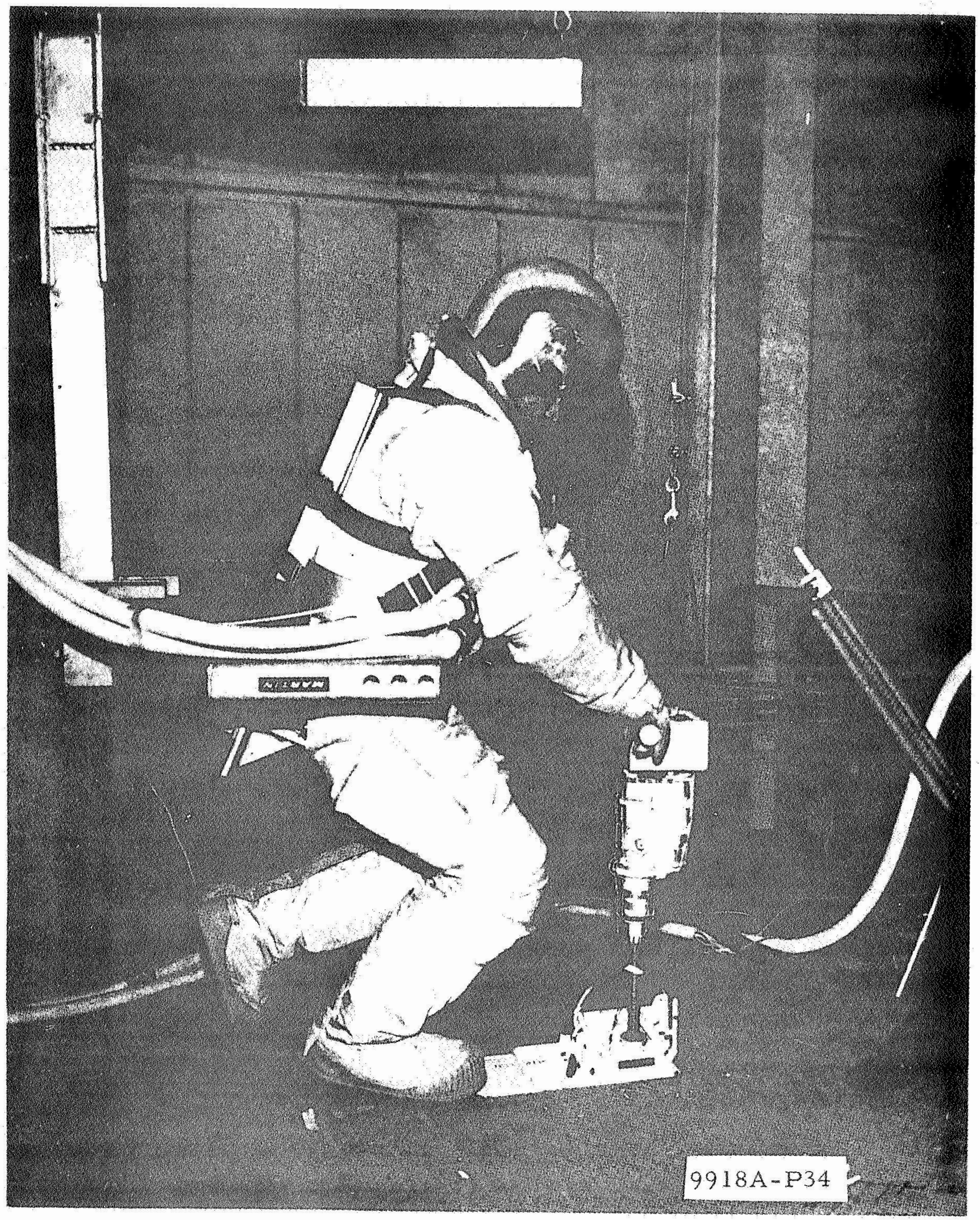


Figure 3.1-1. Apollo Lunar Surface Drill

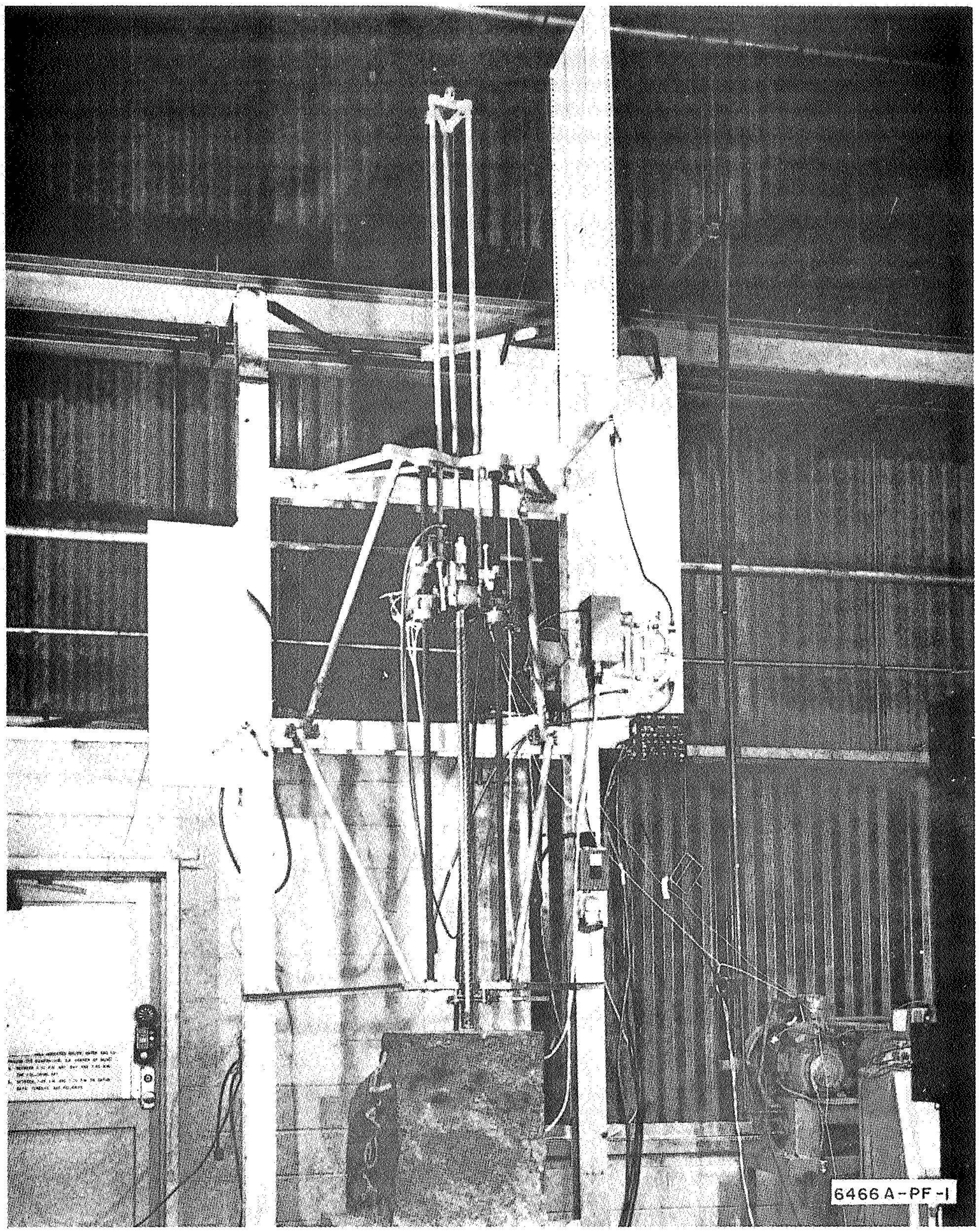


Figure 3.1-2. Westinghouse Lunar Drill Engineering Model

where they are turned inwardly to the cuttings container which is internal to the outer core barrel and a part of the inner core barrel assembly. The inner core barrel slides down over the core as it is drilled. A core lifter arrangement at the lower end of the inner core barrel grasps the core for the core breaking operation and also prevents the core from slipping out after it is broken. After drilling 5 feet and breaking the core, an assembly is lowered down the drill string annulus and automatically fastens to the inner core barrel assembly. The inner core barrel assembly is carried to the surface leaving the drill string in the hole. The inner core barrel assembly is emptied of cuttings and core and replaced by lowering it down the drill string annulus. A 5-foot section of drill pipe is added, and the cycle is repeated.

The diamond rotary bit has a dry life of 125 feet of Dresser basalt which has an average compressive strength of 50,000 psi and a Shore hardness of 84. Dresser basalt is a hard dense intrusive basalt and is reputed to be one of the toughest igneous rocks to drill. The capability to drill dry eliminates the need for drilling consumables to fluidize chips and cool the bit.

A 5-foot long casing is utilized to prevent hole cave-in in unconsolidated rock to that depth. The casing can be lengthened by adding additional segments. (Reference 2)

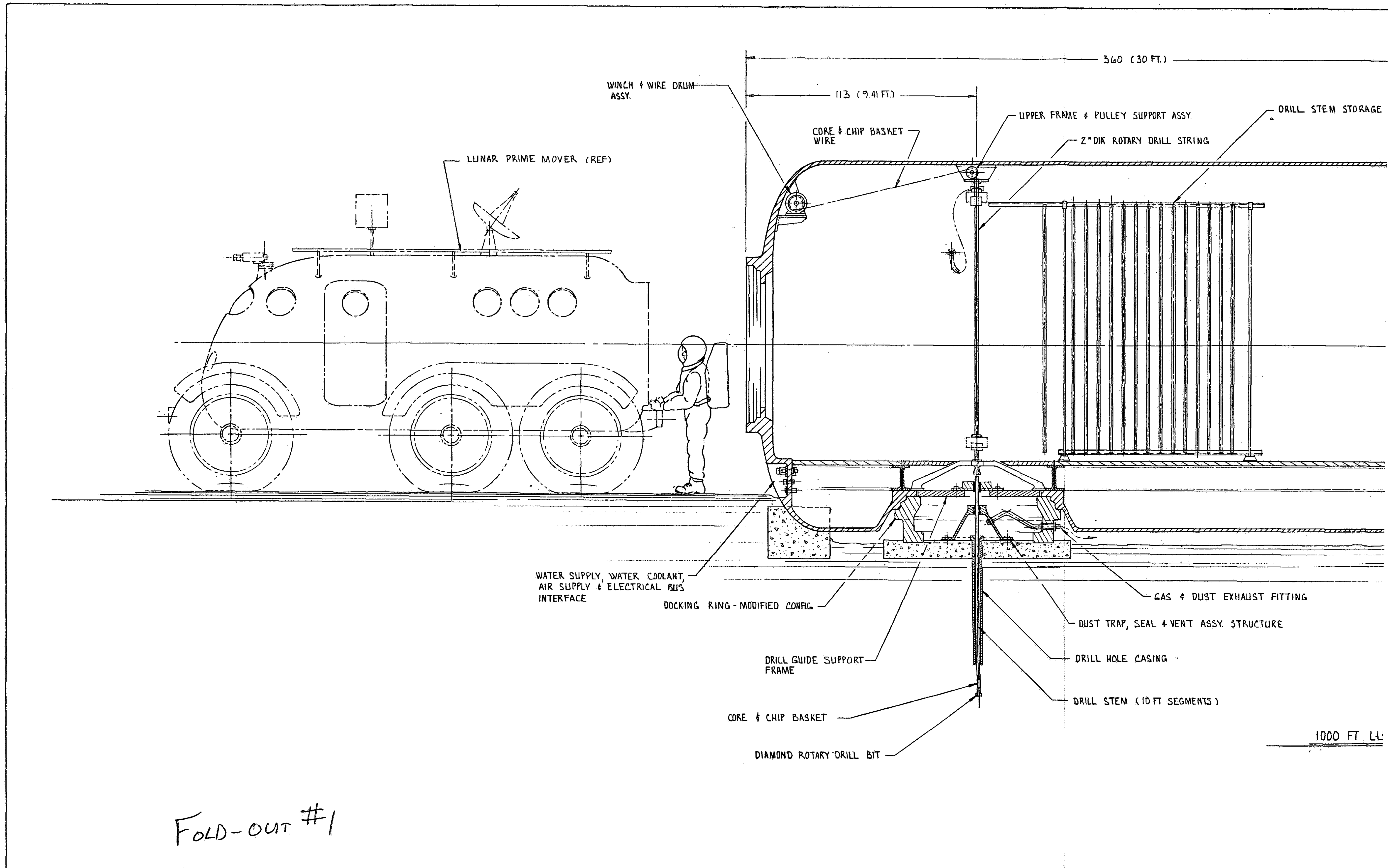
Deep Drill

The 1000-foot LSB drill concept is based on a direct extension of the Westinghouse 100-foot drill design. At this time, there are no deep lunar drills in development. Drawing 2284-10A shows a conceptual representation of this drill in the operational mode. The design is similar to the smaller drill except that a drill stem storage rack is shown for automatic feed of barrels to reduce crew workload. A module is shown enclosing the drill to permit shirtsleeve operations. This simplifies the crew tasks and the equipment design because it does not have to cope with the full lunar environment. This module is one of several which will be delivered to the lunar surface as containers for the prime movers, power carts, and other elements of the LSB. These containers or transportation modules will then be reused on the surface for various specific functions for which they will be predesigned.

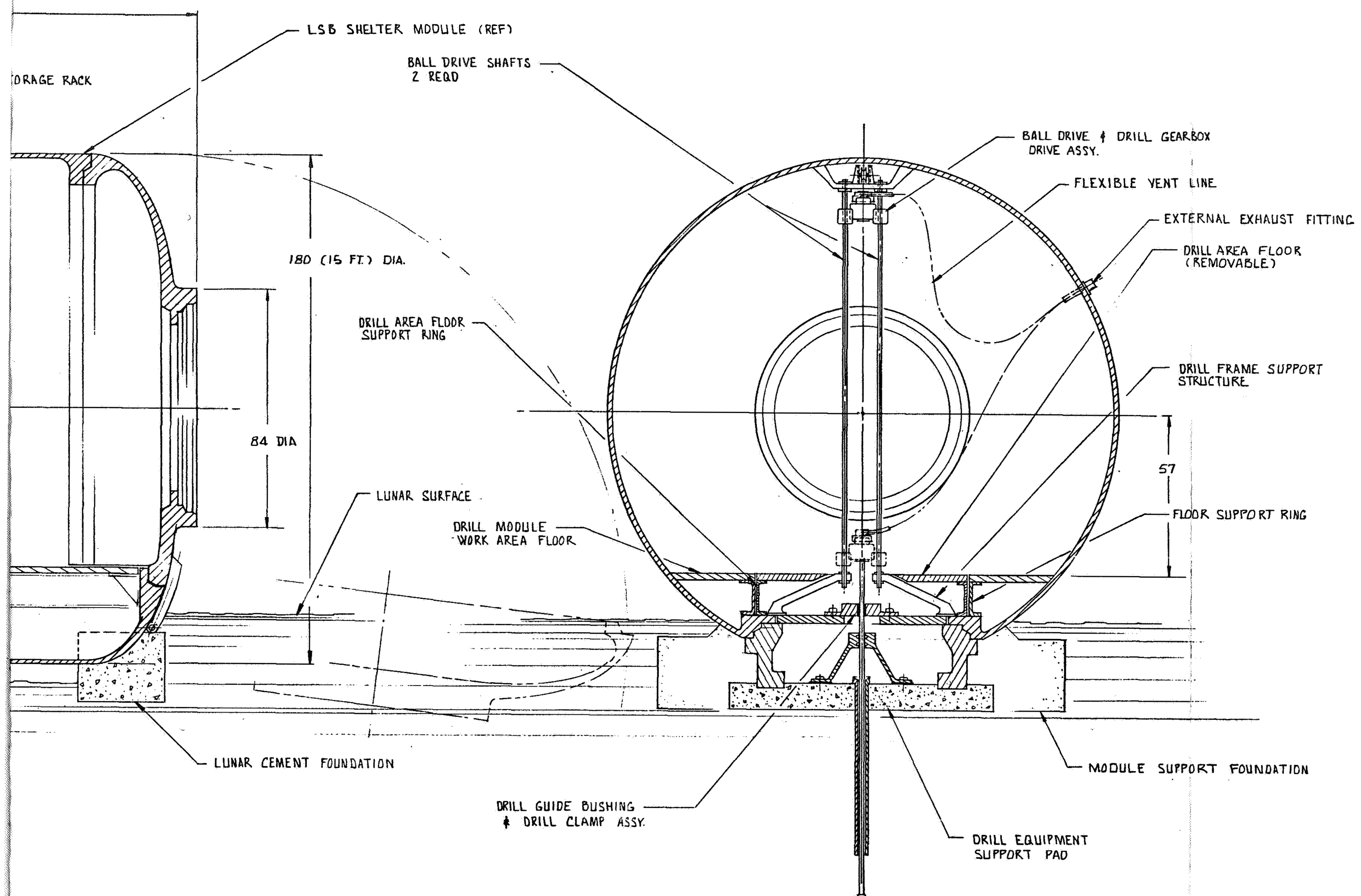
Two desirable additions to this drill design would be a retractable bit which could permit replacement without withdrawing the entire drill string and a method for faster core and chip removal. Improved bit design for longer life will also reduce the drilling time.

3.1.2 Telescopes

The astronomy equipment consists of two nonsolar optical telescopes, four radio telescopes and a grazing incidence X-ray telescope. This equipment was selected to complement and extend the information obtained in earth orbital astronomy and to capitalize on the moon's stable platform, long-duration viewing, sky background, darkness, shielding from earth-based


360 (30 FT.)
113 (9.41 FT.)
WINCH & WIRE DRUM ASSY.
CORE & CHIP BASKET WIRE
UPPER FRAME & PULLEY SUPPORT ASSY.
2" DIA ROTARY DRILL STRING
DRILL STEM STORAGE
LUNAR PRIME MOVER (REF)
WATER SUPPLY, WATER COOLANT, AIR SUPPLY & ELECTRICAL BUS INTERFACE
DOCKING RING - MODIFIED CONFIG.
DRILL GUIDE SUPPORT FRAME
CORE & CHIP BASKET
DIAMOND ROTARY DRILL BIT
GAS & DUST EXHAUST FITTING
DUST TRAP, SEAL & VENT ASSY. STRUCTURE
DRILL HOLE CASING
DRILL STEM (10 FT SEGMENTS)
1000 FT. LU

FOLD-OUT #1



FT. LUNAR DRILL & SHELTER MODULE
SCALE 1/20

FOLD-OUT #2

THIS PRINT REDUCED 50%

1-3-7, 1-3-8

SD 71-477

SCALE 1/20	DR. [signature] DATE 3-19-71 MODEL	SPACE DIVISION NORTH AMERICAN ROCKWELL CORPORATION 12214 LAKEWOOD BOULEVARD, DOWNEY, CALIFORNIA	
1000 FT. LUNAR DRILL CONFIG. LUNAR SURFACE BASE CONCEPT			2284-10A

radiation interference, and large platform dimensions which permit the erection of long interferometers.

Grazing Incidence X-Ray Telescope (Reference 3)

The importance of the soft X-ray portion of the electromagnetic spectrum is in part due to the properties of the interstellar medium, which strongly absorbs between the near ultraviolet and ultra-soft X-ray region; thus, the first opportunity to observe objects at photon energies appreciably higher than visible occurs in the soft X-ray region. Empirically, however, the spectrum of all objects yet observed is rapidly decreasing with increasing energy in this wavelength interval, and consequently precise observations become much more difficult with increasing energy. The soft X-ray window is thus of natural importance.

The principal feature of X-ray astronomy is the presence of discrete sources in which the X-ray emission equals or exceeds all other forms of radiation output. About 30 sources are reported at the present time; the variety and number of sources indicate that X-ray production on this scale is not some minor astrophysical phenomenon, but is dominant in many instances. Major objectives are to provide spatial and spectral resolution of point and extended galactic X-ray objects, as well as polarization data, in the spectral range from about 2 to 200 angstroms.

The experiment program consists of a large X-ray telescope with multiple experiments aimed at measurements of X radiation from stellar objects. Those experiments presently identified are of the following type:

1. Polarization of X radiation (12.4 Å to 3.1 Å)
2. Spectral measurements of X radiation (25 Å to 1.5 Å)
3. Precise location of X-ray sources

This telescope has a 40-inch diameter gross aperture with a 400-inch focal length. An image of an X-ray source is formed by reflection at grazing incidence from a combination of parabolic and hyperbolic surfaces of revolution. The low reflection coefficient of X-rays at angles greater than grazing incidence restricts the effective aperture to a thin annulus; most of the aperture is blocked by an opaque disc. The X-ray image is observed with photographic plates or interchangeable electronic detectors, permitting discrimination of several ranges of X-ray energies.

The need for long observation times to detect weak X-ray sources makes an equatorial mount desirable, i.e., one wherein the principal axis of rotation is perpendicular to the plane of the lunar equator. The motor-driven mounts are provided with position sensors, permitting remote controls to align the telescope with the object to be observed. An auxiliary star-sensing optical system provides accurate automatic tracking capability. Stellar-aspect cameras are used to obtain precise position data. General performance parameters are shown in Table 3.1-1.

Table 3.1-1. General Performance

Energy spectrum	.5 to 200 kev (25 to 0.06 Å)
Energy resolution	1 to 10 kev
Spatial resolution	1 arc second
Field of view	1 to 2 degrees
Coverage	Up to 95 percent of sky -- dependent on location of instrument
Effective aperture	7 cm^2

The telescope may be operated remotely, requiring personnel only during setup, alignment, and maintenance operations, or when a new or reused sensor is incorporated. Radiation, micrometeorite, and thermal protection is provided by an integral protective shielding jacket contoured to completely enclose sensitive equipment.

The experiment equipment consists of a grazing incidence telescope which focuses radiation from selected stellar targets alternately onto one of three X-ray sensors.

1. Polarimeter 12.4 Å to 3.1 Å
2. Crystal spectrometer 25 Å to 1.5 Å
3. Solid state detector 25 Å to 3.0 Å

An X-ray diffraction grating system is positioned in front of the telescope mirror while using the imager to perform spectral measurements of extended sources. Figure 3.1-3 illustrates one conceptual configuration of the telescope assembly.

The X-ray polarization and spectroscopy experiments require an X-ray imaging system of good resolution and significant collecting area. In the suggested system, X-rays are incident on a paraboloid mirror surface, from which they are reflected to a hyperbolid, and then to the focus. The mirrors are in the form of cylinders, and multiple two-mirror systems are used in a concentric array to provide a large total collecting area. Each two-mirror system is therefore a unique form of Cassegrain. The experiments will alternately be placed at the telescope focus.

The objective of the polarimeter experiment is to provide precise measurements of the polarization of X-radiation from a large number of X-ray sources in the energy region between, roughly, 1 and 4 kev (12.4 and 3.1 angstroms). This polarimeter could be used to map the polarization of such interesting objects as the Crab Nebula and the M87 radio galaxy. By

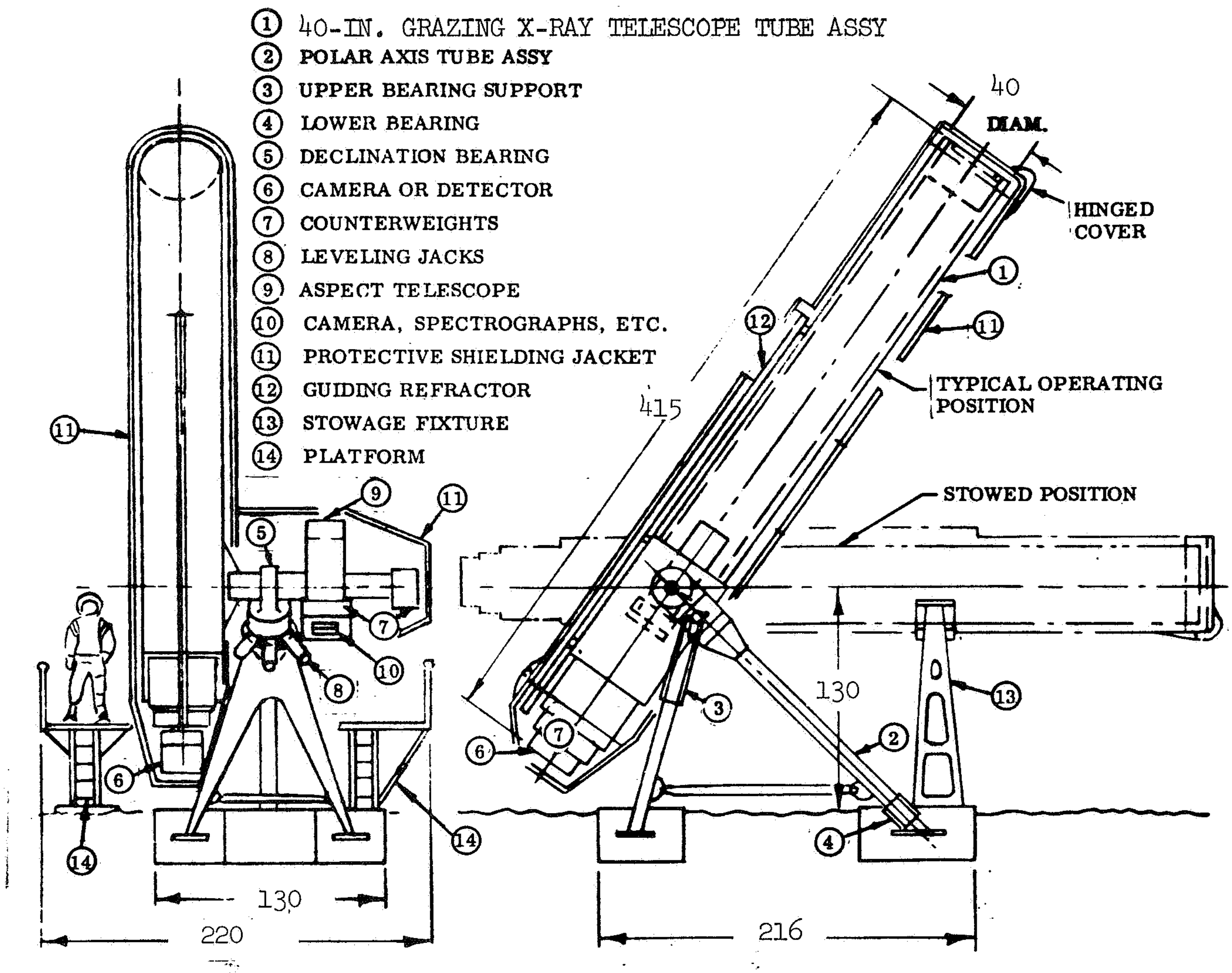


Figure 3.1-3. X-Ray Telescope
(Dimensions in Inches)

measurements of the polarization of astronomical X-ray sources, knowledge can be gained about the originating mechanisms of such radiation. Detection of polarized radiation would be convincing evidence that at least part of the radiation is of the synchrotron type emitted when electrons are accelerated by a magnetic field.

The polarimeter is placed at the focus of the X-ray telescope for conduction of the experiment. The basic part of the polarimeter is the scatterer contained in a tube one inch in diameter and 13 inches long. This tube will probably be filled with solid hydrogen, although liquid hydrogen may be considered. The tube is a 90-percent transparent perforated silver tube sealed with aluminized mylar. Eight geiger counter-type detectors surround the scatterer. These detectors are about 1.25 by 2 by 13 inches long and have metallic (aluminum) housings with aluminized mylar windows on the side facing the scatterer. It is recommended that the detectors be at liquid nitrogen temperature (77 K) to reduce the heat flow into the scatterer. This temperature will be maintained by the presence of liquid nitrogen surrounding the detectors. It is likely that neon will be the fill gas for the detectors since neon has a boiling point below 77 K, and has a high X-ray absorption coefficient in the 1 to 4 kev (12.4 and 3.1 angstroms) range.

X-rays from the telescope are brought to a focus at the end of the scattering tube. A diaphragm is used to isolate the region of the image to be studied. X-rays are scattered in the solid (or liquid) hydrogen by Thompson scattering at right angles to the direction of the electric vector of the incident X-ray. The 8 detectors measure the distribution of the scattered photons. The orientation of the plane and degree of polarization of the X-ray flux from discrete sources in space is thereby determined.

The major problem associated with this experiment is a cryogenic problem; i.e., the polarimeter uses solid or liquid hydrogen. If this should prove impractical, a lithium scatterer can be used which will lower the energy range of the experiment.

Two objectives are considered for the curved crystal X-ray spectrometer. It is proposed to examine detailed features of the line and continuum emission spectra and absorption spectra of 10 to 15 of the interesting X-ray sources in the 8.27 kev to 0.50 kev (1.5 to 25 angstroms) region. It is also proposed to measure the intensity, energy spectrum and isotropy of the cosmic X-ray background within the capabilities of the instrumentation. These new data should determine the types of emission mechanisms and sources that are present.

The X-ray spectrometer consists of a detector, a curved-crystal dispersive element and an X-ray spectral line detector. The spectrometer is a Cauchois focusing instrument with the image detector, curved crystal and line detector all located on the Rowland circle of the crystal. The image detector, placed at the focus of the X-ray image forming telescope, is composed of a hexagonal honeycomb of individual geiger tubes with 0.19 mg/cm^2 mica windows. These tubes are sensitive in the range from 1.55 to 0.62 kev (8 to 20 angstroms) and are surrounded by an anti-coincidence shield of CsI viewed by a single photomultiplier. The image detector has a small hole in in the center for the passage of X-rays. The X-ray line detectors also consists of a honeycomb of geiger tubes surrounded by a CsI anti-coincidence shield and two photomultiplier tubes. The associated electronics are also considered a part of the spectrometer system. In addition, there will be a console for the detection system, a computer for automatic programming of the experiment procedures, and a telemetry interface.

The maximum sensitivity X-ray detector is specifically designed to enhance the capabilities of a grazing incidence X-ray telescope. When normal detection and imaging devices are used with the X-ray telescope, effective photon detection is only 1 percent or less. With this experiment, photon detection would be approximately 100 percent without appreciable degradation of the image. Thus, the instrument could locate an extremely strong source, such as Sco XR-1, to 1 arc second precision; an extremely weak source (M 87) could be located within 10 arc seconds; and an X-ray signal of 1000th of M 87, to within a few arc minutes. Therefore, detection of sources could be extended to 10^9 light years radius, approaching the edge of the meta galaxy. These values are based on an assumed telescope with 100 cm^2 effective collecting area and 1000-second observations. The longer observations feasible on the moon would improve this capability, or could compensate for a telescope having less than 100 cm^2 effective collecting area.

The experiment consists of a modulation collimator backed by a cooled, actively shielded Si(Li) crystal detector and associated electronics. The modulation collimator is a disc (1.2-inch diameter) composed of radial wire spokes in two thicknesses (3 mil and 30 mil). The 3-mil wire would resolve point sources ($\leq$ 3 arc seconds) and the 30-mil wire diffuse sources ($\leq$ 30 arc seconds). The disc will rotate at a constant rate (3 rpm), and will be correlated with the speed of its driving motor. The Si(Li) detector is composed of three separate elements mounted on a single coaxial cold finger cooled to liquid nitrogen temperatures. The cryogenic system may be common with other experiments, provided they are included in the experiment package. A data processing unit will be included in the overall electronics for which the added weight will be 1.5 pounds and power consumption, 1 watt.

The experiment package will be placed at the focus of a grazing incidence X-ray telescope. It will operate in accordance with the observational plan of the telescope. The X-ray image will fall on the modulation collimator and be "chopped". The "chopped" image will then fall on the Si(Li) detector and the resulting signal will be analyzed with respect to energy and frequency. The raw data rate during an exposure will be 10,000 bits/second for 1 arc-second resolution and 1000 bits/second for 10 arc-second resolution. With the data processing unit, the final output telemetry rate will be reduced by two orders of magnitude. The package will weigh 30 pounds, require 50 watts of power, and measure 6 inches by 24 inches.

Optical Astronomy

Diffraction limited images from a large telescope in space can provide a significant increase in our knowledge of the spatial structure of astronomical objects and permit the detection of fainter objects than presently possible from the ground because of increased angular resolution. It will also allow higher stellar spectral resolution to be produced more efficiently by instruments employing dispersive optical systems.

This experiment consists of a 100-inch diffraction-limited large space telescope, and a 50-inch telescope. The 50-inch and the 100-inch telescopes will allow for attachment of various instruments at the focal plane as provided by several investigators.

Goals and objectives of this experiment are to observe stellar objects in the 900 - 10,000 angstrom spectral region using imaging, spectrographic and photometric techniques.

50-Inch Telescope (Reference 4)

The 50-inch telescope (Figure 3.1-4) is configured as a complete facility at the preselected observatory site. The telescope is a 50-inch aperture optical telescope with an f/3 primary mirror and a Cassegrain optical configuration providing a choice of f/10 or f/50 focal ratios. Auxiliary equipment includes photographic, photometric, spectorgraphic, and TV imaging devices. The telescope may be controlled remotely from the shelter or operated autonomously from stored commands or by remote control from earth.

Diffraction-limited reflection optical elements are used throughout to attain the greatest feasible resolution. Specifications relative to a wavelength of 2500 angstroms are given in Table 3.1-2.

Table 3.1-2. General Performance

Diffraction limit	0.05 arc sec
Guidance	0.01 arc sec
Optical surface tolerance	0.02 wavelength
Resolving power	0.12 arc sec

The polar axis of the telescope is aligned with the lunar axis of rotation to a fraction of an arc minute, and is periodically adjusted so as to maintain alignment by monitoring the automatic guidance tracking signals.

Infrared measurements (Reference 3) will be made using the 50-inch optical telescope by adding an IR instrumentation section immediately behind the primary optical mirror. Infrared studies promise new ways of studying the nature and structure of our galaxy and other galaxies. Ground observations are restricted to certain spectral bands with one large gap from 25 to 700 microns. Since the gap is inaccessible from earth and currently unknown, the opening of this region can be expected to substantially modify ideas of the nature of significant processes.

Unbiased surveys of essentially all the sky are necessary in order to understand what kinds of infrared objects exist. Surveys at wavelengths longer than 20 microns will probably be effective in finding entirely new

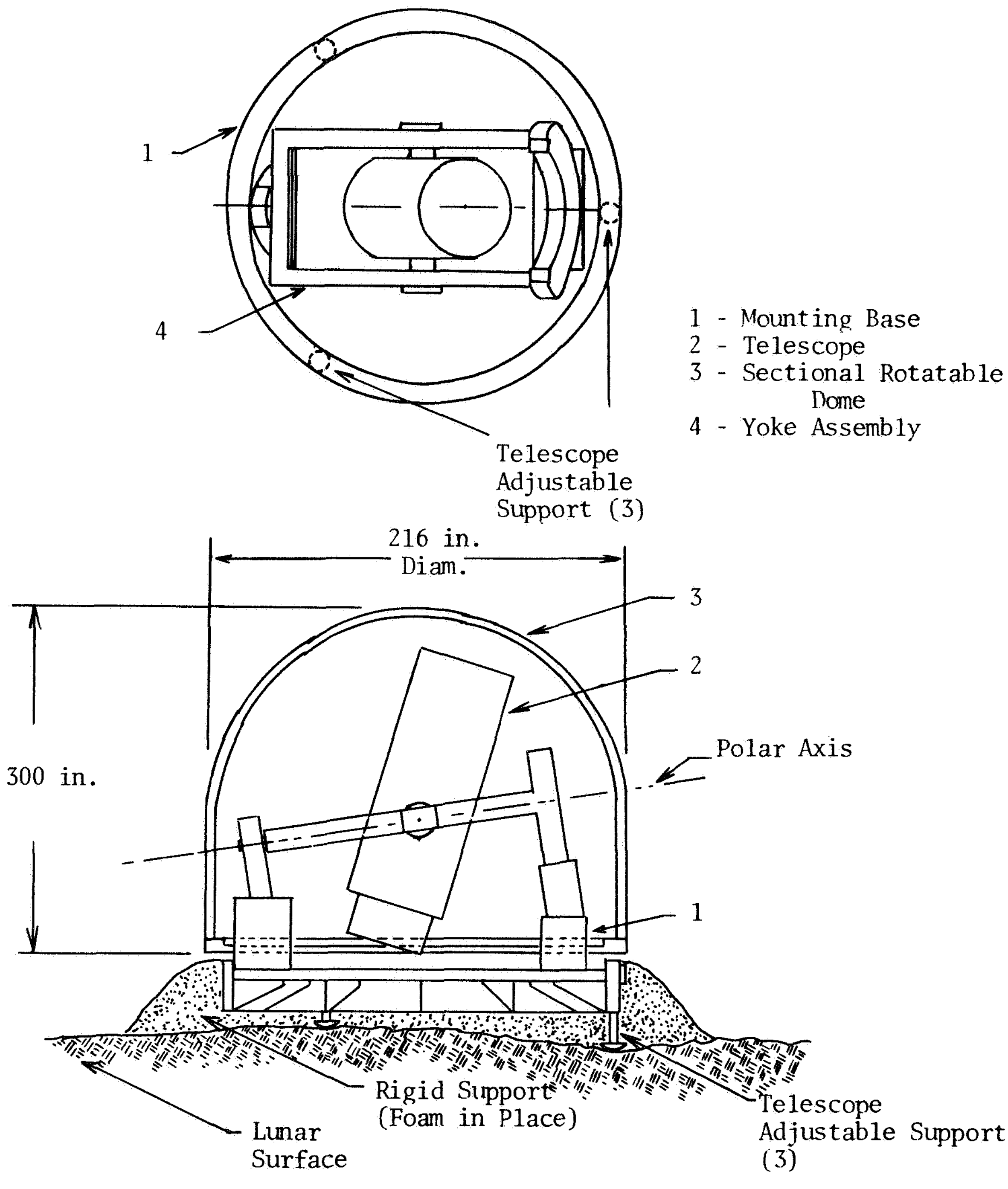


Figure 3.1-4. 50-Inch Optical/IR Telescope

types of infrared targets such as extragalactic objects. A second essential study is a survey to determine the luminosities of a large number of sources. Since there are objects which emit a major fraction of their energy in the infrared, broad band measurements which lead to accurate total luminosities are required for all types of galactic and extragalactic objects.

Objectives in a survey program would include mapping our galaxy, other galaxies, and cosmic background radiation. Very little is known about our galaxy as a whole, and even less about its appearance in the infrared. Whole new classes of objects and types of phenomena may be being ignored for lack of survey-mapping program. It would be expected that emission from interstellar dust clouds would be observed. The energetic processes that result in substantial infrared emission from Seyfert galaxies and a proportion of quasars give rise to emission that probably peaks near 100 microns. A variety of interesting theoretical suggestions have been made to predict weak cosmic infrared continua at various frequencies.

The IR telescope is unique among the astronomy instruments in that it must be cooled in its entirety to very low cryogenic temperatures. This requirement results from the fact that a body will radiate energy in the IR region according to its temperature and its surface emissivity. Thus, if various parts of the optic system such as the mirrors, the secondary supports, and the baffles are not sufficiently cooled, they will radiate energy that may be seen as "noise" by the IR detector at the focus of the primary optical path.

A telescope at a temperature of about 77 K (liquid nitrogen temperature) would emit negligible radiation noise in the 1 micron to 25 microns wavelength range, where the greatest activity in IR astronomy is currently centered. In the 25 microns to 100 microns wavelength range, the radiation noise from a 70 K telescope is at its maximum; however, adequate observation should still be possible, based on radiation fluxes observed from known astronomical objects. From 100 microns up to perhaps 1000 microns, an essentially unexplored IR radiation region, noise from a telescope at this temperature is again negligible.

The detectors in IR telescopes, at the focus of the optical path, must be kept at even lower cryogenic temperatures. To suppress "noise" in the detection and recording system, temperatures as low as 1.5 K are desired in some cases. Note that these extremely low temperatures apply only to the detectors and not to the telescope as a whole.

With regard to the entire telescope, two basic methods of achieving the cryogenic temperatures specified exist, passive cooling and active cooling. Passive cooling is achieved through shielding the telescope from unwanted radiation from the earth and from the sun to a sufficient extent that the telescope, exposed only to cold space, achieves equilibrium at the desired temperature. Active cooling involves the use of cryogenic refrigeration systems; in these systems, the cryogenic fluids may be used either on an open-cycle, resupplied basis or may be continuously recycled through a closed refrigeration system (which places a power demand on the shelter). Passive cooling will be utilized for the LSB telescope, while active cooling will be required for the detectors. The minimum lunar surface temperature which occurs just prior to sunrise is about 90 K; the average lunar nighttime temperature is 115 K. These temperatures appear sufficiently low to permit adequate passive cooling.

A typical IR instrument consists of a straightforward Cassegrainian optical system, mounted on a gimbal system or yoke, that enables the telescope to be pointed as required. The IR instrumentation section (an interferometer, a radiometer, and an IR detector array) is mounted directly behind the primary mirror of the Cassegrainian optics. An auxiliary optical path, for simultaneous visible-light imaging, is conducted along the arms of the yoke and through the yoke pivots to the backside of the insulation where the TV viewfinder tracker, the vidicon, and the electronics can be located without the heat that they emit affecting the temperature of the telescope. To minimize the power being dissipated by the IR instrument, all amplification (other than preamplification) and processing of signals received is done outside the insulation. Power required to drive the interferometer is kept to a minimum. Instrumentation changes are made at infrequent intervals to prevent indiscriminant heating of the telescope. A pellicle in the f/10 Ritchey-Chretien optical system is used to extract a portion of the received energy (over the field of view) and route it into the optical link of the view finder/tracker system.

An interferometer is incorporated in the instrumentation section of the IR telescope. The infrared energy collected by the telescope is passed through a hole to the optical arrangement of the interferometer which divides the energy to create an interference pattern. A bolometer detects the interference pattern as a function of time and the position of the movable mirror.

In the spectral region of 5 to 14 microns, mercury-doped germanium (Ge:Hg) radiometer operating at a temperature of between 4 K and 40 K is normally used for detection of radiation. A radiative-cooled mercury-doped-germanium detector radiometer assembly weighing 6 pounds can be mounted in the IR instrumentation section. For this type of radiometer, it is expected that any installed detector will stabilize thermally at some temperature near 35 K. Variations in the radiative aperture will enable different types of radiometer detector materials to be optimized at other temperatures for use in other spectral regions.

To accomplish an IR sky survey within a reasonable operating period, an IR detector array is incorporated into an assembly similar to that discussed in the preceding paragraph. Scanning of the heavens can then be accomplished by holding the IR telescope at a given angle with respect to the lunar equatorial plane and scanning a full circle on the celestial sphere as the moon rotates. The angle measured from the equatorial plane is changed for each successive rotation until the entire celestial sphere is scanned. The detector would not be operated when the telescope was in sunlight due to excessive noise. Considering the small field of view of the Ritchey-Chretien optics of the telescope, a 100-element array of mercury-doped-germanium detectors, weighing about 9 pounds, would enable a 4 arc-minute "slice" of the celestial sphere (2.5 arc-sec/element, at 10-micron wavelength) to be obtained per rotation. Additional detectors and/or a north-south sweep could be used to provide more coverage per rotation.

100-Inch Telescope (Reference 5)

The 100-inch horizontal telescope consists of 6 major components: (1) a segmented 200-inch movable flat mirror installation, (2) the dome for its protection, (3) a 100-inch primary off-axis mirror installation, (4) an observation room, (5) an instrument room, and (6) a horizontal tunnel. The components are designed to be landed as manageable units, moved into position, and installed with reasonable assembly procedures. The horizontal protective tunnel enclosure would be foam-filled in place. Total weight is estimated to be 33,000 pounds. The outside diameter of the dome over the 200-inch siderostat is 356 inches; the overall length of the installation is about 128 feet.

The light-collecting vertical angle of the 200-inch flat siderostat is limited in the direction of the primary mirror optical axis, therefore, the primary axis is placed in an east-west line so that complete viewing in this direction will be provided by the moon's rotation. North-south viewing down to the horizon permits observation of almost the entire sky. It is desired that the observatory be located in a readily accessible topographic high. To the north and south, the terrain should slope away from the observatory and should present no major prominences.

The basic design is a horizontal Herschelian optical system utilizing a siderostat and f/10 photographic and f/100 spectrographic configurations of 100-inch aperture. Because a Herschelian telescope focuses skew rays off the optical axis, the image deterioration, even in an f/10 mode, may be more than is desirable for good photography. Therefore, use is made of a 100-inch off-axis portion of a larger paraboloidal mirror at the prime focus on-axis for the f/10 photographic telescope. A Cassegrainian secondary can then be added for the f/100 spectrographic telescope.

A 240-inch, paraboloidal, primary mirror and a 30-inch hyperboloidal, secondary mirror allow a 100-inch off-axis portion of the primary to be used without masking by the secondary mirror.

For light gathering and resolution purposes, the configurations are those of a 100-inch aperture with 1000-inch focal length at the f/10 prime focus and with 10,000-inch effective focal length at the f/100 Cassegrainian focus. They may be expressed as off-axis portions of an f/4.167 prime focus and an f/41.67 Cassegrain -- both with a 240-inch aperture.

Only a 12.5-inch off-axis portion of the secondary mirror is used, matching the 100-inch off-axis portion of the primary.

The Gaussian image plane for photography at the prime focus is located in an observing room 1000 inches from the primary mirror. The secondary mirror is located 875 inches from the primary and 125 inches from the observing room. To have the Gaussian image plane of the Cassegrainian focus in or near the same observing room, the system is folded with an optically flat mirror located 513 inches from the secondary mirror, and 638 inches from the observing room location of the image.

The spectrograph can be folded so that both the reflection grating and the photographic emulsion are in or near the observing room. The optically flat mirror for this folding would be located in the tunnel at a distance of one-half of the focal length of the grating. Theoretically, the focal length of a spectrograph is independent of the focal length of the telescope forming the image. Since the quality of the image formed by the spectrograph can be no better than the quality of the image received, the focal length of the concave reflection grating should be of the same order of magnitude as the focal length of the telescope for high dispersion spectroscopy.

The siderostat is a segmented 200-inch optically flat mirror that reflects the light from the observed object into the optical train. The siderostat is housed in a dome that is opened only in the direction of the area under observation. The image of the siderostat rotates about the optical axis; allowance for this condition must be made in mounting the photographic plateholder, the spectrograph, and the videograph.

Visual pointing, guiding, and/or observation can be achieved without interruption of the photographic or spectrographic modes by the introduction of half-silvered, optically flat mirrors into the optical train. Basic operation, however, should be computer controlled, including siderostat, dome, and receiving instrument rotation. It is also visualized that star-tracker guidance will be utilized.

Some performance data are summarized in Table 3.1-3. Control characteristics are preliminary estimates.

Table 3.1-3. Linear Diameter of Diffraction Image Data
(100-Inch Telescope

Focal Length	1000 Å (10^{-5} cm)	5500 Å (5.5×10^{-5} cm)	20-micron (2.0×10^{-3} cm)
10^3 in.	1.0 micron	5.5 microns	0.2 mm
10^4 in.	10.0 microns	55.0 microns	2.0 mm

Telescope Control Characteristics

Item	Characteristic
Slewing rate for siderostat	120 degrees per minute
Setting rate	2 arc sec per sec
Guiding (close control) rate	7×10^{-3} arc sec per sec
Deflection drift	1 arc sec in 1 hour
Pointing accuracy	20 arc sec over celestial sphere

It should be pointed out that, at present, the largest diffraction-limited mirror has a 36-inch aperture at 5500 angstroms. To make mirrors approximately three and six times the aperture with about six times the accuracy is a major undertaking. In addition, the mirrors will be required to maintain their figure in the lunar environment of one-sixth g.

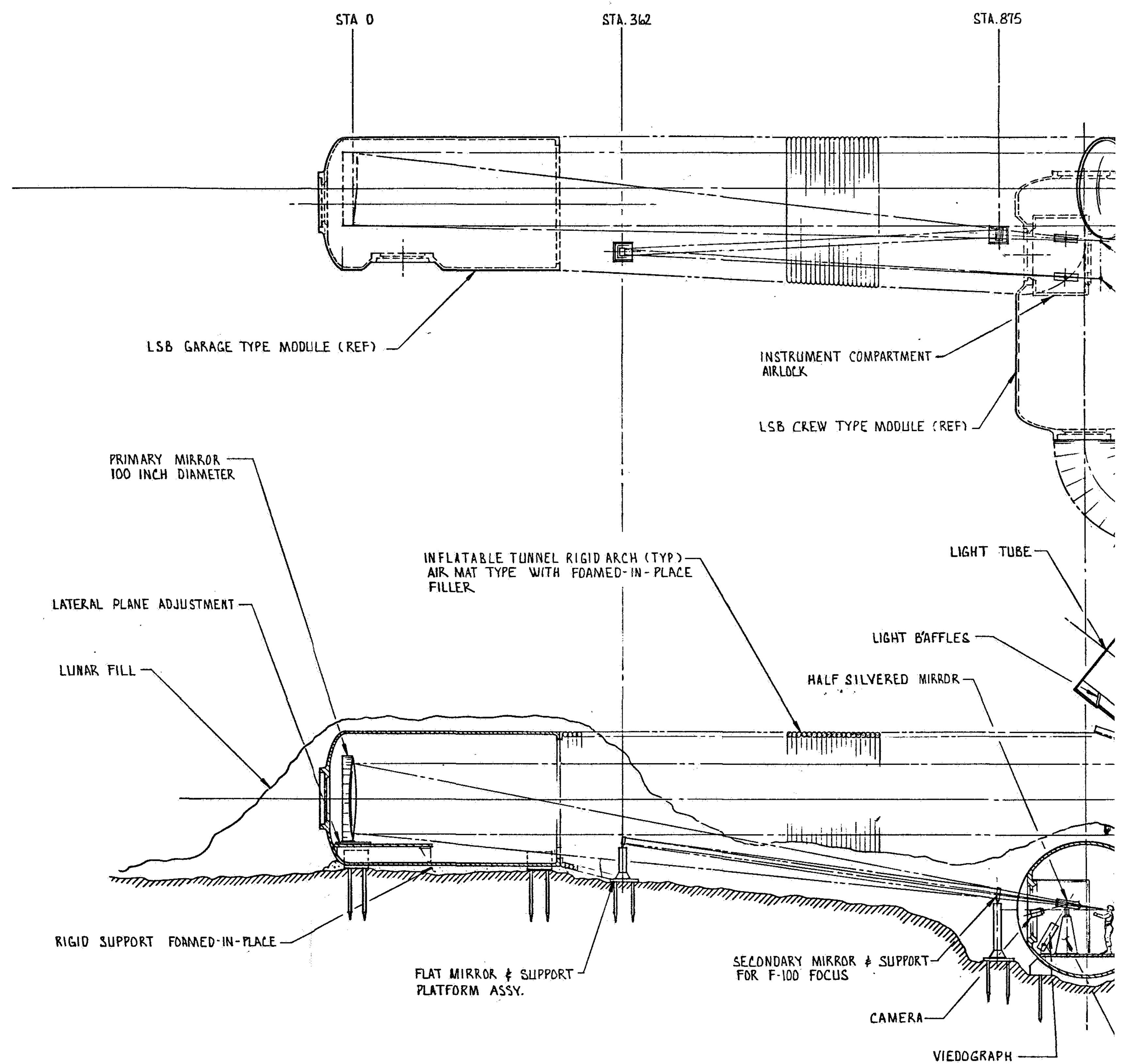
For the optical configuration of this telescope, the image deteriorates very rapidly away from the center of the field of view. Consequently, the field of view is very restricted, particularly at the large focal lengths.

The suggested configuration for the 100-inch horizontal telescope for the LSB is presented in Drawing 2284-11. This design is modified from that shown in Reference 5. The optical design is unchanged, but the observation and instrument rooms and the 100-inch mirror's protective cone have been replaced with spare transportation modules to reduce costs. An airlock is mounted on the docking hatch of the instrument room to permit the detectors to be operated outside of the environmentally controlled room. Basically, the concept utilizes lunar rock in place of the heavy structure of conventional large telescopes and minimizes the amount of heavy equipment that must be precisely moved during the course of an observation. To limit the amount of assembly work performed in the lunar environment, the concept permits the telescope components to be delivered in nearly complete units. Videographic, spectrographic and photometric instruments which may be interchanged, replaced and updated via a hatch in the airlock will be located on the instrument mounting platen of the telescope.

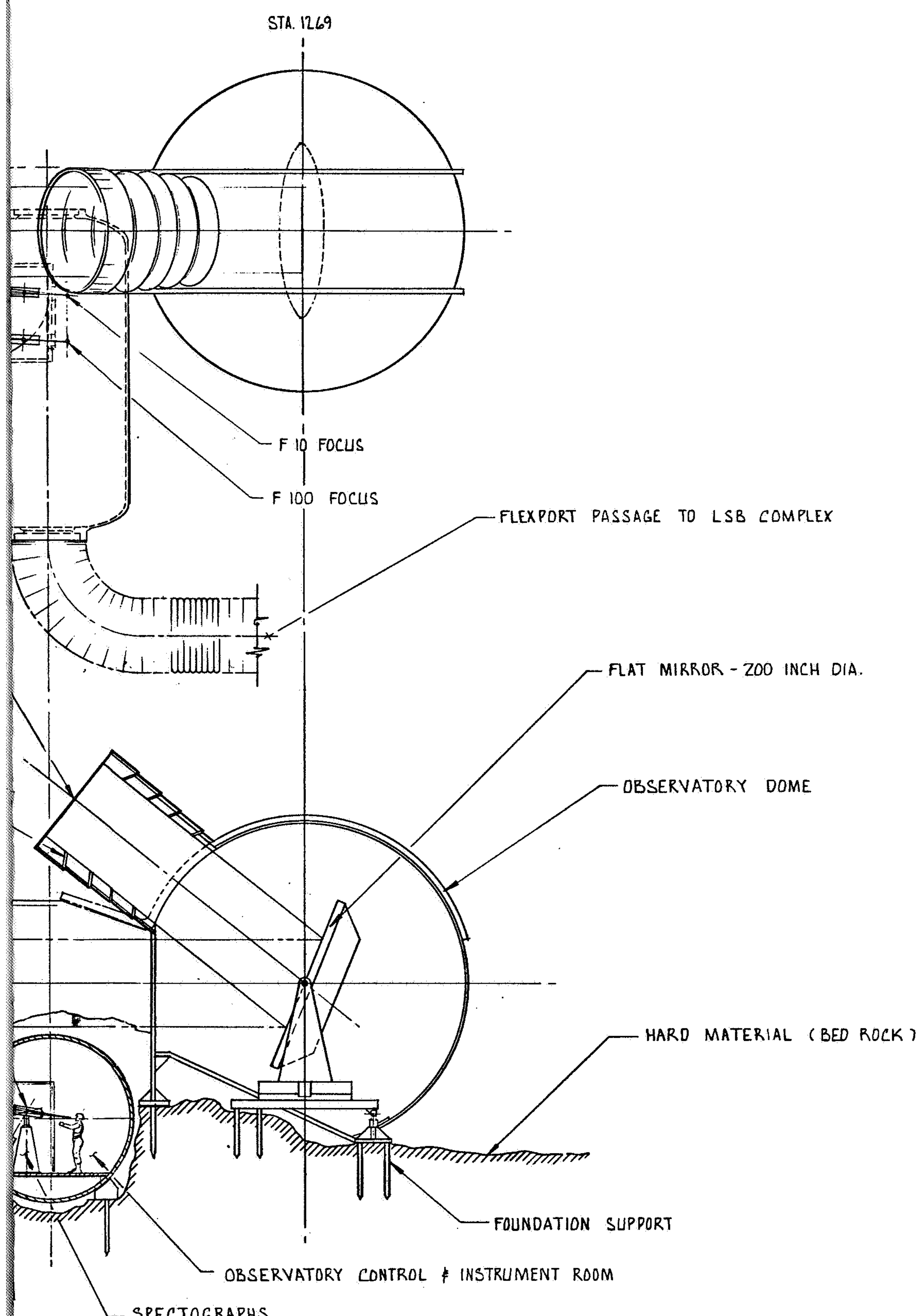
The proposed experiment program would be conducted in two phases. The initial weeks of operation will be devoted to optical technology experiments which will provide an engineering evaluation of the optics and subsystems operation and performance. The remaining years will be devoted to an astronomical observation program.

The initial experiments will be devoted to an evaluation of the areas critical to the telescope performance, i.e., optical train, data handling, fractional arc second control, telescope supports, and thermal control. The experimental primary mirror may be either of active or passive monolithic construction, or individual actively aligned mirror segments. The individual segments would be aligned to each other to comprise the diffraction-limited aperture telescope. The alignment of the mirror segments would be sensed by the phase-measuring interferometer and moved to the proper location by the active optics actuator servomechanisms. The performance of the individual segments could be individually determined and compared.

The scientific objectives are to observe discrete and extended stellar objects such as star clusters, diffuse nebulae, planetary nebulae, galaxies, quasars and peculiar objects in the 900-angstrom to 10,000-angstrom spectral region using imaging, spectrographic and photometric techniques. These will be accomplished through multiple experiments covering the entire celestial sphere. The planned experiments, based on Reference 3, are:


STA 0
STA. 362
STA. 875
LSB GARAGE TYPE MODULE (REF)
INSTRUMENT COMPARTMENT AIRLOCK
LSB CREW TYPE MODULE (REF)
PRIMARY MIRROR 100 INCH DIAMETER
INFLATABLE TUNNEL RIGID ARCH (TYP) AIR MAT TYPE WITH FOAMED-IN-PLACE FILLER
LIGHT TUBE
LATERAL PLANE ADJUSTMENT
LIGHT BAFFLES
HALF SILVERED MIRROR
LUNAR FILL
RIGID SUPPORT FOAMED-IN-PLACE
SECONDARY MIRROR & SUPPORT FOR F-100 FOCUS
FLAT MIRROR & SUPPORT PLATFORM ASSY.
CAMERA
VIEDOGRAPH

Fold-out #1



FOLD-OUT #2

THIS PRINT REDUCED 50%

1-3-21, 1-3-22

SD 71-477

SCALE: 1/80	DR. Thompson / DATE 3-24-71 / MODEL	SPACE DIVISION NORTH AMERICAN ROCKWELL CORPORATION 12214 LAKEWOOD BOULEVARD, DOWNEY, CALIFORNIA
100-INCH HORIZONTAL TELESCOPE CONCEPT, LUNAR SURFACE BASE		2284-11

1. Field image videographic recording
2. Concave grating spectroscopy
3. 70 mm and 225 mm photometry

The function of the videograph instrument is to record, with the highest possible resolution, the images of specific objects such as galaxies, globular clusters and quasi-stellar sources in different wavelength bands in order to determine their structural characteristics. To this end, a 70-mm format (See Table 3.1-4) has been devised. Since a filter wheel with the required aperture would be excessively large, a device similar to the 70-mm camera is used for selecting the desired filter for the observation. The instrument format may be reduced to 35-mm if the state of the art in electronic imaging or data management makes the larger format unfeasible or uneconomical.

Table 3.1-4. Field Image Videographic Instrument Characteristics

Format	70 mm x 70 mm
Optical resolution	110 lines/mm
Bits/frame	3.24×10^9
Power	30 watts

For the measurement of Cepheid variable stars, as a means of determining the distance of the galaxies in which they are located, it is helpful to photograph a reasonably large area so that many stars are recorded in a single exposure. To satisfy this requirement, a large format plate camera is included. The plate used is 225-mm square (200-mm clear, see Table 3.1-5).

Table 3.1-5. 225-mm Field Image Camera Characteristics

Film camera characteristics	
Type	Plate
Aperture	200 x 200 mm
Remote change cycle time	60 seconds
Power consumption during change	4 W
Film type limitations	Panchromatic emulsions on glass plates
Exposures per magazine load	16 maximum
Filter characteristics	
Wavelength (short	3400 angstroms
Wavelength (long)	5500 angstroms
Resolution $\pm$	100 angstroms
Band centers	3500, 4300, 5400 angstroms
Remote change cycle time	60 seconds
Power consumption during change	4 W
Weight	88 pounds

A 70-mm plate camera may be added to the field image instrument to supplement the videographic instrument. If incorporated, the camera characteristics will be as noted in Table 3.1-6. The camera provides a feed and a take-up magazine with a transport to take each plate from the feed magazine to the exposure position and then on to the take-up magazine. A similar device is used for selecting the desired filter.

Table 3.1-6. 70-mm Field-Image Camera Characteristics

Film camera characteristics	
Type	Plate
Aperture	50 x 50 mm
Remote change cycle time	30 seconds
Power consumption during change	2 W
Film type limitations	Panchromatic emulsion on glass plates
Exposure per magazine load	32 maximum
Filter characteristics	
Wavelength (short)	3477 angstroms
Wavelength (long)	6813 angstroms
Resolution ±	100 and 250 angstroms
Band centers	3727, 4101, 4340, 4861, 4959, 5007, 6563 angstroms
Remote change cycle time	30 seconds
Power consumption during change	2 W
Weight	55 pounds

For measuring the Doppler shift radiation received from quasi-stellar sources, a concave grating spectrograph is included. The spectrograph includes a slit, a concave grating and an image plane. A reference light source illuminating the fringes of the slit provides a comparison spectrum to permit precise wavelength calibration. The spectrograph output will be viewed by a videographic instrument and a camera. The camera will be used to supplement the video data. Instrument characteristics are shown in Table 3.1-7.

Table 3.1-7. Concave Grating Spectrograph Characteristics

Type	Normal Incidence
Wavelength	
Short	800 angstroms
Long	3000 angstroms
Resolution	1 angstrom at 2000 angstroms
Entrance aperture	
Slit width	20
Slit height	150
Incident radiation	
f/No. limitation	15
Spatial resolution	1
Main grating	
Type	Concave
Size	31.3 x 32.3 mm
Ruling frequency	400 lines/mm
Dispersion	50 angstroms/mm at 2000 Å
Angle of diffraction range	-0.46 deg. to +4.59 degrees
Recorder characteristics	
Type	Film
Aperture	25 x 44.1 mm
Remote change cycle time	30 seconds
Film-type limitation	Schumann
Exposures per magazine load	16
Power consumption during cycle change	2 W
Weight	62 pounds (including 55 pounds for plate camera)
Videographic instrument	
Format	25 x 44.1 mm
Optical resolution	110 lines/mm
Bits/frame	4.21×10^8
Power	30 watts

Radio Telescope (Two-Element Interferometer) 300 kHz-1000 kHz

Radio telescope locations on the moon provide isolation from earth interference and visibility in spectrum ranges closed to the earth surface by atmospheric and ionospheric obscuration. While a number of related experiments may be performed in earth orbit, isolation from earth is not available, and the stabilization of radio telescopes not practical in orbit is readily achievable on the lunar surface.

The goals and objectives of this particular telescope are to resolve galactic and extragalactic sources in the frequency range of 300 kHz to 1000 kHz. The telescope will allow a map of the visible sky to be constructed indicating steady state sources, and defining absorptions in the hydrogen clouds along the galactic plane and elsewhere that may be discovered. Repetitive observations will be performed to identify and observe long period time variant sources in the frequency range.

Secondary objectives would be to support observations of solar events and flares with high resolution data in the frequency range.

The telescope is a two-element interferometer, with the centers of the elements separated 5.6 miles (9 km) along an east-west baseline as indicated in Figure 3.1-5. Each element consists of an array of 16 end-loaded folded dipoles, with each dipole 490 feet (150 meters) in length, oriented parallel to the baseline, and with centers deployed along a north-south line from each end of the baseline. Spacing between the dipoles would vary from 490 feet (150 meters) for dipoles near the baseline to 985 feet (300 meters) for dipoles farthest from the baseline. Variations on this spacing, including random, have been suggested, with actual dimensions dependent on a final design and model results. The spacing will be such that each overall element length in the north-south direction will be 2 miles (3250 meters).

Each dipole will be supported 98 feet (30 meters) above the center of ground plane consisting of 20 evenly spaced wires parallel to the dipole covering an area 490 feet (150 meters) north-south by 985 feet (300 meters) east-west. Feeds will be open wire from the center of the dipoles to the preamplifier-tuning units below the dipoles, and from there to phasing control networks at the center of the element. Open wire line will be supported clear of the surface along the baseline to the experiment control area approximately midway between elements. Control lines may run along the surface. The design is simpler than the complete Mills Cross in Reference (5). The design could be expanded to the Mills Cross concept with additional weight and installation complexity of about four times the basic instrument.

A number of variations in the telescope alignment and roughness of the site can be tolerated. However, a poorly prepared site can result in variation during test and calibration that is difficult to distinguish from equipment problems. In order to avoid lengthy preoperational tests and adjustments, deviations from the ground planes, such as hills and craters, should be minimized. Projections less than one percent of the wavelength or

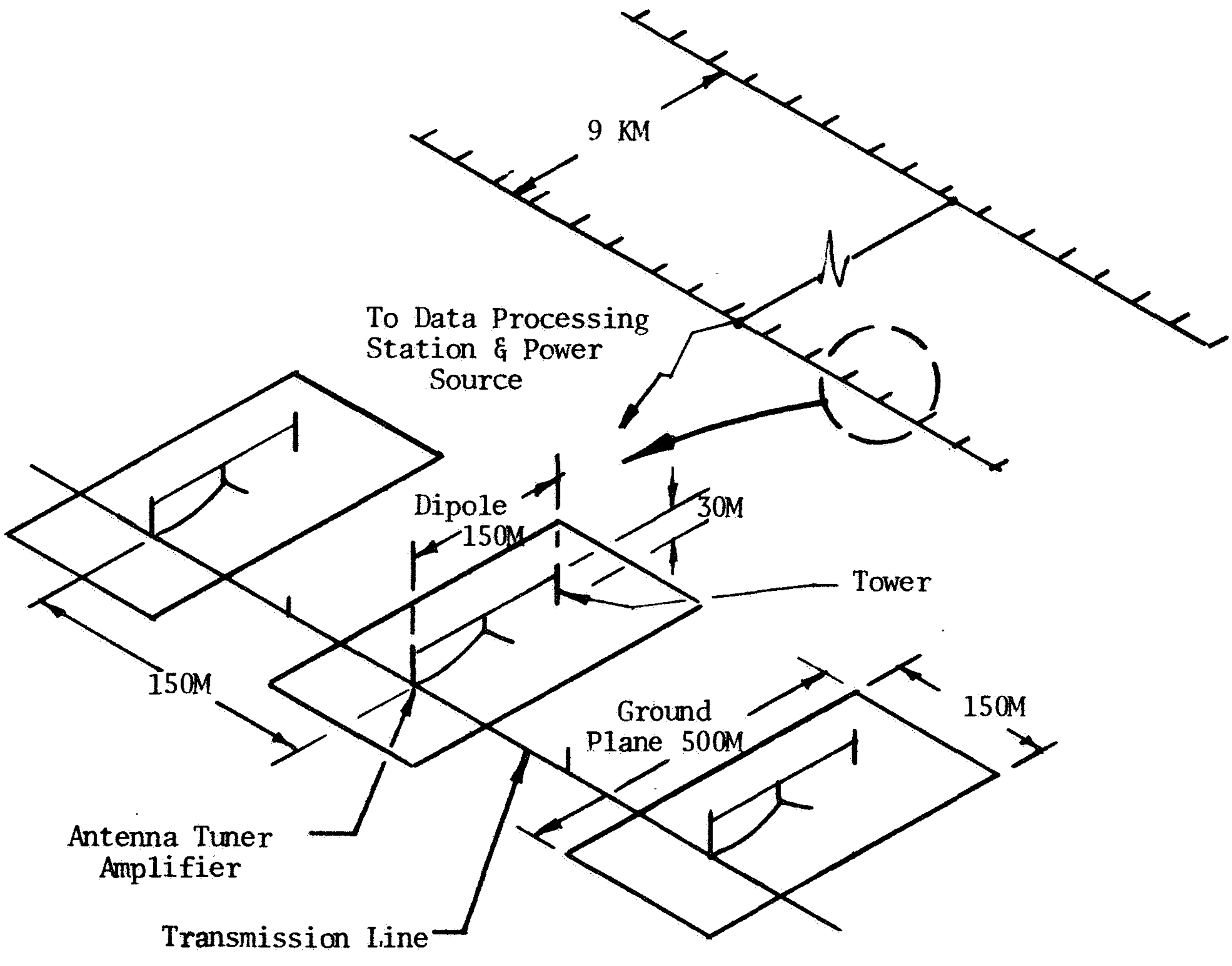


Figure 3.1-5. Two-Element Interferometer Radio Telescope
(.3-1 MHz)

10 feet (3 meters) should have no effect, but projections greater than 5 percent of the wavelength should be avoided. Overall alignment of the telescope with respect to the geometry used in earth calibrations should be held within 5 percent of the wavelength.

In general, conducting structures of greater than 50-foot dimensions should not be located within two miles (3 km) of either element, although specific structure designs could be accommodated and the effects designed out.

For simplicity, other horizontal antenna arrays should be located within the elements of dipoles of two frequency ranges interlaced together. Various arrangements are possible as long as symmetry is maintained. An anticipated difficulty is that numerous trips could be required for tuning purposes due to the interaction of elements.

Little is currently known of correlation between optical sources and low frequency radio sources. Indications are that planets and the quiet sun may not be strong at the low frequency end of the spectrum. Solar flares should be very high in LF content, but should not be counted on for calibration purposes.

A preferred calibration would be a swept oscillator (.3 to 1 MHz) in an orbital vehicle. Initial operations could presumably start as soon as impedance and noise measurements were made at the operations area, and corrections in data performed as calibration data were obtained during the operating life. The swept oscillator could be about 0.3 pound including batteries. The time position of the oscillator in orbit should be known. Utilization of the received signal for determination of position would require a higher class of oscillator, and would probably require an undue amount of access to the base computer.

Installation should be aided by semi-automatic deployment of masts and lines. One approach would be to count on exact measurements to repeat the configuration established in earth-based alignments and tuning. However, the possibility of variations in deployment or tuning alternations during transportation, suggests that an impedance measurement can be performed at each half wave antenna after it is set up. A test set, estimated at about 4 pounds (including batteries), would provide a signal source, bridge, and readout to allow the feed impedance to be measured and a tuning adjustment to be made if required. Also, a quick-check could be made by displacing the signal source from the antenna, and checking the level received.

The measurements will vary as the number of antennas in the element are completed. That is, the reading for the first antenna will vary from the second due to the effect of the first.

In order to obtain valid measurements, it is preferred that the ground plane wires be completely deployed in an element before starting deployment of the antennas. If this is not done, depending on detailed design of the system, another trip may be required for retuning after the element has been assembled.

The array should provide an east-west resolution at 1 MHz of about 1.9 degrees near the local zenith or along a line directly north or south of the zenith. North-south resolution should be ~ 5 degrees. Normal operation should be to within 30 degrees of the northern or southern horizon, with usable operations to within ~ 10 degrees of the horizon. East-west scans may be performed to similar limits. However, normal operation would be within 25 degrees of the local meridian to limit the degradation of resolution to 10 percent.

Sensors would include a receiver system covering the telescope frequency range, a dual radiometer and analyzer with phase switching and rotating lobe capability, and a calibration source consisting of frequency, noise temperature, and time standards. Local metering and recording would be provided for on-site evaluation of operation. Computer support would be required for evaluation of alignment from the received signals and for comparison of the data received on successive runs.

A sustained operation would consist of four hours of mapping near the local meridian, conducted at ~ 80-hour intervals. Data from these runs would be on the order of 4.5×10^6 bits including identification, calibration and overhead bits. The complete map sequence, including both frequency and position elements with respect to intensity, requires a minimum of ~9 runs. The continued runs would be to identify long-term variations and to detect any new sources which might appear during the telescopic period of operation.

Discrete sources will be observed in a direct radiometer, phase switching and/or rotating lobe mode depending on the characteristics of the source. The analyzer portion of the radiometer would include cathode ray tube displays to allow on-site evaluation of these characteristics.

The telescope would also support observations by solar system radio telescopes during major events such as solar flares.

Radio Telescope (Two-Element Interferometer) 1 MHz to 15 MHz

This telescope is a scaled down version of the 0.3 MHz to 1 MHz telescope previously discussed. The scale is indicated in Figure 3.1-6. All dimensions are reduced by a factor of ten, including tolerances and protected areas.

Installation, calibration and operation will be similar to the low frequency telescope, with the exception that correlation with earth radio telescopes will be possible at the upper end of the frequency range. Instrumentation is similar with the receiver range shift to higher frequencies being the major change. The calibration equipment could be designed to support both telescopes if the instrumentation location is colocated. The two interferometers would operate together to extend the total observed spectrum from .3 to 15 MHz.

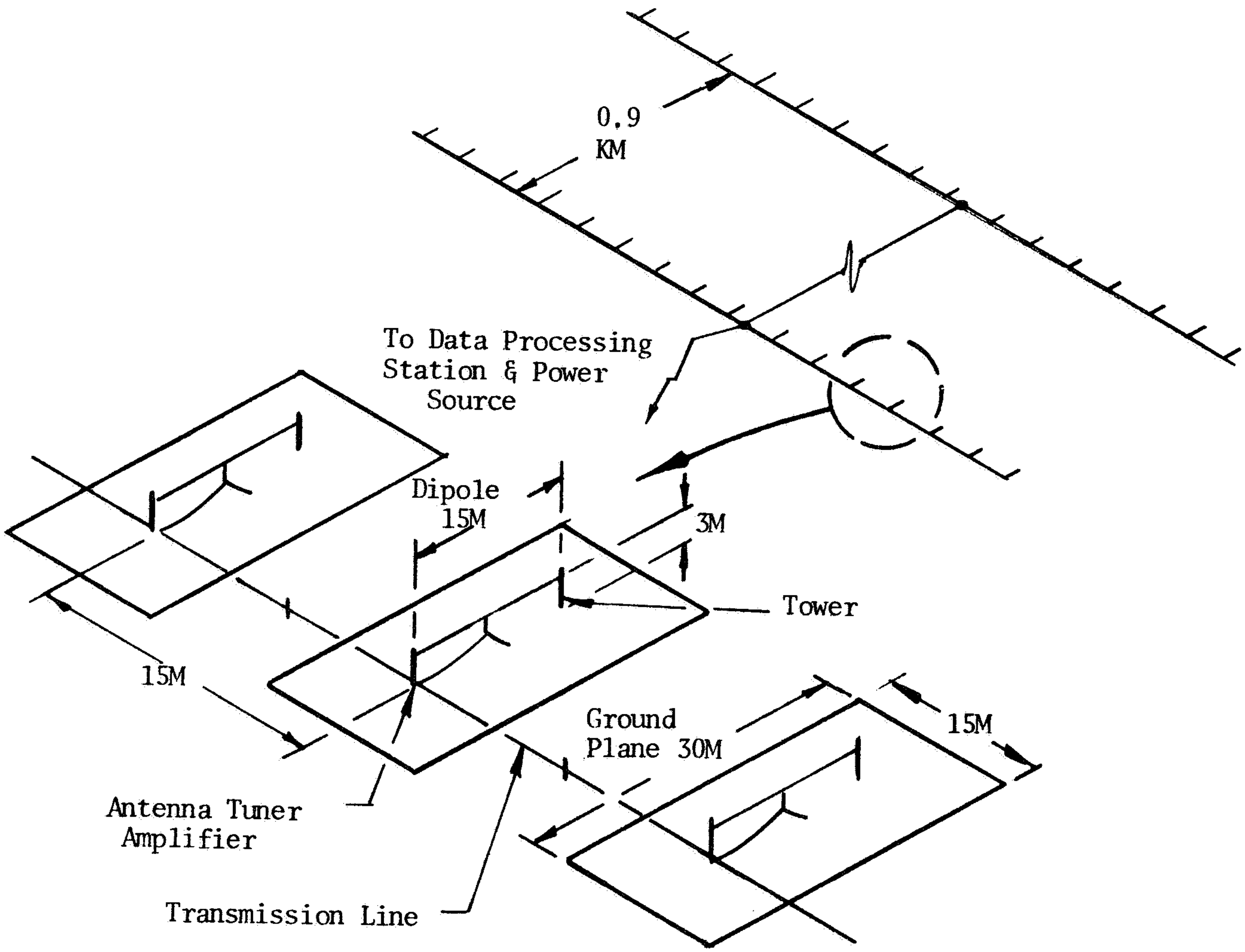


Figure 3.1-6. Two-Element Interferometer Radio Telescope (1 to 15 MHz)

Radio Telescope (Phase-Switching Interferometer) 0.6 MHz to 1.2 MHz

This telescope is a simpler low gain version of the low frequency two-element interferometer, suitable for monitoring of solar system sources for frequency and intensity variations with time. The physical arrangement consists of the two crossed loops illustrated in Figure 3.1-7. The antennas are, in general, insensitive to structures and terrain characteristics and are flexible in that little or no site preparation is required. Broad band preamplifiers at the base of each antenna feed the phase-switching radiometric receiver. Data will be from the sun and planets. Records will be maintained of frequency and intensity as a function of time during activity from these sources. Quiet periods will be monitored with little or no data gathered, and the major activity is anticipated to be related to solar events. Resolution will be ~ 7 degrees along the line between the elements for the two-mile (3-km) spacing.

Radio Telescope (Temporal Variations) 5 MHz to 500 MHz

The purpose of this telescope is to observe solar systems and any other sources producing high strength signals in the range of 5 to 500 MHz, and to record variations observed over that range for comparisons with signals observed by earth observatories. As shown in Figure 3.1-8, the telescope consists of two conventional log periodic arrays. The log periodic antennas exhibit a constant gain over a wide frequency range. Two antennas are indicated, each of which covers a 10 to 1 range to achieve the total 100:1 range monitored.

Receiving equipment consists of swept radiometric receivers with outputs showing frequency and relative intensity as a function of time. The coverage angle is broad and dependence is placed on the angular separation of solar system sources. Primary resolution information would be obtained by earth-based instruments, with the lunar monitoring providing identification of effects due to the earth environment.

3.2 MINOR SCIENCE EQUIPMENT

While most of the major scientific equipment has yet to be built and tested, the reverse is true for a majority of the minor equipment. In addition, although the minor equipment outnumbers major equipment by ten to one, the minor equipment total weight, power, and volume requirements are only one tenth of these totals for the major equipment. It is felt that the impact of minor equipment on the lunar shelter designs can safely be ignored in any subsequent studies prior to Phase D.

Minor equipment selected for the LSB are listed in Appendix A and, for the most part, consist of geological, geophysical, and geochemical instruments. The instruments selected are based directly on current practice. All are small, lightweight, low powered, simple devices suitable for transporting on long surface sorties, capable of reuse, and long-term, reliable operation. Their performance estimates and capabilities to satisfy the measurement requirements are based on or derived from space-rated equipment

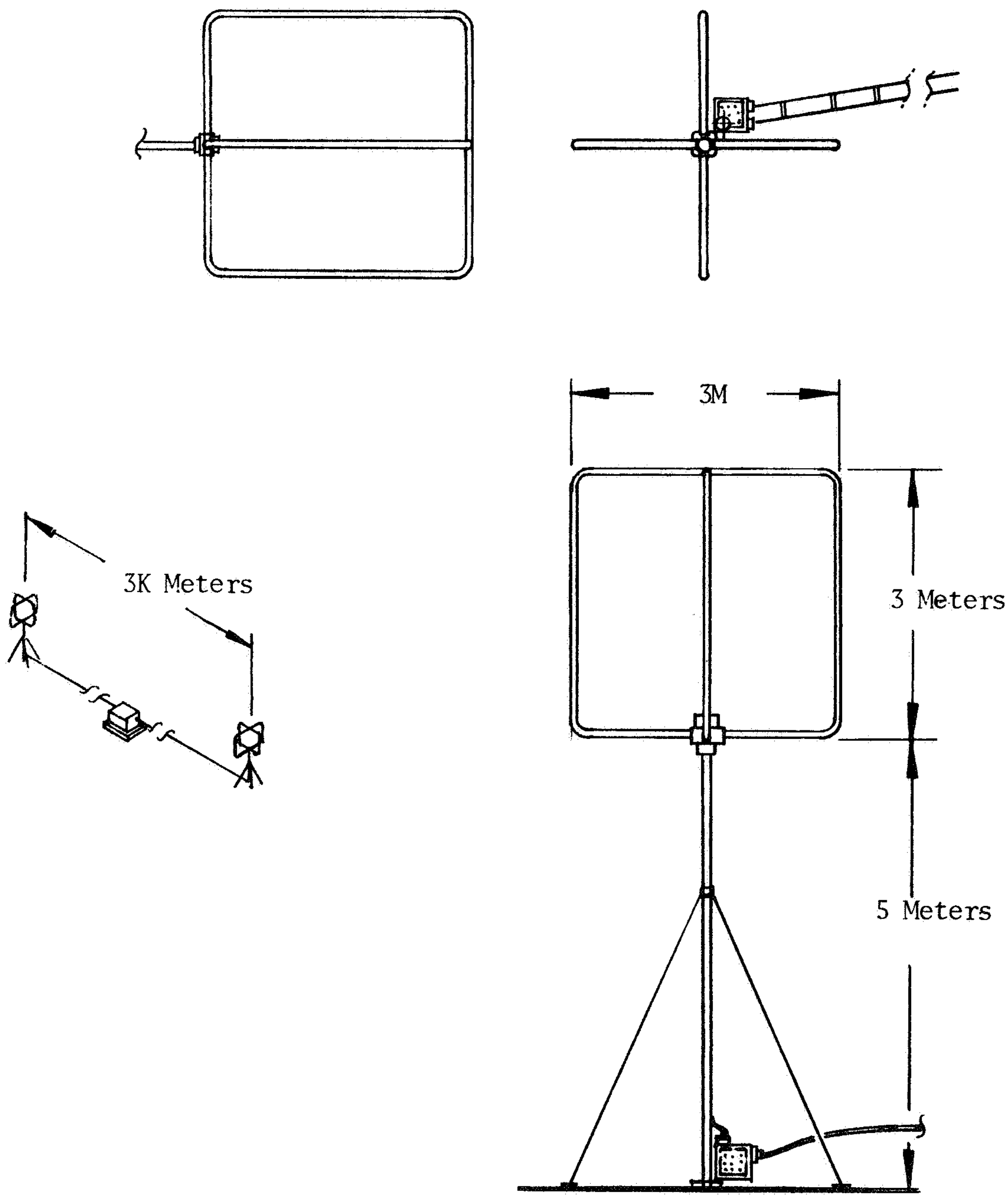


Figure 3.1-7. Crossed Loop Radio Antenna (.6 to 1.2 MHz)

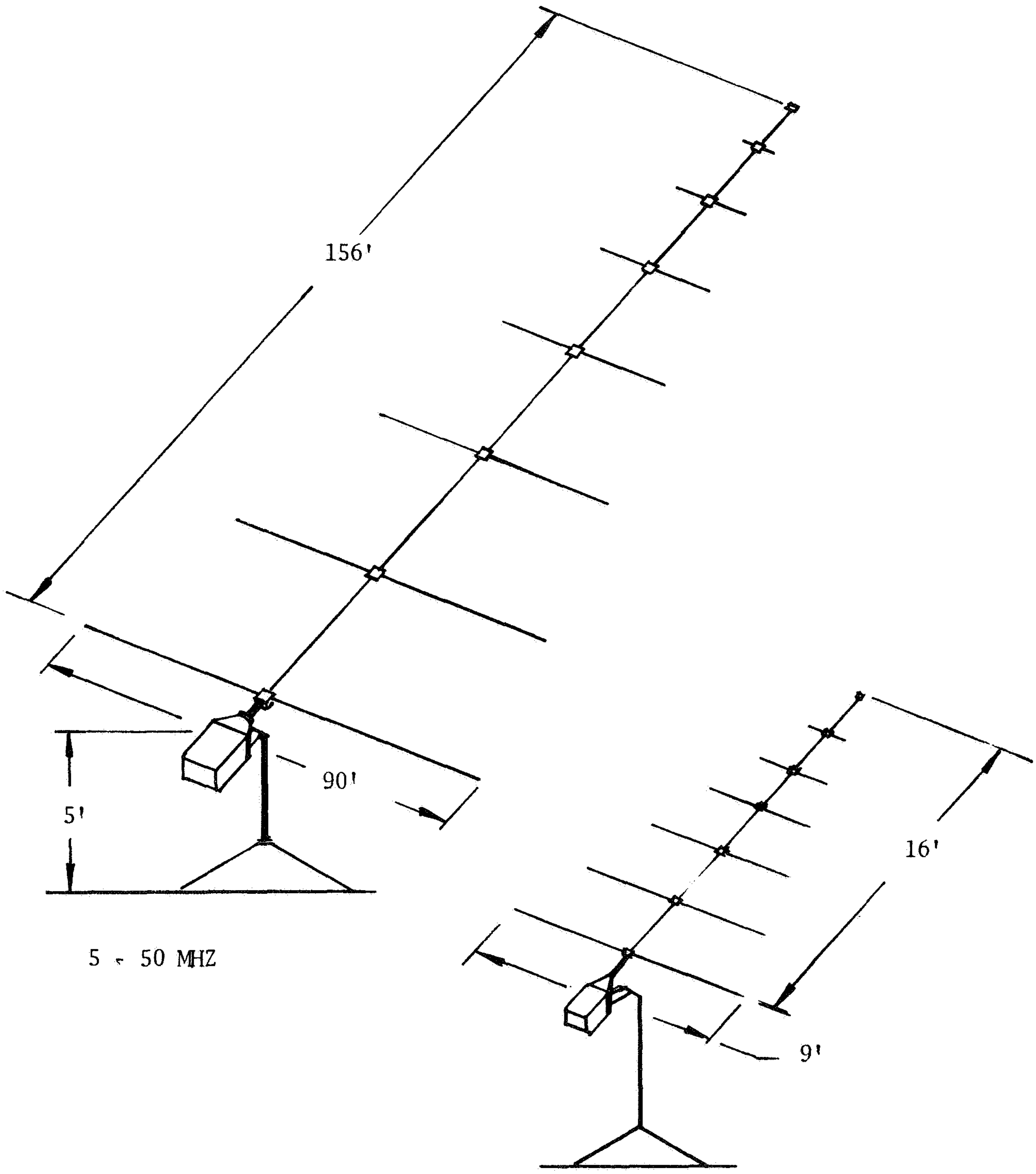


Figure 3.1-8. Log Periodic Radio Antennas (5 to 500 MHz)

such as ALSEP and devices used on Apollo missions. They probably represent only a reasonable approximation of their 1985 configurations, but the primary physical characteristics are felt to be known with a precision sufficient for the purposes of this study.

3.3 EXPERIMENT DEFINITION

An experiment has been defined in Section 2.0 as "a description of the activities required to obtain data in support of one or more observation requirements." It does not include the transportation of science equipment to and from the experiment site, but rather the operations with the instrument and related equipment at the experiment site. Appendix B contains the experiment definitions for the LSB program. The experiment definitions include a timeline of the tasks such as unloading, setup, checkout, calibration, data gathering, teardown, and stowage along with logistics requirements, crew support, and hazards and constraints associated with the equipment. This information is used subsequently to plan the extent and duration of the surface exploration sorties.

Table 3.3-1, the master experiment plan, correlates the experiments of Appendix B with the objectives, disciplines, and subobjectives defined in Section 2.0. From this table, it can be seen that astronomy and the geosciences are dominant as would be expected in order to provide the basic data for answering the fundamental questions about the solar system and the moon. Of the approximately 72,460 pounds of science equipment identified for the LSB, 64,650 pounds are associated with the astronomical telescopes and equipment, the 1000-foot drill weighs 4200 pounds, about 2000 pounds are utilized for exploration on remote sorties, and only 1610 pounds are utilized at the main shelter for the remainder of the experiments and disciplines.

Table 3.3-1. Master Experiment Plan

Disciplines	Subobjectives		Experiments
Astronomy	AY-1	Celestial X-Rays	4012
	AY-2	Celestial Gamma Rays	None
	AY-3	Radio/Optical Observations	4012, 4014, 4015, 4016, 4017
	AY-4	Lunar Electrical Properties	4021, 4022, 4023, 4024, 4025, 4051
	AY-5	Cislunar Medium	4026
	AY-6	Radio/Optical Measurements	4027, 4028, 4029, 4030
Geology	GG-1	Lunar Surface Features	4032, 4033, 4039, 4058
	GG-3	Dynamic Surface Processes	4032, 4033, 4039, 4047, 4088
	GG-4	Long-Term Processes	4032, 4033, 4048, 4057, 4058, 4060, 4061
	GG-5	Chronology	4032, 4033, 4048
	GG-6	Geologic Maps	4032, 4033, 4047, 4048, 4059, 4060, 4061
	GG-7	Morphology	4032, 4033, 4060, 4061
	GG-8	Site Analysis	4032, 4033, 4039, 4047, 4060, 4061
Geochemistry	GG-2	Lunar Materials	4032, 4033, 4037, 4038, 4048, 4057, 4058, 4059, 4060, 4061
Geophysics	GP-1	Selenodesy	4045
	GP-2	Lunar Interior	4032, 4040, 4048, 4057, 4058, 4059, 4088
	GP-3	Dynamic Properties	4046, 4047, 4088
	GP-4	Earth-Moon Interaction	4045
Lunar Atmosphere	LA-1	Ambient Properties	4053
	LA-2	Dynamic Properties	4055
	LA-3	Transient Phenomena	4053, 4055
Particles and Fields	PF-1	Solar Wind-Moon Interaction	4050
	PF-2	Plasma Physics	4050
	PF-3	Near Moon Fields	4051
	PF-4	Particle Environment	4050
Bioscience	BI-1	Life Forms	4001, 4003
	BI-2	Organism Effects	4003
	BI-3	Plant/Animal Effects	4006
Aerospace Medicine	AM-1	Magnetic Effects	4009
	AM-2	Gravity Effects	4009
	AM-3	Synergistic Effects	4009
	AM-4	Vision Effects	4011
Geodesy	GC-1	Geodetic Control	4044
Cartography	GC-2	Topographic Maps	-
Engineering, Technology, and Operations	ET-1	Planetary Exploration	All
	ET-2	Long-Duration Life Support	4064, 4066
	ET-3	Exposure Effects	4071
	ET-4	Water-Oxygen Extraction	4032, 4033
	ET-5	Propellant Production and Storage	4081, 4082
	ET-6	Construction Support	4078, 4079, 4081, 4082, 4084
	ET-7	Material Utilization	4046, 4084, 4085, 4086, 4087

4.0 MISSION DESCRIPTIONS

The adopted approach to lunar exploration envisions the transportation of scientific equipment to various discrete locations on the surface which possess geologically interesting features. These might include mare, highlands, craters, mascons, volcanoes, rilles, peaks, domes, faults, outcrops, cones, lava flows, ash deposits, and ejecta. Experiments which must be conducted at these features almost universally consist of those of the geosciences.

Astronomy experiments, on the other hand, are relatively immobile once a suitable site has been located. Initial sites will be selected to provide optimum viewing of the celestial sphere with minimum interferences. Additional sites may be desired later to optimize viewing for special purposes but these will probably utilize new telescopes.

Another class of experiments is not site dependent as it is directed towards phenomena which are considered to be homogeneously distributed about the moon. These experiments are those included in the lunar atmosphere, particles and fields, and bioscience disciplines. In addition, the aerospace medicine experiments and the engineering, technological, and operational experiments will be conducted wherever the personnel are located and so are not lunar site dependent.

Because of its scope and duration, a single experiment, #4048, Deep Drilling and Sampling, is treated as a special mobility case. Ordinarily, it would be included in the site dependent experiments and thus be transported about like any other. However, the time and personnel required to drill a deep hole and the weight of equipment involved make this a separate mission class with its own peculiar shelter support requirements -- specifically, the large power requirement.

As a result of this natural grouping of experiments into distinct classes, it is possible to identify separate supporting operations for each class and to treat each as a separate mission on the lunar surface. Later, they will be integrated into a single LSB mission.

Table 4.0-1 lists all the experiments and allocates their utilization during the LSB mission -- either by remote sortie, deep drilling, or observatory and shelter experiments. Also identified for each experiment is whether each can be performed at night, does not require continuous manned support, or should be accomplished as a precursor experiment. It will be noted that there is a considerable overlap between remote and shelter equipment usage. This results from considering the shelter site as a typical experiment site as is visited on the remote sorties.

Table 4.0-1. Experiment Allocations

Equipment Number	Utilization				Operational Factors		
	Shelter	Remote	Drilling	Observatory	Night	Unmanned	Precursor
4001	X				X		
4003	X						X
4006	X				X		
4009	X				X		X
4011	X				X		
4012				X	X	X	
4014				X	X	X	
4015				X	X	X	
4016				X	X		
4017				X	X	X	X
4021				X	X	X	X
4022				X	X	X	X
4023				X	X	X	X
4024				X	X		X
4025				X	X		X
4026				X	X	X	X
4027				X	X		
4028				X	X		
4029				X	X		
4030				X	X		
4032	X	X					X
4033		X			X		
4037	X				X		
4038	X	X			X		
4039		X			X		
4044	X	X			X		
4045	X	X			X		
4046	X	X			X		
4047	X	X			X	X	
4048			X		X		
4050	X					X	
4051	X					X	
4053	X	X				X	
4055	X					X	
4057	X	X			X		
4058	X	X			X		
4059	X	X			X		
4060	X				X		
4061	X				X		
4064	X				X		
4066	X				X		
4071	X				X		
4078	X				X		
4079	X				X		
4081	X				X		
4082	X				X		
4084	X				X		
4085	X				X		
4086	X				X		
4087	X				X		
4088	X	X			X		

The LSB mission thus can be separated into four separate and highly diverse missions: remote surface exploration, astronomical observatory, deep drilling, and the earth-moon-earth logistics resupply. Each of these missions require support from the lunar shelter. In this section, scenarios are presented of each mission to provide a basis for the subsequent mission analysis. These scenarios develop the initial mission performance requirements. In the case of remote exploration, however, additional analysis is required to identify these requirements due to the increased complexity of these missions. In succeeding sections, these missions will be defined in greater detail in order to permit realistic analyses which can define specific shelter support requirements.

4.1 REMOTE EXPLORATION MISSIONS

Two classes of remote sorties occur in lunar surface exploration and they are differentiated by the extent of manned EVA operations required in each. In one class, a crew is transported by surface or flight locomotion directly to an experiment site where extensive EVA operations are required to accomplish a specific set of experiments. The experiments and support equipment need not accompany the crew enroute. The crew is subsequently delivered back to the shelter where the vehicle is inspected and repaired and the experiment data are analyzed. In the other class, called a traverse, the variety of experiments is reduced, the experiments are more repetitious, and EVA is only performed occasionally. On this sortie, transportation to the point where the traverse begins is as before; i.e., no stops for experiments. However, instead of a point location for experimentation, the experiments are repeated at regular intervals along a line of fixed direction and length. When this path has been traversed, the vehicle and crew return to the shelter. The traverse experiments are designed for IVA performance and the only planned excursions from the vehicle, which serves as the shelter throughout this sortie, are for conducting active seismic surveys and drilling at geologically interesting points along the traverse. The experiments and support equipment must accompany the crew while on the traverse.

4.2 OBSERVATORY MISSION

This mission is concerned primarily with the site selection, site preparation, deployment, assembly, checkout, calibration, and operation of the seven, fixed-site telescopes.

4.2.1 X-Ray Telescope

This equipment will support the experiments to obtain an X-ray map of the sky and to determine position accuracies of 1.0 to 0.5 arc second by occultation of X-ray sources of interest (Experiment 4012). A site on the equator and in a large (60-mile diameter) crater with a relatively sharp rim will provide maximum sky coverage and an occulting edge. The site will be prepared prior to installation of the equipment by surveying, leveling, and installing foundations.

The telescope is delivered in eight subassemblies with a total mass of 3529 pounds (Table 4.2-1). Transportation of the payload module from the delivery site to the telescope site must be provided and a crane or handling hoist is necessary for moving the telescope subassemblies into place. The man-hours estimate for assembly assumes that the payload is at the telescope site and does not include payload module off-loading time from the delivery vehicle, or transit time to the telescope site. One hundred ten spacesuit man-hours are estimated to be required for the telescope assembly and 40 spacesuit man-hours for activation, alignment, calibration and checkout. There is no life support system associated with the X-ray telescope. Power requirements are estimated to be 20 watts during operation with 300 to 400 watts peak and may be supplied by an RTG.

Table 4.2-1. X-Ray Telescope Subassembly Mass

Subassembly	Mass (lb)
Platform	110
Stowage fixture	110
Upper bearing support	330
Polar axis tube assembly	220
Telescope tube assembly	1544
Aspect telescope assembly	660
Electronics	507
RTG (optional)	48
Total	3529

The experiment will be operated in cycles of one month duration and for a minimum of 12 cycles to a maximum of 36 cycles. Operation of the telescope requires emulsion-coated plates which would be expended, for a typical mission, at an approximate rate of one pound per day. Two spacesuit man-hours per day are required for adjustment and maintenance operation and for film changing and retrieval. Sixty shirtsleeve man-hours/cycle are required for analysis of data.

4.2.2 50-Inch Optical Telescope

This equipment will support the experiments to determine sky brightness of the full sky (Experiment 4016) and to observe the infrared phenomena related to the planets, stars and galaxies (Experiment 4029). A site on the equator is desirable in order to provide maximum sky coverage. Approximately 90 spacesuit man-hours are required to prepare the telescope module for experiment operations. This consists of leveling the telescope, assembling the dome and installing the light tube and optics in their mounts. Activation, alignment, calibration and checkout of the telescope will require 10 spacesuit and 5 shirtsleeve man-hours. There is no life support system associated with the telescope module. It will be located near enough to the LSB to allow periodic visits by EVA to change and retrieve film and interchange sensors or a portable shelter or outpost will be provided for crew support. Approximately two spacesuit and one shirtsleeve man-hour/day are required for nonscientific activity. The telescope will be operated continuously during the first year for Experiment 4016 (approximately 1100 shirtsleeve and 400 spacesuit man-hours/year) and intermittently thereafter, timesharing equally with Experiment 4029 (approximately 550 shirtsleeve and 200 spacesuit man-hours/year). The two experiments will be time shared as viewing conditions permit.

Average power requirements are 250 watts continuous and 400 to 500 watts peak. The nonexpendable mass of the telescope subassemblies is 10,684 pounds. The expendables mass which consists of film and containers and processing materials is 475 pounds. Film and processing materials are expended at an average rate of 4.4 pounds/day.

4.2.3 100-Inch Optical Telescope

This equipment will support the experiments to perform galactic observations with a large, diffraction-limited optical telescope (Experiment 4030). A site on the equator is desirable to provide maximum sky coverage and will be prepared prior to delivery of the equipment by surveying, leveling, excavating and installing foundations. Film and processing materials are expended at an average rate of 4.3 pounds/day and life support expendables, assuming 10 man-hours/day, are used at a rate of 9.6 pounds/day.

Transportation of the equipment elements from the delivery site to the telescope site must be provided and a crane or handling hoist is necessary for moving the telescope subassemblies into place. The man-hour estimate for assembly assumes that the equipment is at the telescope site, and does not include equipment off-loading time from the delivery vehicle or transit time to the telescope site. Three hundred twenty-five spacesuit man-hours and 80 shirtsleeve man-hours are required for the telescope assembly. Activation and checkout of the life support systems will require 10 spacesuit man-hours and 100 shirtsleeve man-hours, and activation, alignment, calibration and checkout of the scientific instruments will require 75 spacesuit man-hours and 150 shirtsleeve man-hours. The control and instrument room is designed for pressurized and nonpressurized operations. The optical system will operate nonpressurized at all times. Continuous power of 4 kilowatts at 28 vdc is required. One spacesuit man-hour/day and one shirtsleeve man-hour/day will be required for maintenance and nonscientific operation of the telescope facility. Six shirtsleeve man-hours/day are required for scientific activities which include film changing and processing, instrument adjustments and alignments and data screening for return to earth. The data returned will be primarily in the form of film.

4.2.4 Radio Telescope (Two-Element Interferometer) 300 kHz - 1000 kHz

This equipment will support the experiment to observe flux densities from galactic and extragalactic sources in the frequency region of 300 kHz to 1000 kHz (Experiment 4014). A desirable site for this experiment is located near the equator for maximum sky coverage. The baseline orientation should be east/west. The site must be reasonably level to allow for vehicle traffic during installation and must be surveyed prior to antenna deployment. Site preparation will require approximately 48 spacesuit man-hours.

The antenna consists of two parallel elements 5.6 miles apart. Each element has 16 end-loaded folded dipoles space a half wavelength apart on 100-foot high towers. Intermediate poles will support the transmission lines between dipole assemblies. An amplifier unit is mounted at each dipole. A ground plane is provided at each dipole, consisting of 20 evenly spaced wires 984.3 feet long and placed parallel to the dipole. The transmission lines will be either (1) connected to the LSB via hardline, (2) connected to a relay station from which the data will be transmitted to the LSB, or (3) connected to an on-site data processing shelter at which the data will be processed and stored automatically on tapes for retrieval by crew or for retransmission to the LSB.

A two-man vehicle with cabin will be required to transport the antenna components to their place of installation and to deploy the wire. The total mass of the antenna is approximately 11,533 pounds. The estimated time required for installation of the antenna is 236 spacesuit man-hours. The time required to lay transmission line from the antenna to the LSB is approximately 0.6 miles/hour (spacesuited). To set up and activate a single relay station would require 0.4 hour. An on-site data processing station, if required, would be delivered as a separate payload and require its own power supply. The time required to activate such a station would be six hours. The power requirement for LSB operation of the antenna is approximately 25 watts. The power required for relay station operation is 10 watts and for data processing operation is 200 watts.

Four shirtsleeve man-hours will be required to calibrate the antenna. The experiment will be operated in cycles of one month duration for a minimum of 12 cycles to a maximum of 36 cycles. The crew time required to monitor and process data and screen for selected data to return to earth (tapes and/or transmission) will require 80 shirtsleeve man-hours/cycle.

4.2.5 Radio Telescope (Two-Element Interferometer) 1 MHz - 15 MHz

This experiment requires a similar setup as above (the 300 kHz - 1000 kHz interferometer). The dimensions are scaled by approximately 0.1; however, the installation procedures will remain essentially the same. Site preparation will require 24 spacesuit man-hours, installation of the antenna will require 120 spacesuit man-hours, and calibration will require four shirtsleeve man-hours. This interferometer can be installed in the vicinity of the one previously discussed and could be configured to utilize the same transmission line poles, relay station, or data processing station, with some modification.

The experiment will be operated in cycles of one month duration and for a minimum of 12 cycles to a maximum of 36 cycles. The crew time required for scientific activity will be 80 man-hours/cycle.

4.2.6 Radio Telescope (Phase-Switching Interferometer) 0.6 MHz - 1.2 MHz

This equipment will support the experiment to observe those solar system sources exhibiting temporal variations in the frequency range 0.6 MHz - 1.2 MHz (Experiment 4027). A desirable site for this experiment is located on the equator for maximum sky coverage and on the near side for earth atmosphere observations. The site should be reasonably level and clear of large obstructions and must be surveyed prior to delivery of the equipment. The antenna consists of two sets of 3-meter crossed loops mounted at a height of 5 meters and installed 1.8 miles apart. The loops weigh approximately 220 pounds, and the transmission lines 220 pounds. The receiver weighs 55 pounds and requires 12 watts of power.

Installation of the antenna will require approximately 16 spacesuit man-hours. This time assumes the equipment has been delivered to the antenna site and does not include transit time from the delivery point. The receiver output can be connected to the LSB via hardline, to a relay station for transmission to the LSB, or to a data processing station at which the data will be processed and stored automatically on tapes for retrieval by the crew or for retransmission to the LSB. The time required to lay transmission lines from the antenna to the LSB is approximately 0.6 miles/hour (spacesuited).

The experiment will be operated in cycles of one month duration and from a minimum of 12 cycles to a maximum of 36 cycles. The crew time required will be 108 shirtsleeve man-hours for the first cycle and 50 shirtsleeve man-hours/cycle thereafter.

4.2.7 Radio Telescope (5 MHz - 500 MHz)

This equipment will support the experiment to observe solar system sources in the region of 5 MHz to 500 MHz for correlation with observations made from the earth (Experiment 4028). The preferred location for this experiment is on the far side, but a limb location is acceptable.

Installation of the antennas will require 16 spacesuit man-hours. This time assumes the equipment has been delivered to the antenna site and does not include transit time from the place of delivery. The receiver output can be connected to the LSB via hardline, to a relay station for transmission to the LSB, or to a data processing station at which the data will be stored automatically on tapes for retrieval by crew or for retransmission to the LSB. The time required to lay transmission lines from the antenna to the LSB is approximately 0.6 miles/hour (spacesuited).

4.3 DRILLING MISSION

Analyses of candidate experiments have identified a number of experiments that require drilling operations. These experiments are designed for lunar material sampling and meteorite collection, surface and subsurface seismic velocity studies, borehole logging, and heat flow studies.

Sample collection and meteorite studies will require shallow to intermediate drilling for soil structure definition and sampling. Information on near surface fine structure and subsurface material may be obtained from collected drill core samples. It is estimated that core diameters will range between 1 to 1.5 inches for depths of 20 to 100 feet. These core samples will be collected from areas selected as representative of the lunar surface. Drill holes 1 to 1-1/2 inches in diameter to depths of 1 to 10 feet will be sufficient for shallow logging, heat flow, and seismic study experiments.

Experiments to determine the extent and uniformity of deeper subsurface formations will require drill hole depths to 100 or 150 feet. Core samples with minimum contamination are expected at these intermediate depths. Bore hole logging, heat flow and seismic measurement experiments will also be conducted.

Deeper subsurface exploration, bore hole logging experiments, and seismic studies will require still deeper drill holes. Bore hole depths as deep as 1000 feet are expected. Core samples of undisturbed lunar subsurface formation materials are expected to be obtained during the drilling of the hole.

Deep drilling operations require considerably more time, manpower, electrical power, and equipment weight and complexity than shallow and intermediate drilling. For this reason, its mobility will be somewhat limited compared with the lighter drills which will be brought along on all of the remote exploration missions. In subsequent sections, therefore, drilling missions will refer to deep drilling operations only, and the smaller drills will be included in the exploration mission payloads as part of the geoscience equipment.

Deep drilling locations have not been specified to any greater precision than the general location of the LSB site. This may include drilling sites up to several hundred miles from the shelter, limited primarily by terrain geometry. It is expected that the drilling module will constrain mission routes to fairly gentle slopes and small diameter rock fields.

Analyses of surface and subsurface soils may be performed in the shelter geochemical laboratory in order to add any scientific findings that will aid in locating a suitable site. Both shallow and intermediate depth drilling equipment may be used to drill exploratory holes 10 to 100 feet deep.

Depending on the amount of loose surface soil, rock and debris, site excavation may be required to provide rigid footing to support the equipment or equipment foundation. Once the site is properly cleared, exploratory drilling will begin. Proximity parallel drilling will likely reduce the amount of shallow and intermediate test holes required, provided analysis of sample cores can be performed in a relatively short period of time.

Core analyses could be a determining factor in any decision to cease or continue the drilling operations. Geoscience experiment requirements indicate that an average of two deep holes will be necessary at each LSB site. It is estimated that three intermediate holes will be required for each 1000-foot hole, and each of the intermediate holes will require about five shallow holes to be drilled before the decision is made to begin the deep drilling operations.

The transportation of equipment will essentially involve unstowing the drilling equipment and moving it from the LSB to the potential drilling site. Electrical harnesses, instrumentation and displays for communications, control and operation monitoring must be installed and checked out. These requirements are a part of equipment setup, activation, and initial checkout. Other requirements include assembly and erection of a drill rig structure and supports.

Assuming a 4-foot per hour drill penetration rate, it would require 250 hours of drilling time to reach a depth of 1000 feet. The time required to remove core and rock chips, lower and raise drill, exchange bits and service must be added. Core and chip removal time is primarily a function of core length and core barrel exchange time. For a core length of 10 feet and a core barrel exchange time of 10 minutes, approximately 17 hours would be required. This time would be doubled for a 5-foot core.

A contingency factor of 2.0 is applied to the drilling time to obtain actual drilling time for IVA operations, and 2.5 is used for EVA operations. This safety factor is a correction from ideal minimum time to include the effects of hole cave-in, jamming and equipment problems.

A total duration of 170 hours would be used in lowering and raising the drill. Again, this time would double (340 hours) if the core length were only 5 feet long. Depending upon the drill configuration, significant time may be involved in addition and retraction of drill rods and exchanging drill bits. A semi-automatic drill during normal operation will require astronaut participation for 30 to 35 percent of the total task time. This would include a second or third astronaut (in shirtsleeves) monitoring the operations from inside the LSB or mobile shelter.

Deactivation and disassembly of equipment will require about 30 spacesuit man-hours. However, if it is not required to tear down or remove the drilling structure after the hole is completed, this amount of time may be reduced significantly. Total duration required for IVA and EVA drilling is 90 days and 181 days, respectively, based on 9 hours per day, 7 days per week. This rate averages at 5 hours/day actual IVA drilling time, and 3.5 hours/day for EVA drilling.

Core barrel containers must be packaged and stored for the return trip to earth. The deep drilling equipment will remain. It is estimated that 2800 pounds of core samples will be returned to earth from two deep holes.

4.4 LOGISTICS MISSION

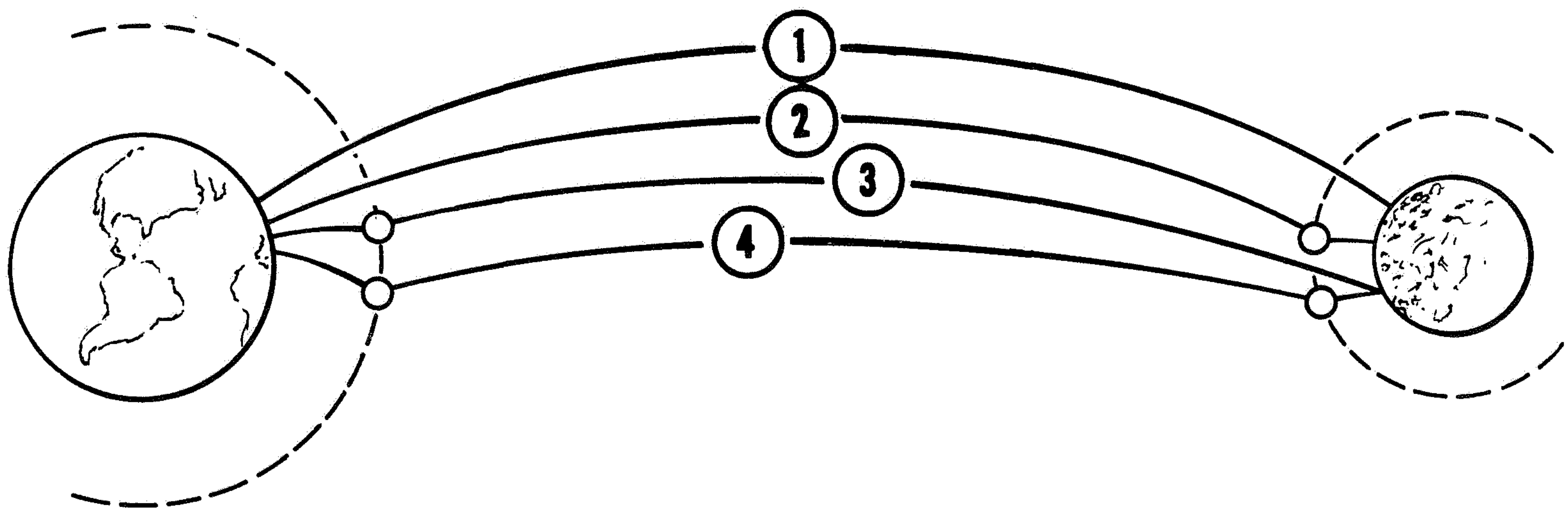
The logistics mission includes all those operations involved in the transportation of the crew, consumables, and equipment between the earth's surface and the LSB site. Both an initial buildup phase and regular resupply and crew rotation must be considered. The characteristics of the space transportation systems, which will be operational in the LSB era, are not definitive at this time and a number of systems options for support of the lunar surface operations can be identified using both existing hardware and the various vehicle design studies which have been conducted and are presently underway. The typical characteristics of some of these system options were briefly examined during the study in order to assess any potential implications to the LSB design or operations.

One way of categorizing these systems is on the basis of the transfer points, or nodes, in the overall flow from the earth's surface to the lunar surface. The significance of these nodes lies in the complexities introduced by zero-g sorting and handling of the crew and cargo in order to transfer them from one vehicle to another. Figure 4.4-1 illustrates the principal modes resulting from various combinations of cargo transfers in earth orbit and lunar orbit and identifies some of the system options which match the modes. The Apollo system is typical of the minimum node mode in that although there are several staging points in the mission, the lunar surface cargo is integrated into the lander prior to earth departure and only the crew transfers from one vehicle to another. The current emphasis on the introduction of various concepts of reusable elements in the logistics system creates a requirement for crew and cargo transfer at one or more points as indicated in Figure 4.4-1. One potential variation which has recently been investigated (Reference 6) would involve essentially two lunar orbit transfers, one at or near the L_2 libration point and one at some lower circular orbit. The advantage of this mode is that the cargo transfer at the libration point increases the payload capability of the cislunar shuttle sufficiently to potentially offset the losses in the subsequent descent to the lunar surface.

In general, each nodal point introduced tends to increase the payload fraction of the system in the same way that staging does. At the same time, the nodes involve space-based systems with their associated complexities and require the accomplishment of transfers of crew and cargo in the zero-g environment. Issues relative to safety and rescue are involved also but were not investigated in this study.

Of the mission and system options illustrated in Figure 4.4-1, two baseline logistics systems, which are both examples of Mode 4, have been investigated for this study. The two options correlate with the two basic options on the extent of the activities in the lunar program; one, that there will be an Orbiting Lunar Station (OLS) operating concurrently with the LSB, and two, that the OLS program is not implemented. If the OLS is operating concurrently with the LSB, then the logistics system must support its requirements in addition to the LSB's and there is a natural node or cargo transfer point in lunar orbit. These two factors, in conjunction with the current high priority assigned to the Earth Orbital Shuttle (EOS) have led to the selection of a logistics system composed of the EOS, the Chemical Interorbital Shuttle (CIS), and a reusable space tug configured for lunar landing and based at the OLS. The same system also supports the OLS program and sorties.

If the OLS does not exist, the total delivered payload required at the moon is reduced and there is no convenient basing point for the tug in lunar orbit. For this situation, the selected baseline was changed to include the EOS, the Reusable Nuclear Shuttle (RNS), and a tug based at the LSB. The choice of cislunar shuttles for the two baselines was based on payload capabilities which were current for the two systems at the time of the selection



SYSTEMS OPTIONS

CARGO TRANSFER POINTS	FIRST LEG	SECOND LEG	THIRD LEG
(1) NONE	SAT V W/LANDER		
(2) LUNAR ORBIT	SAT V OR DERIV.	LUNAR BASED LANDER	
(3) EARTH ORBIT	EOS, SAT V DERIV., SAT IB, OIS, OR ?	CISLUNAR SHUTTLE (RNS, CIS) W/LANDER	
(4) LUNAR ORBIT & EARTH ORBIT	SAME AS ABOVE	CISLUNAR SHUTTLE	LUNAR BASED LANDER

Figure 4.4-1. LSB Cargo Transfer Points

and does not represent the result of any tradeoffs between them in this study. The key point is that the selected logistic mode is influenced by the payload capability available as well as the payload requirement and the operations to be supported.

While it was not selected, one variation of the above approaches was considered potentially desirable because of the resulting simplification of lunar orbit operations. Briefly, the approach involves bringing the complete tug from earth orbit each time and returning it to earth orbit for refueling and reloading, either on the same cislunar shuttle or on the subsequent one. The advantage is the reduction of lunar orbit operations to a relatively simple rendezvous and single docking with all propellant transfer and cargo loading relegated to the presumably safer vicinity of earth. The disadvantage, and the reason the approach was not utilized, lies in the increased number of cislunar shuttle flights required to compensate for the payload lost by carrying approximately 10,000 pounds of extra tug hardware to the moon and back.

Further details of the utilization and capabilities of the selected baseline logistic systems are contained in a later section. It should be noted that the selection of these baselines in no way implies that they are required in order to implement the Lunar Surface Base program. Their selection was based on trends current at this time and was for illustrative purposes.

4.5 LUNAR SURFACE NATURAL ENVIRONMENT

In the previous sections of this report, brief mission descriptions have been given of each of the four missions which support and are supported by the LSB. The next step in the requirements definition process is to specify the natural environment within which they operate. This will lead to various approaches to protect the personnel and equipment against individual environmental extremes or combinations of extremes. The lunar environments of particular concern include the temperature extremes, meteoroids, and solar flares.

4.5.1 Thermal Influence

The elements of the LSB will be exposed to a natural thermal environment which varies considerably throughout a synodic month. During the 354-hour lunar day, these elements will be heated by direct sunlight, sunlight reflected from the lunar surface (albedo), and by infrared (IR) energy emitted from the moon. Throughout the lunar night, the only source of external heating is the lunar IR emission, which declines to an extremely low level just before sunrise. The resulting temperature as measured on an exposed surface can range from a high of over 400 K to a low of 90 K as shown in Figure 4.5-1. The actual values depend on the base location with respect to the lunar equator and its outer coating.

The thermal control system must (1) reduce the heat loss or gain to the shelter to a manageable level, (2) maintain externally mounted equipment and scientfic instruments within specified temperature limits during habitation

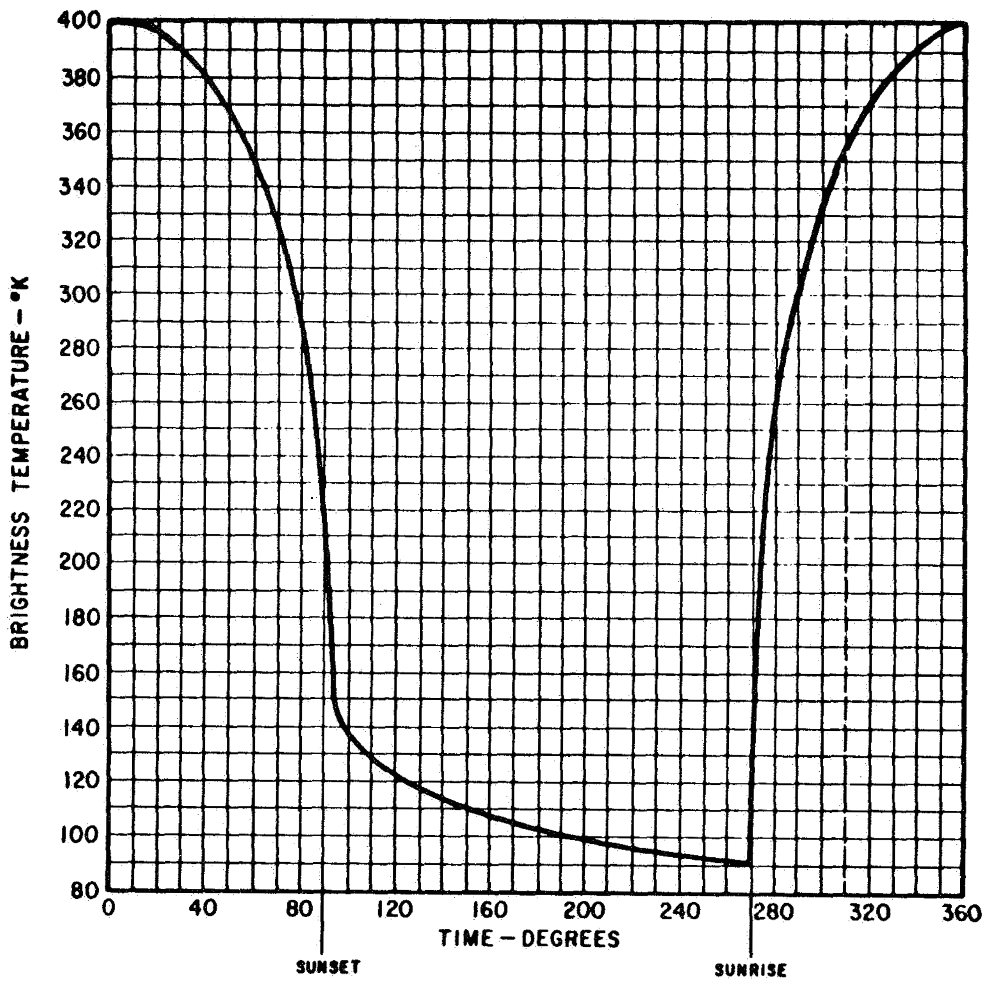


Figure 4.5-1. Fourier Approximation of Measured Surface Temperature on Lunar Equator for One Lunar Cycle (Reference)

and during quiescent storage, and (3) aid in the thermal control of equipment such as mobility devices when these are located near the shelter.

Most of the high performance thermal coatings, used to limit shelter surface temperatures, suffer some long-term degradation resulting from the sun's ultraviolet rays, meteoroid impingement, proton flux and lunar dust deposits.

Site geometry also influences the thermal load on the shelter and infrared heating becomes a predominant factor where crater or mountain walls are close by. The relationship between site and shelter wall geometry can exercise a significant influence on the termal control requirement, as shown in Figure 4.5-2(a). Protective concepts are normally limited to use of insulation and protective coatings; however, they can also take advantage of the effects of the geometric relationships. One concept, useful as a protective shelter for vehicles, communications antenna, the logistics vehicle, and radio telescope equipment, is shown schematically in Figure 4.5.2(b). It involves the deployment of a conical shroud in the form of a tent, supported by pneumatic beams and surrounding the system to be protected. It also provides some meteoroid protection.

The performance of some typical insulating materials is presented in Table 4.5-1. Insulation is a requirement for lunar night operation to reduce heat loss and to eliminate condensation on the shelter walls. It also reduces the heat gain during the day and thus relieves part of the load on the radiators. A combination of insulators may prove superior.

Table 4.5-1. Insulating Material Properties

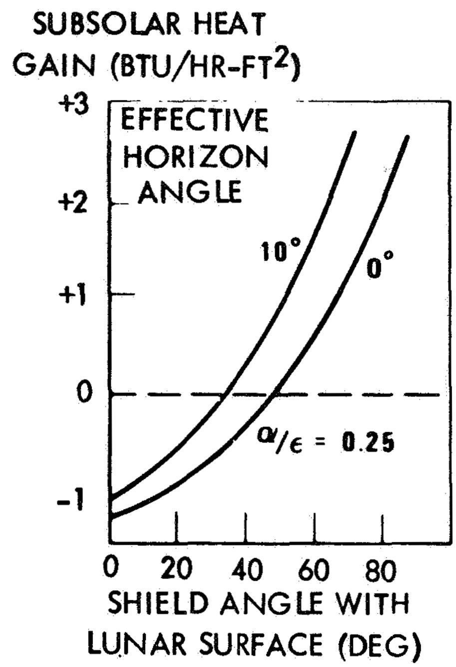
Material	Conductivity (Btu/hr-ft/°F)	Density (lb/ft^3)	Depth (in.)*
Superinsulation	.0002	0.7	1.0
Polyurethane foam	.01	4.0	24
Fiberglass material	.0016	2.0	8
Lunar soil	.0024 to .0068	100	11 to 26

*For 1 Btu/hour-foot^2 heat loss at lunar night conditions

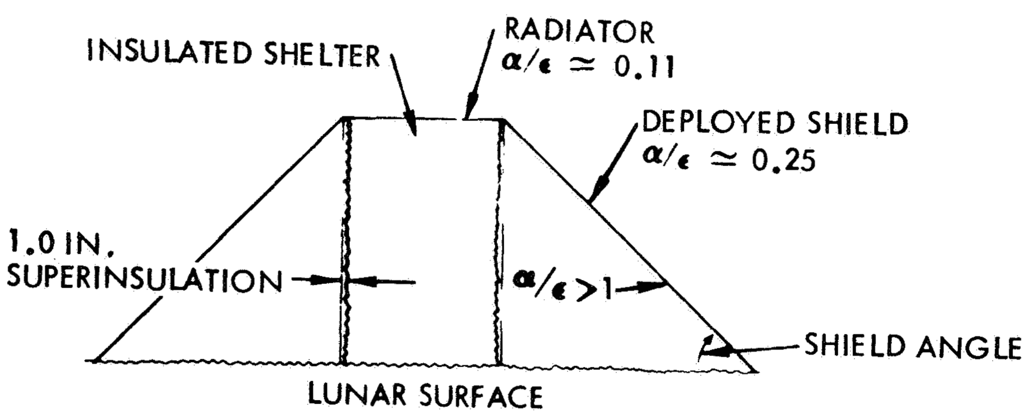
Use of lunar soil as an insulator when deployed around the outside of the shelter eliminates the need for structural penetrations and can nearly achieve the theoretical effectiveness. Less lunar soil would be required if the shelter were internally insulated -- the soil depth being reduced by the performance capability of the material and thickness of material utilized.

4.5.2 Meteoroid Influence

The combined meteoroid environment as experienced on the lunar surface presents a greater hazard than in free space. The additional hazard is created by the secondary ejecta which result from the meteoroids impinging on the



Part a



Part b

Figure 4.5-2. Thermal Control

lunar surface. These particles are of a larger mass but of a slower velocity than those encountered in free space. The environmental models used are as follows (from Reference 7):

Average Annual Total Meteoroid Environment

For $10^{-6} \leq M \leq 10^{0}$

$$\text{Log } N_t = 14.597 - 1.213 \log M$$

For $10^{-12} \leq M < 10^{-6}$

$$\text{Log } N_t = -14.566 - 1.584 \log M - 0.063 (\log M)^2$$

where N_t = Number of particles per square meter per second of mass M or greater

M = Mass in grams

Average Total Ejecta Flux Mass

For $0 \leq V_{ej} \leq 1.0$

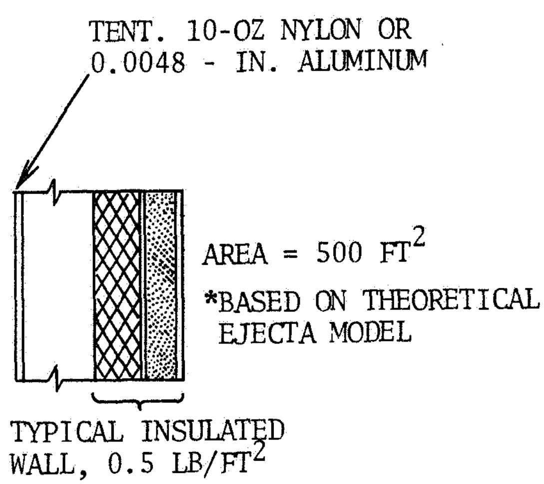
$$\text{Log } N_{ej_t} = -10.75 - 1.2 \log M$$

$$V_{ej} = 0.1 \text{ km/sec}$$

The protective design options involve use of structure or lunar soil. Where structure is used, the total protective mass may be minimized through use of an outer bumper and sufficient spacing between it and the pressure barrier to permit particle dispersion. However, the effects of the projected ejecta environment tend to reduce the effectiveness of this approach. For example, the typical structural cross-sections presented in Figure 4.5-3 provide adequate protection against the cometary meteoroid environment. The associated curves compare the performance of this minimum weight wall section when the bumper is equal weight or when made from aluminum or nylon for the two separate environments for short missions. It indicates that either bumper concept is effective against cometary particles but both are considerably less effective against the ejecta particles.

To provide adequate protection against the combined environments through use of basic structure only, requires a combination of the foregoing design concepts plus added shielding outside the pressure wall. The outer bumper breaks up the particles and the shield impedes their progress, stopping them prior to the pressure wall. Figure 4.5-4 indicates the amount of protection required in this concept to provide a probability of 0.9999 of no penetration.

An alternative concept involves use of the lunar soil. As indicated by Figure 4.5-5, a blanket of lunar soil built up to a depth of several inches will protect the shelter against the projected meteoroid hazard. It is estimated that six inches of soil will reduce the risk of a puncture during a 2- to 5-year base life to less than one chance in ten thousand.



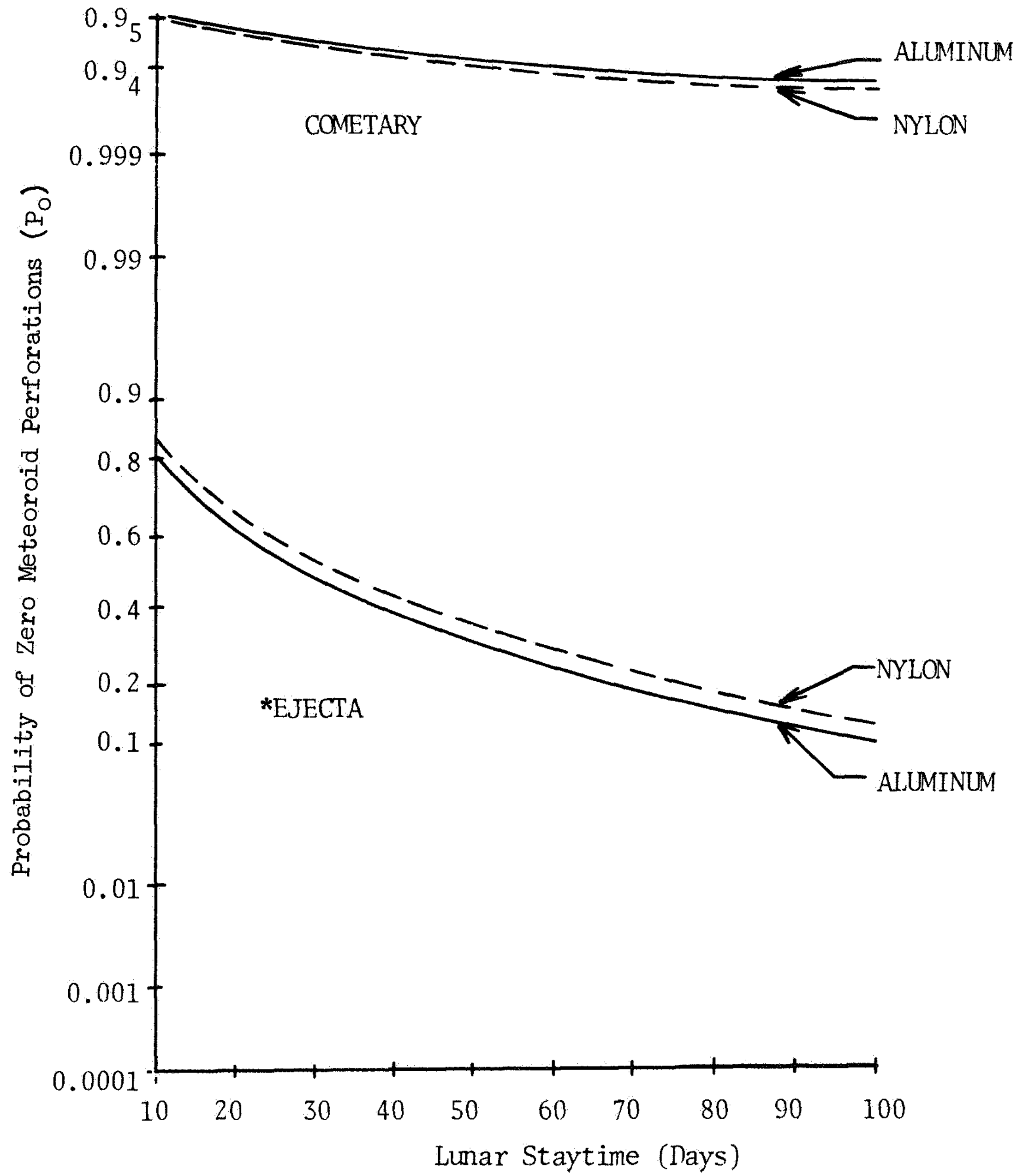


Figure 4.5-3. Comparison of Meteoroid Shielding Provided by Equivalent Weight Tents of Nylon and 2024-T3

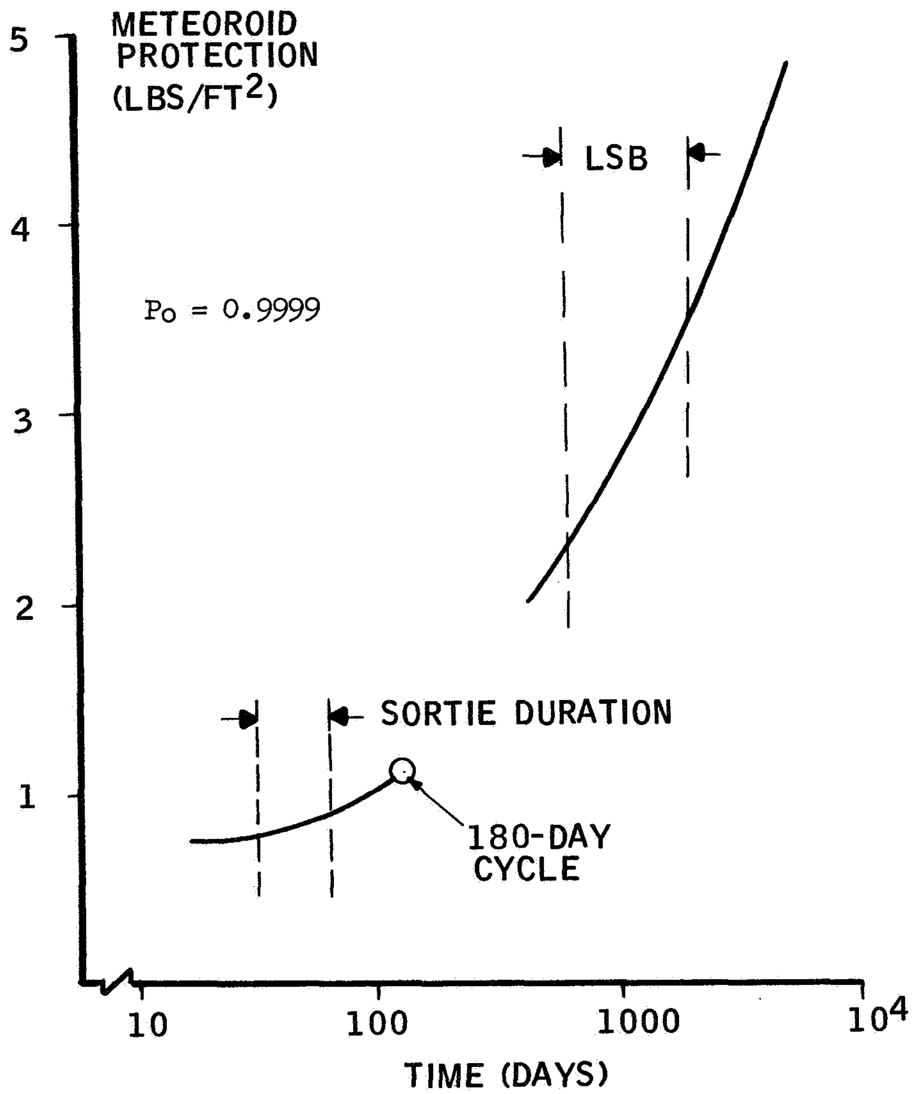


Figure 4.5-4. Meteoroid Protection Requirements - Rigid Structure With Outer Bumper

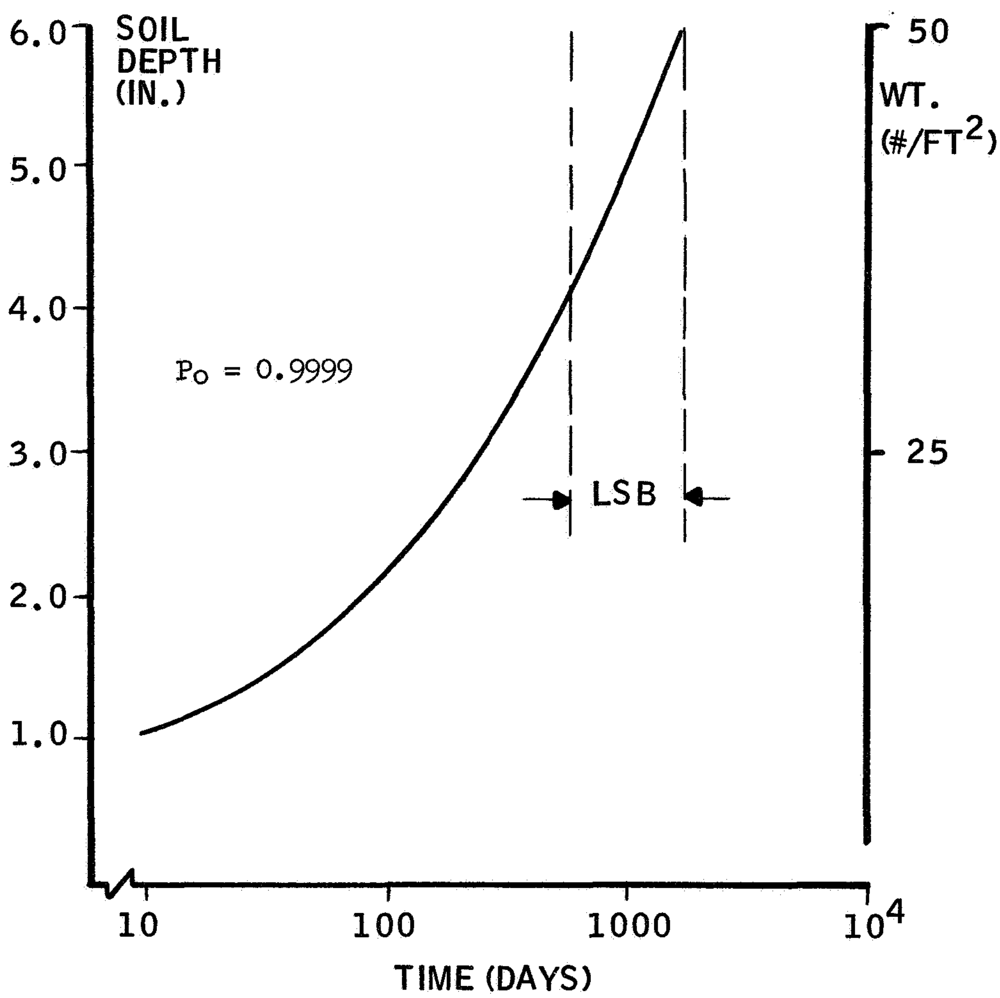


Figure 4.5-5. Meteoroid Protection Requirements - Lunar Soil

4.5.3 Solar Flare Influence

Solar cosmic radiation presents a severe hazard to the lunar exploration party. It is known that the intensity of a given flare and the probability of its occurrence varies greatly within the approximately 11-year solar cycle. Radiation is known to create a detrimental effect on exposed personnel long before it will affect equipment. The sensitivity levels are approximately an order of magnitude apart. Personnel are affected both at skin level and at the blood forming organs (BFO). Exposure has varying effects on personnel ranging from sickness to death; the range of radiation tolerance runs from about 200 to almost 1000 rads depending on crewman size and physical condition. Prevention of injury can only be accomplished through shielding the personnel from the energy. Since all personnel do not react the same, and since all flares do not produce the same energy level, each factor has to be treated on a probabilistic basis. The factors to be considered therefore include:

1. The probability of a flare
2. The probability of the flare achieving a dangerous level
3. The probability of the flare producing sickness or death
4. The time of exposure
5. The shielding available

The protective options are limited to the use of some form of mass between the flare and the personnel and equipment or film. Protective concepts can include use of separately shielded compartments ("storm cellars") or protecting the total shelter with structure or lunar soil.

The dates of the important flares from Solar Cycle 19, the most severe cycle reported since the observations began in the late 18th century, are shown in Table 4.5-2 (from Reference 7). The use of these data are felt to provide a conservative basis for determining shield thickness for the shelter. Since the shelter will be manned for extended periods, peak solar proton events constitute a probable threat model.

Free space skin and blood-forming organ doses in rads from the flares of Cycle 19 are also shown in Table 4.5-2 for various shield thicknesses. The flare characteristics are of importance in determining the potential protective measures. As indicated by Figure 4.5-6, the time history of the largest cumulative spectrum flare recorded, the November 12, 1960 event, the dose rate rises rapidly reaching its peak within 20 hours of the initial activity. Therefore, protection facilities must be accessible within two or three hours in order to be effective.

The shielding for a "crew cycle duration" concept, based on the study guideline of not exceeding 200 rads to the skin with a probability of .99, is presented in Figure 4.5-7 for a 90-day exposure cycle. It involves consideration of the foregoing five factors and provides protection against the smaller flares. These data are adequate for a typical surface sortie duration. Here, a reasonable shielding weight need not exceed four pounds per square foot. However, for a total manned duration of two to five years, the probability that one of the crew may be overexposed is very high.

Table 4.5-2. Effect of Shielding on Free Space Doses in Rads
(20 Recorded Events)

	Shielding Configuration									
Date	1/0*	2/0	5/0	10/0	20/0	1/5	2/5	5/5	10/5	20/5
2/23/56	280.00	181.00	91.80	50.20	24.80	64.78	58.00	43.75	30.40	17.90
8/3/56	8.50	5.00	2.20	1.00	0.40	1.39	1.21	0.85	0.53	0.27
1/20/57	122.00	43.50	8.30	1.80	0.30	3.42	2.57	1.23	0.46	0.11
8/29/57	77.00	25.10	4.20	0.80	0.10	1.63	1.20	0.54	0.19	0.04
10/20/57	18.50	10.30	4.10	1.80	0.70	2.53	2.17	1.46	0.88	0.41
3/23/58	148.00	53.60	10.90	2.50	0.40	4.67	3.55	1.75	0.69	0.17
7/7/58	150.00	53.70	10.50	2.30	0.40	4.38	3.30	1.60	0.61	0.15
8/16/58	23.70	8.60	1.80	0.40	0.10	0.75	0.57	0.28	0.11	0.03
8/22/58	45.00	14.90	2.50	0.50	0.10	0.96	0.71	0.32	0.11	0.02
8/26/58	75.00	23.10	3.40	0.50	0.10	1.19	0.85	0.36	0.11	0.02
5/10/59	470.00	211.10	59.30	18.30	4.40	30.18	24.28	13.60	6.70	2.10
7/10/59	420.00	214.00	73.20	27.40	8.40	41.56	34.65	21.76	11.84	4.80
7/14/59	650.00	284.50	75.90	22.30	5.00	37.56	30.00	16.75	7.80	2.50
7/16/59	382.00	194.80	67.20	25.30	7.80	38.30	31.98	20.16	11.03	4.50
9/3/60	13.00	7.20	2.90	1.20	0.50	1.77	1.52	0.10	0.06	0.03
11/12/60	484.00	269.60	105.50	44.90	16.20	64.53	55.12	36.87	21.83	10.05
11/15/60	288.00	151.90	55.90	22.40	7.50	30.04	7.91	18.14	10.33	4.49
11/20/60	17.30	9.50	3.60	1.50	0.05	2.14	1.82	1.20	0.69	0.31
7/12/61	25.70	8.40	1.40	0.30	0.03	0.54	0.40	0.15	0.06	0.01
7/18/61	128.00	64.20	21.60	8.00	2.40	12.16	10.11	6.30	3.39	1.35

* Shielding configurations are given as X/Y where X = shielding thickness in g/cm^2 of aluminum and Y = shielding thickness in g/cm^2 of tissue.

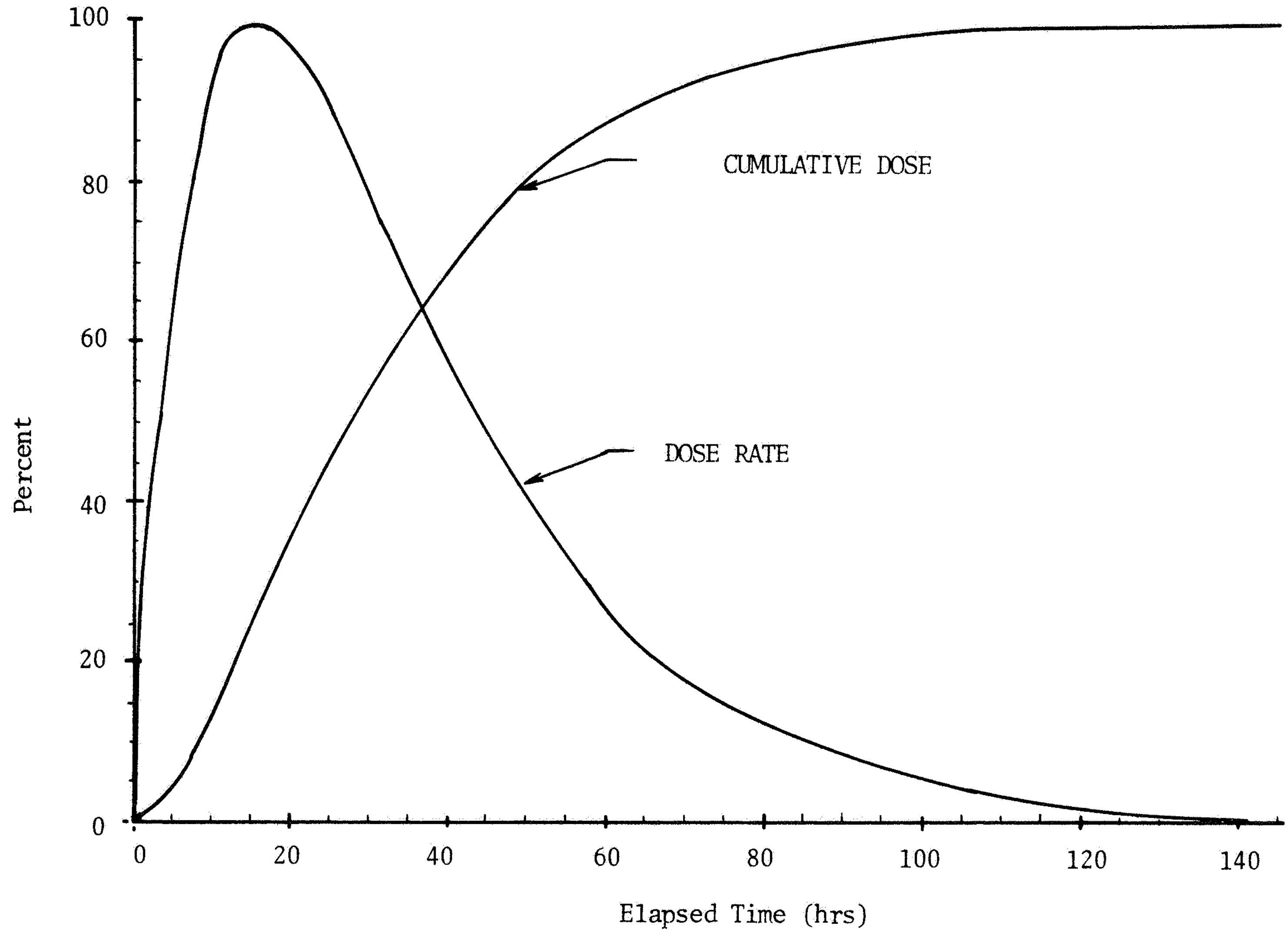


Figure 4.5-6. Solar Flare Time Characteristics

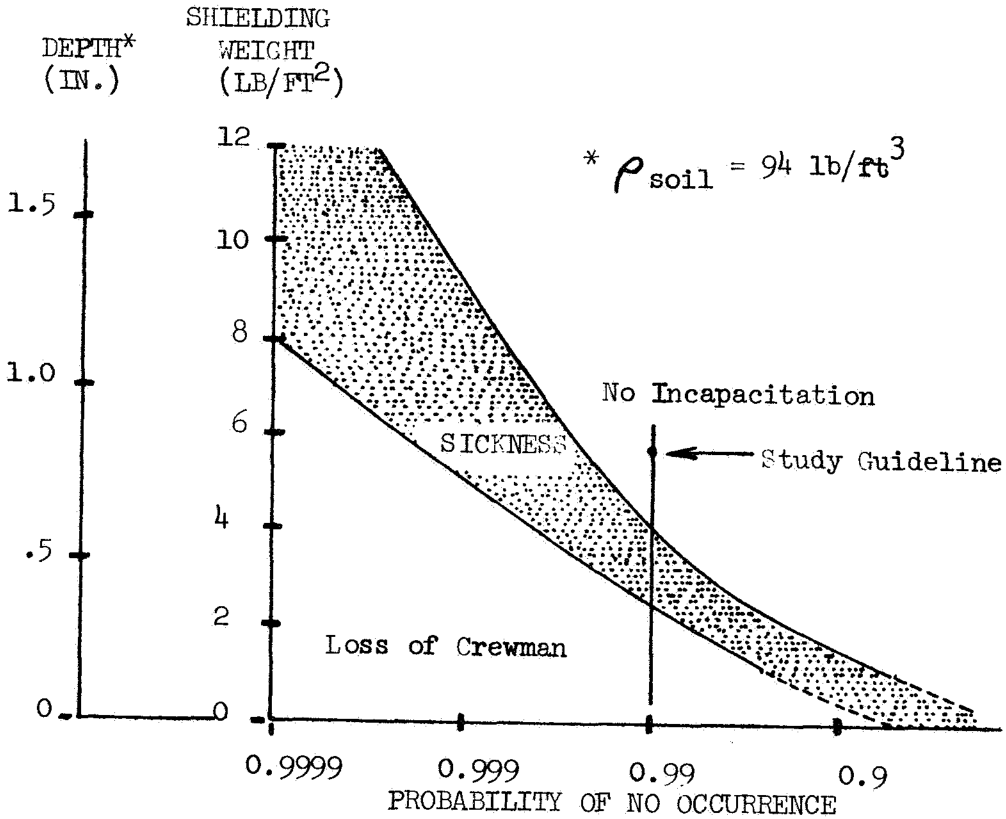


Figure 4.5-7. Shielding Requirements, 90-Day Exposure Cycle

A duration independent concept is defined in Figure 4.5-8 to the same criteria as the previous case. In this case, it is assumed that the maximum observed cumulative spectrum flare occurred during base occupancy. The resulting shielding weight required to reduce the radiation to the study guideline level is about 11 pounds per square foot of exposed area. This can be implemented for the LSB using lunar soil at an estimated density of approximately 94 pounds per cubic foot. The resulting soil depth would be less than two inches.

4.5.4 Protection against the Combined Environment

A review of the foregoing data indicates that protection against all three deleterious environments can be optimally accomplished through use of a combination of lunar soil externally and some added internal insulation. The amount of soil required is modest, amounting to no more than six inches depth, loosely packed around the modules. This depth of soil will provide protection in excess of .9999 probability of not exceeding the maximum allowable flare dose nor of having a meteoroid puncture.

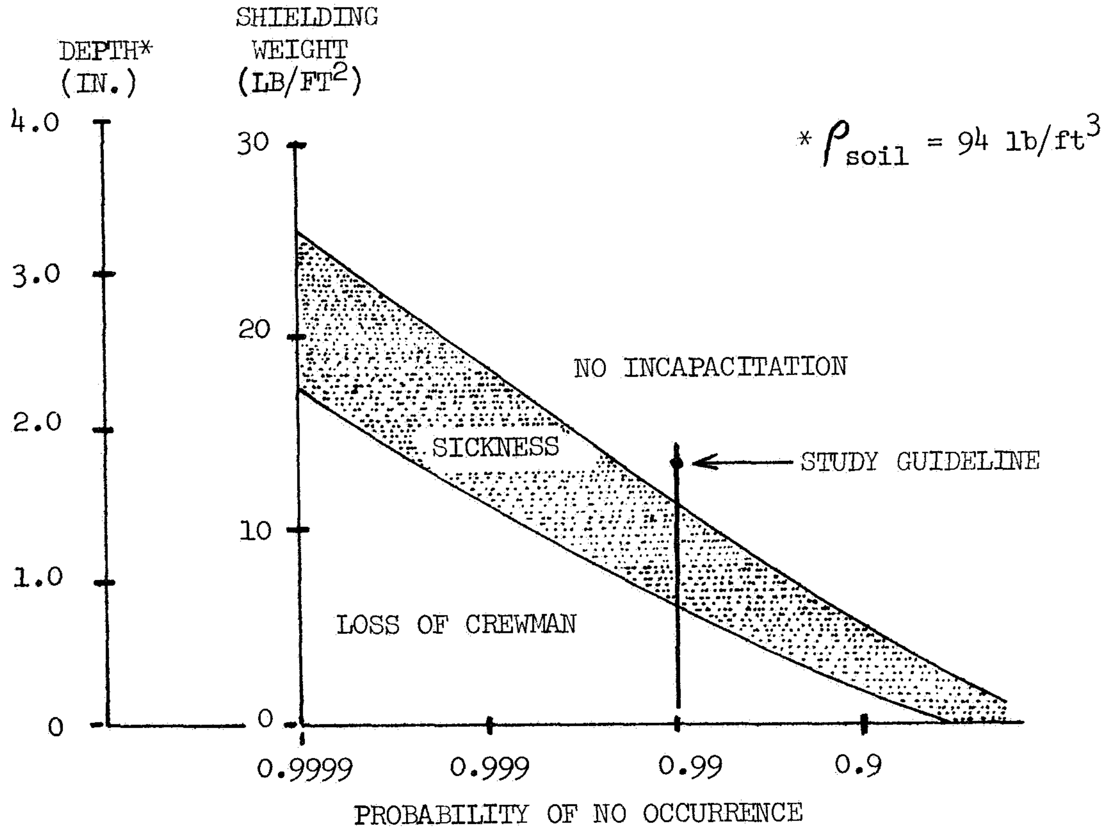


Figure 4.5-8. Shielding Requirement for Maximum Observed Flare

Use of lunar soil in preference to delivering the equivalent protection in the form of shielding from earth can reduce the delivered shelter structural weight by over 16 pounds per square foot of exposed area. For example, for a four-man module, this would amount to over 16,000 pounds if the whole module were shielded.

4.6 LUNAR SURFACE CHARACTERISTICS

Terrain surface geometry which affects vehicle performance and its optimization is defined as:

1. "Microgeometrical" surface roughness which induces vehicle vibrations (pitch, roll, bounce) and affects maximum speed, ride comfort, and control

2. "Macrogeometrical" surface roughness which encompasses slopes and such passable obstacles as ditches, walls, and crevasses that reduce speed

3. Impassable obstacles such as mountains, craters, rilles, valleys, large crevasses and bluffs which have to be bypassed and thus increase distance of travel

Detailed information regarding lunar surface roughness as defined above is not presently available. However, a sample of terrain properties which were used to derive correction factors to measured map distances to estimate actual travel distances are shown in Figures 4.6-1 through 4.6-6 (from Reference 8). Figures 4.6-1 and 4.6-2 illustrate the probability of expected slopes to be encountered on the remote sorties. Figures 4.6-3 and 4.6-4 show the power of the terrain input to a vehicle as a function of spatial frequency of features for a smooth lunar terrain and a rough terrain. The frequency range of greatest interest to the vehicle designer is between .05 and .5 cycles per meter; i.e., features with base lengths of 2 to 20 meters. Figures 4.6-5 and 4.6-6 present the cumulative frequency distributions of craters and blocks on smooth mare, rough mare, and upland terrain. For mobility studies, the obstacle height is taken as half of the block diameter. Reference 8 gives the following distance increase due to terrain sloping based on the assumption that the increase in traverse distance is proportional to the secant of the angle of slope above horizontal.

Angle (deg)	Percent Increase of Map Distance
10	1.5
15	3.6
20	6.3
25	10.2
30	15.5

Obstacle circumvention is a major contributor to path length if the obstacles are large (craters, crevasses). Small size obstacles (boulders, mounds, small craters) do not greatly increase the distance traveled although they increase the traverse time due to the lowering of vehicle speed needed to give the driver enough time for decision-making in the maneuvers and keeping the vehicle upright when negotiating curves.

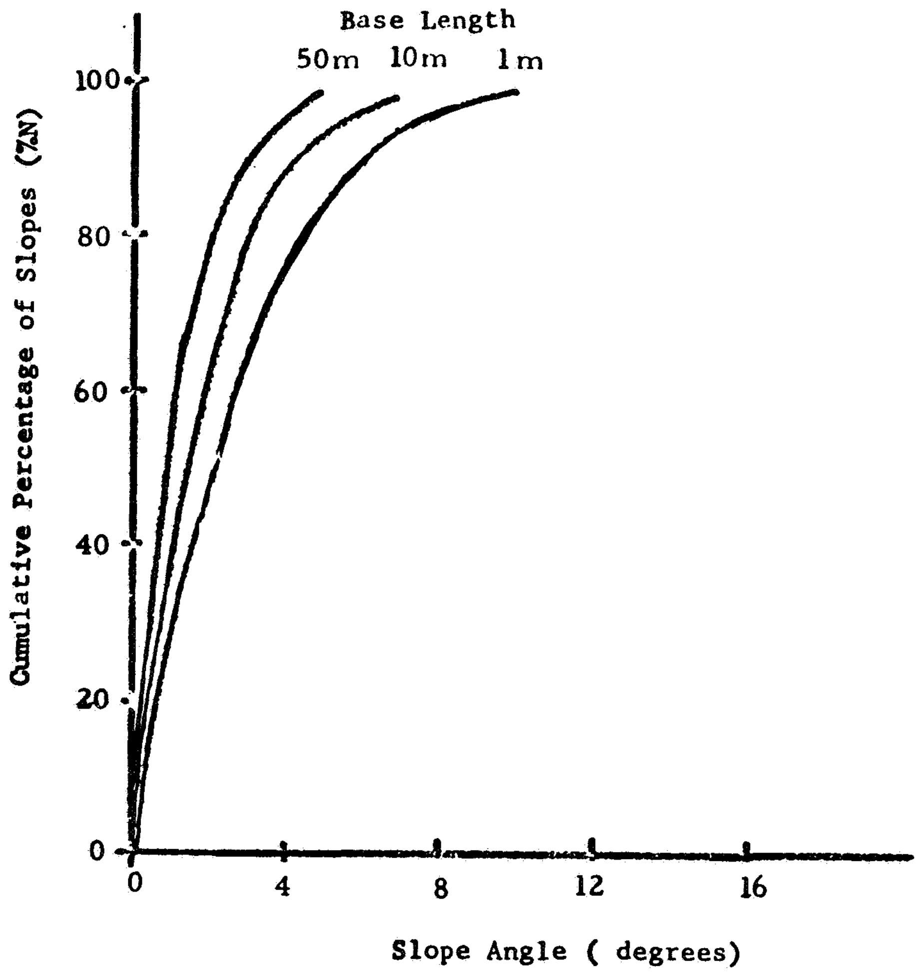


Figure 4.6-1. Smooth Mare Cumulative Slope Frequency Distributions for Three Base Lengths

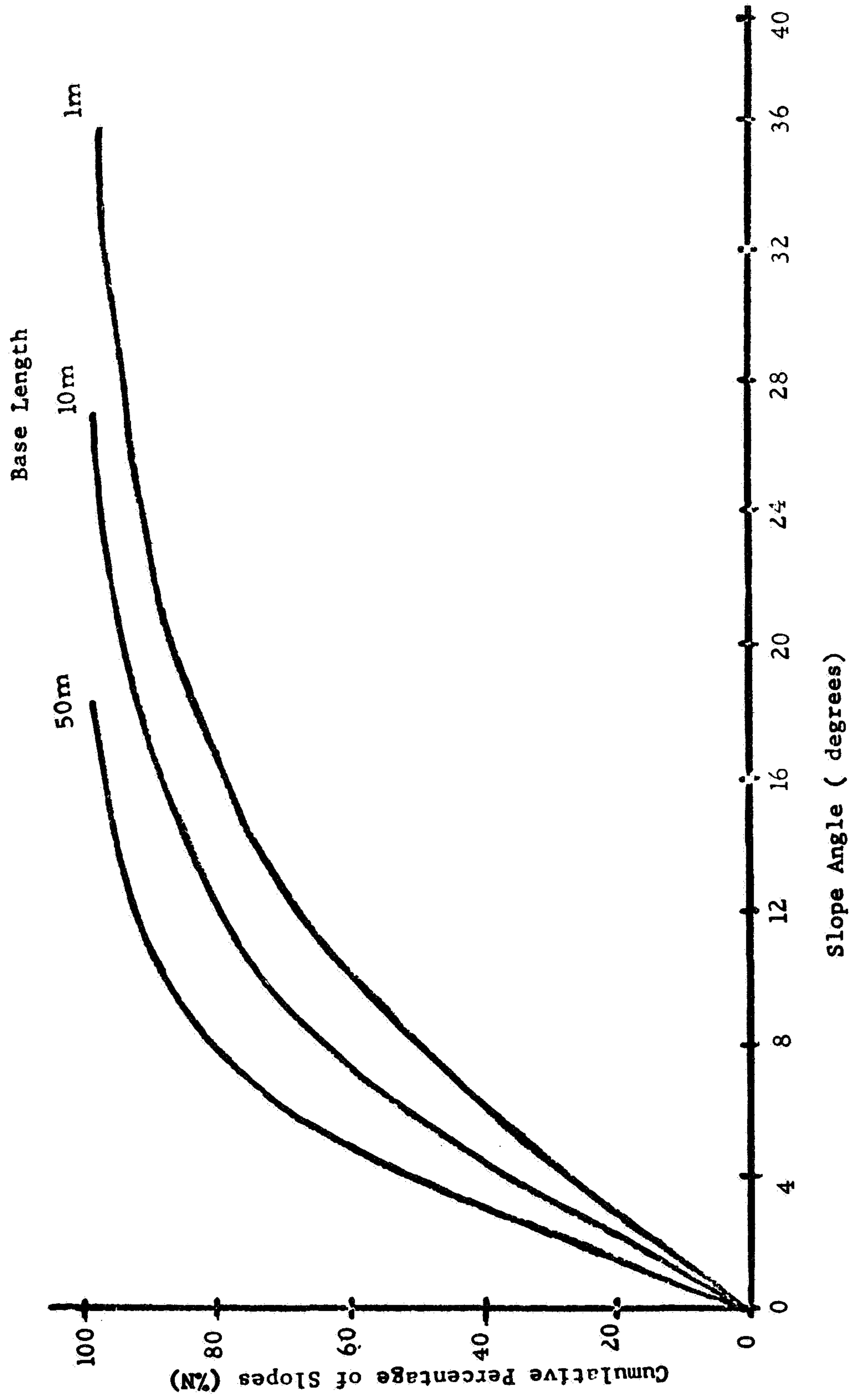


Figure 4.6-2. Rough Uplands Cumulative Slope Frequency Distributions for Three Base Lengths

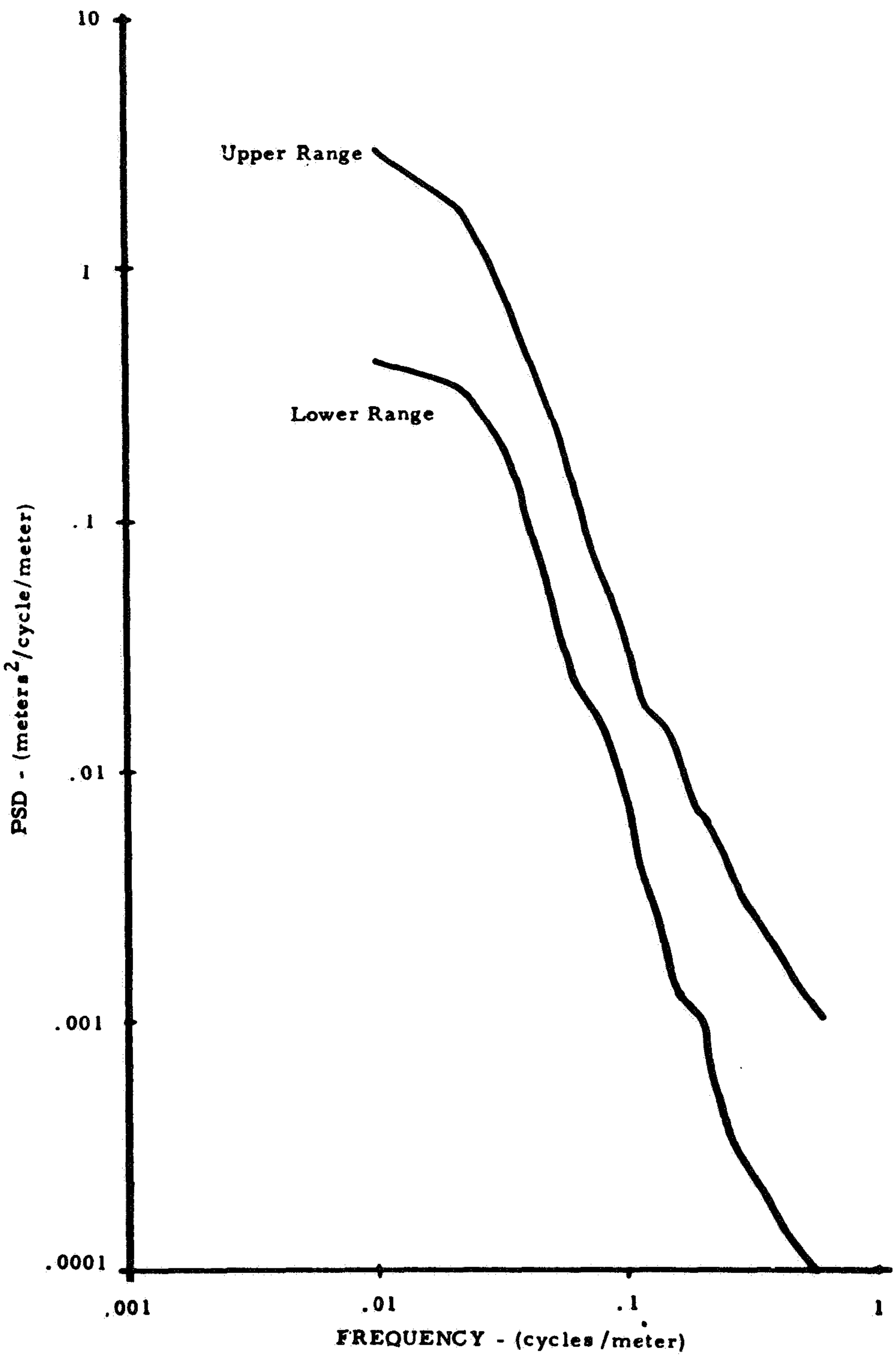


Figure 4.6-3. Smooth Mare Power Spectral Density vs. Frequency

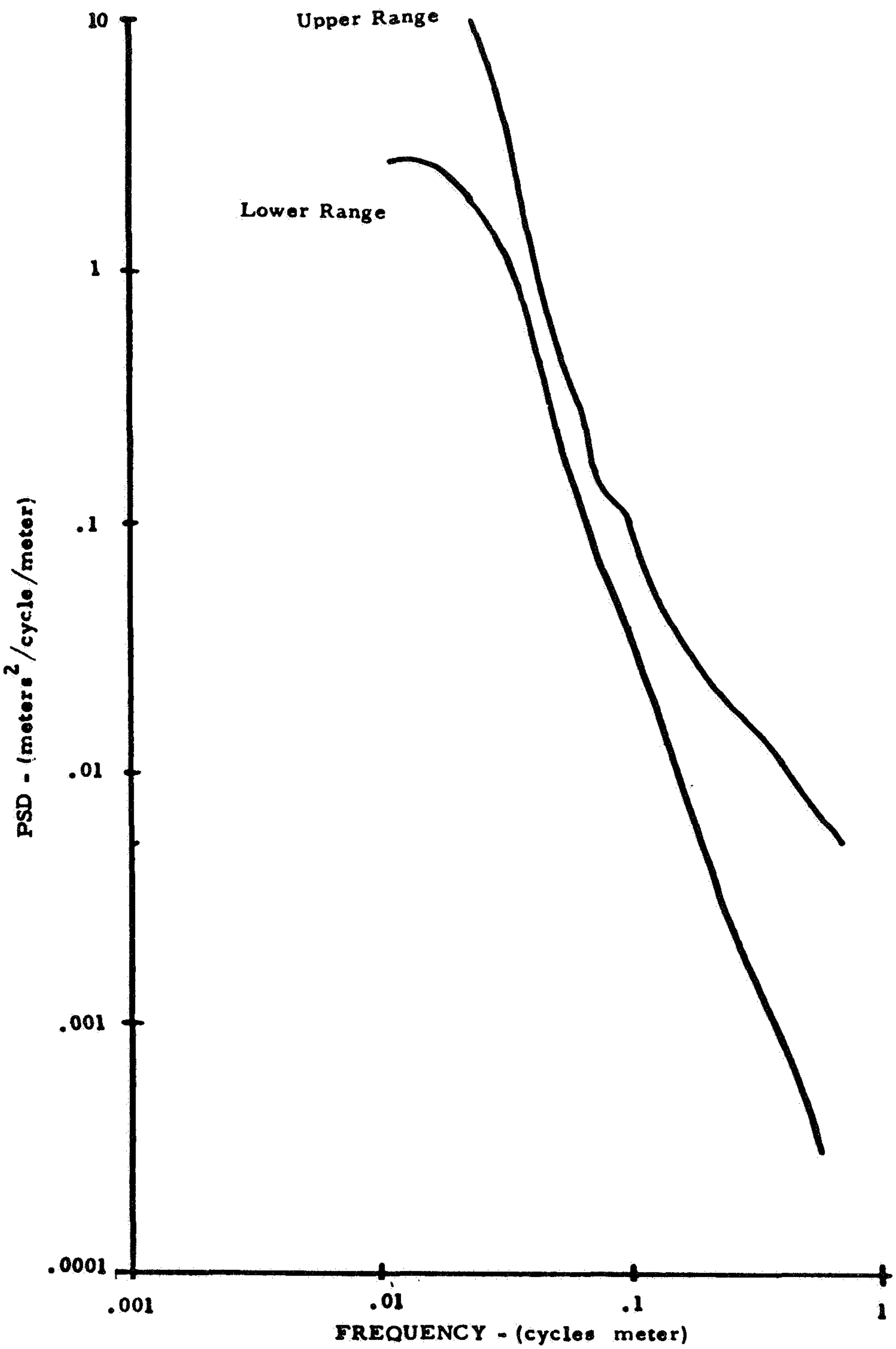


Figure 4.6-4. Rough Upland Power
Spectral Density vs. Frequency

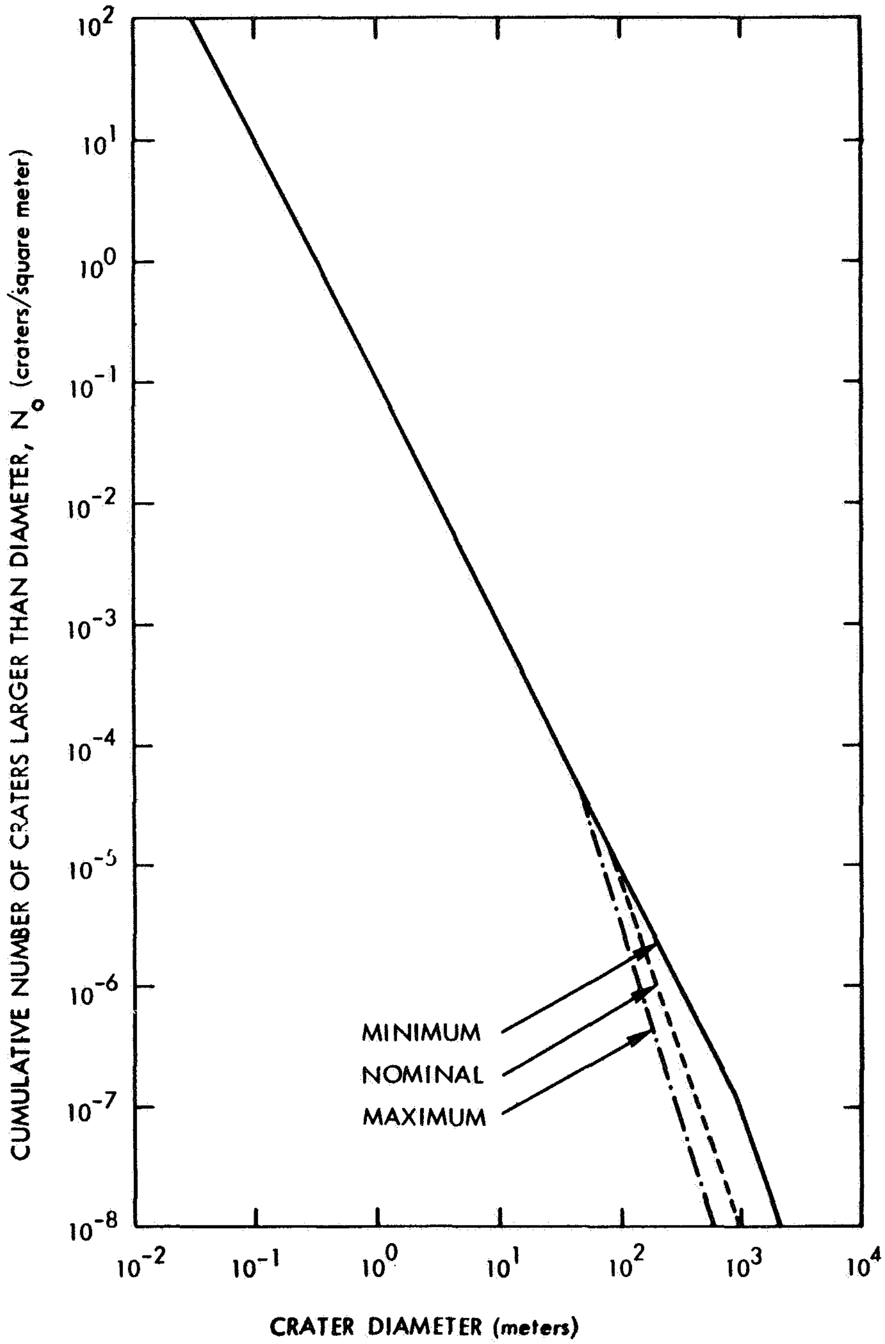


Figure 4.6-5. Cumulative Crater Distribution for Smooth Mare, Rough Mare, and Upland Terrains

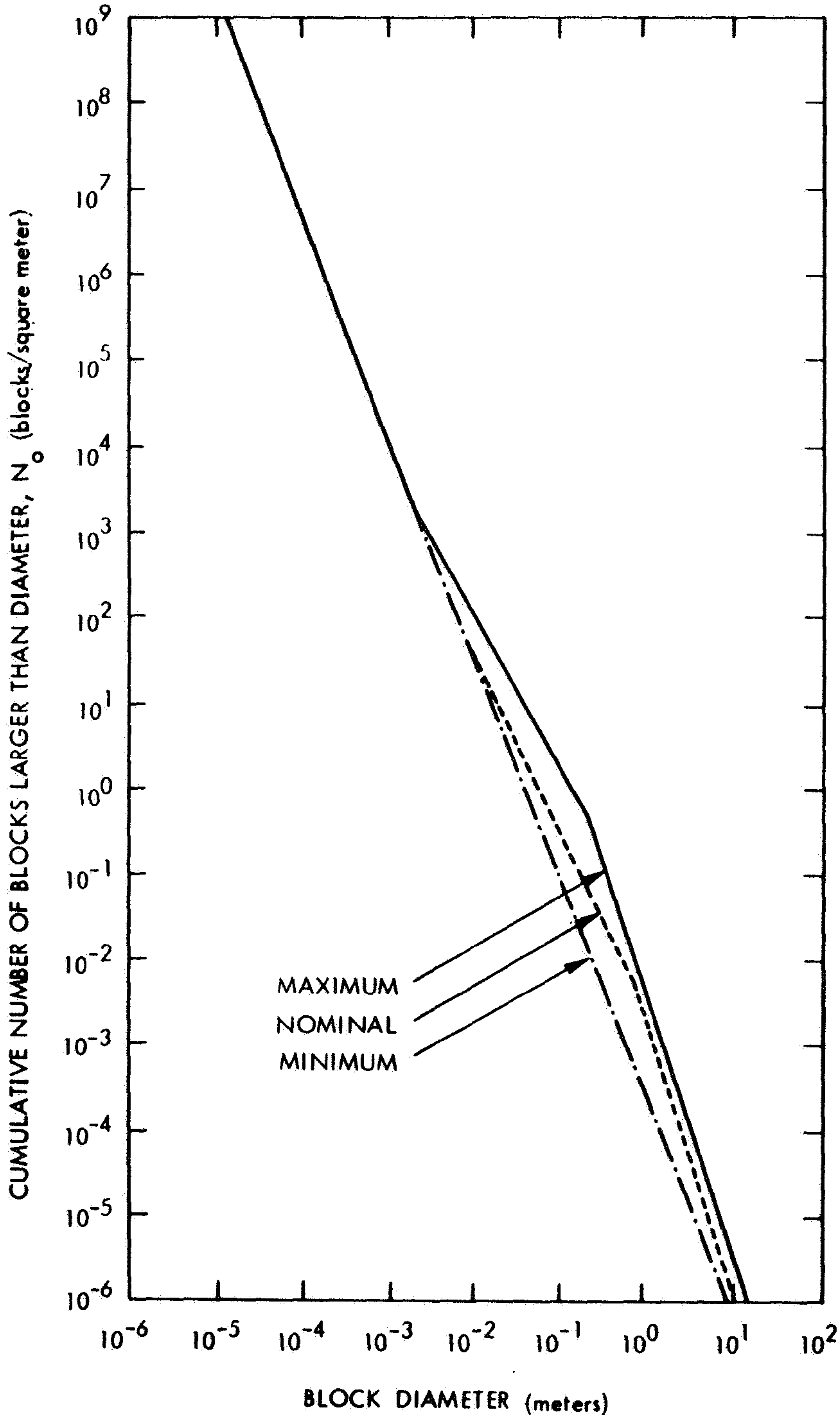


Figure 4.6-6. Cumulative Number of Blocks in Intercrater Region of Smooth Mare, Rough Mare, and Upland Terrains

The increase in distance is a function of obstacle size and distribution. From Reference 8, the following formula for calculating the additional travel distance necessary to circumvent circular obstacles having a known areal density has been derived:

$$L = .331\ ND^2$$

where L = Average additional distance per unit length of traverse required to detour around craters

D = Diameter of crater rim-crests

N = Number of craters of diameter D per unit area

Included in the constant term is a correction for crater rim deposits which increases the actual crater rim diameter, D, to an effective diameter of about 1.4D.

Four lunar terrain types, smooth and rough maria, hummocky and rough upland, have been investigated in Reference 9 and the following typical crater cumulative frequency distribution, N, has been empirically determined as functions of crater rim-crest diameter:

Smooth Maria:

$$N = 10^{-1}\ D^{-2} \qquad (D < 40 \text{ meters})$$
$$= 10^{.602} D^{-3} \qquad (40 < D < 100 \text{ meters})$$
$$= 10^{-2.038} D^{-1.68} \qquad (100 < D < 200 \text{ meters})$$
$$= 10\ D^{-3} \qquad (200 \text{ meters} < D)$$

Rough Maria:

$$N = 10^{-1}\ D^{-2} \qquad (D < 100 \text{ meters})$$
$$= 10\ D^{-3} \qquad (100 \text{ meters} < D)$$

Hummocky and Rough Uplands:

$$N = 10^{-1}\ D^{-2} \qquad (D < 1000 \text{ meters})$$
$$= 10^{2}\ D^{-3} \qquad (1000 \text{ meters} < D)$$

To determine the length adjustment, the following assumptions and techniques were used:

1. Assume the only travel restrictive craters are greater than 5 feet in diameter
2. From the given cumulative distribution functions, bands of Δ diameter (D) craters were chosen and the actual number distributions determined

3. To account for the nested crater possibilities (by going around one crater, the area inside is eliminated from the overall control area), an iterative procedure determined the adjusted crater area (in effect, the number of craters inside other craters is eliminated)

4. Using the adjusted number density, the average travel distance increase for each delta-D band is determined which summed, equals the total adjust travel increase

The results are given in Table 4.6-1 for various upper bounds on restrictive craters; i.e., the path charted avoids craters greater than this upper bound. Included where possible are backup data from Reference 9, which involves a more sophisticated method but neglects rim deposits in determining the effective diameters.

Table 4.6-1. Crater Circumvention Path Length Adjustment

Crater Diameter* Upper Bound (ft)	Path Length Adjustment**		Adjustment from Reference %
	Maria %	Uplands %	
15	8	8.5	-
35	12	13	-
100	21	21	-
160	23	23	-
245	24	24	-
330	24	25	11 - 17

*The band of crater diameters impeding travel is greater than 5 feet, but less than this upper bound; craters larger than this are avoided in laying out a planned traverse.

**Note: Neglecting crater rim deposits will reduce percent increase by one-half

4.7 MAN-MACHINE TASK ALLOCATIONS

The LSB experiment program of exploration and exploitation is predicated upon the utilization of man's sensing, decision, and control capabilities to maximize the scientific return from the program. This approach reduces the cost of experimental equipment since automation is not required and increases the potential utility of the sensors to include targets of opportunity which may differ significantly from pre-mission planning.

Considerable emphasis has been placed on the identification of crew, habitability, and manpower requirements in this study because of the duration of crew assignments expected, the distance from earth and thus the relatively long rescue intervals, the hostile environment and the resulting confined living conditions, and the high cost of transporting and maintaining each crew member at the LSB.

Essentially, the science tasks allocated to the crew are the same as those which would be assigned on a similar earth-based facility except that the more hazardous tasks and the more routine tasks are presumed to be automated to optimize crew utilization, although detailed designs are not presented.

The observatory's major science equipment -- the telescopes and the deep drill -- have been assumed to be automated as completely as possible insofar as control, maintenance, fault isolation, and data processing tasks are concerned.

The nominal crew represents a range of scientific and technical disciplines which are utilized as an autonomous unit in much the same manner as naval vessels or remote expeditions such as the South Pole IGY Base which are resupplied periodically via logistics support. To achieve this autonomous independence, the LSB crew must include the skills and capabilities to conduct all normal base operations and maintenance functions, and be able to cope with all the expected emergencies that may occur. In addition, the crew is expected to conduct a comprehensive scientific program whose objective is to investigate and explore the total lunar environment.

The intent of this portion of the study is to develop crew criteria and LSB design requirements which avoid constraining the achievement of flexible mission objectives, yet remain compatible with crew health, safety, and provide a maximum utilization of the available skills. The crew capabilities outlined in this section are based insofar as possible on the following criteria for crew operations.

1. The crew will be freed of routine operations to the greatest practical extent by the use of automated base support systems

2. System and mission status will not necessarily be transmitted to earth on a real time basis

3. Crew responsibilities will include:

    a. Checkout and status monitoring of base subsystems and experiments

    b. Fault isolation, maintenance, calibration, and repair of base subsystems and experiments and other base equipment

    c. Spares and expendables, inventory and control, and configuration management

    d. Monitoring and control of experiment activities, evaluation and editing of raw data to delete nonsignificant information, data processing and data reduction as required, and assignment of transmission priorities and modes

e. Safety, damage control, corrective action, and emergency procedures

f. Command and control of the Lunar Base including daily scheduling of operations, experiment and application activities, including remote sortie operations, and the assigning of crew duties

Crew requirements supporting the LSB have been developed in four phases during this study. The first phase consisted of developing crew metabolic criteria and its impact on lunar surface operations. This was done to assist in subsequent analysis of the scientific program work loading. The second phase covered the definition of crew skills and manpower requirements as related to the base scientific program. The third phase consisted of developing the habitability criteria needed for base synthesis and layout development. The fourth and final phase effort was expended in developing base station-keeping requirements and in defining a composite crew size and the required crew skills for base buildup and for the on-going science program. The following section discusses the composite crew requirements. The metabolic and habitability criteria are presented in other sections of the report.

4.8 CREW REQUIREMENTS

There are several factors concerned with crew operations that must be given considerable attention in order to provide an acceptable level of crew performance with a minimum amount of stress. These crew-related factors include providing the crew with an acceptable environment in which to live, and that the level and complexity of the tasks required to operate the LSB and carry on the lunar exploration program is well within the capabilities for which the crewmen will be selected and trained. The habitability criteria for developing a suitable and acceptable environment for the LSB are given in a later section.

The overall crew functions that require support to achieve lunar surface program objectives are given in Table 4.8-1. These functions have been divided into five major categories to assist in outlining the scope of LSB operational requirements. Other factors directly affecting crew performance and efficiency are concerned with crew skills, skills mix, crew size, work shifts, duty cycles, personal time, staytime, tour of duty, and finally, the organizational concept for base operations.

4.8.1 Crew Skills

Based on a gross analysis of LSB crew skills/specialties required for base and remote sortie operations and on the lunar surface science program, the skills/specialties shown in Table 4.8-2 appear to cover the basic requirements for LSB operations. These skills/specialties have been identified in terms of functional requirements, scientific, and support personnel for identifying in turn, skills needed within a particular job assignment.

Table 4.8-1. Crew Functions

Administration - Management	Experiment Operations	Maintenance	Flight Operations	Housekeeping
Base Command Stationkeeping (Base) Communications (internal and external) Utility systems management Safety mgmt. Crew services Scheduling Experiment (base & sortie) Logistics Maintenance Crew Data management Base and expmt. Crew care Emergency proced. Base Remote sortie Remote sortie operations	Base Laboratories Observatory (astro) Deep drilling Other scheduled experiments Data management Sample and specimen handling Remote Sortie Scheduled experiments Contingency experiments Data management Sample and specimen handling	Routine (daily requirements) - possible data management system Scheduled (periodic) Base Subsystems Power ECLSS Information management system Structures - airlocks, hatches, galleys, lighting Crew Base Support Facilities Maintenance shops Electronics Mechanical Crew equipment - suit storage, drying and repair Garage Prime movers Experiment Facilities Geology laboratories Astronomical laboratories Deep drill site Landing Site Mobile cryogenic reliquifaction trailer Remote Sortie Equipment Prime movers Flyers Portable shelters Trailers Power carts Experiment Equipment Observatory Deep drilling Other Unscheduled Maintenance Same systems and equipment as for scheduled maintenance	Base Tug Rescue opns - sortie RNS Resupply Support Cargo module transfer Propellant transfer Crew Transfer (rotation) Lunar Surface Support Operations Cargo unloading Cargo transport to base	Base Food management and preparation Galley cleanup Dining and recreation area cleanup Personal hygiene area cleanup General base cleaning Trash disposal Cargo handling and storage Remote Sortie Same as above but on a reduced scale

Table 4.8-2. Crew Skill/Specialty Requirements

Function: Science

Skill/Specialty	Bioscience					Astronomy													
	4001	4003	4006	4009	4011	4012	4014	4015	4016	4017	4021	4022	4023	4024	4025	4026	4027	4028	4029
Commander/Planetologist																			
Electronics Engineer						x	x	x			x	x	x	x	x	x	x	x	
Aeronautical/Mech. Engineer						x			x										x
Electronics Technician						x	x	x			x	x	x	x	x	x	x	x	
Electromechanical Technician						x			x										x
Pilot Eng. - Tug Flyer																			
Medical			x	x	x														
Cook - Dietitian																			
Photo Lab Support	x	x	x			x			x	x									x
Geo/Chem. Lab Support	x	x																	
Optical Lab Support	x	x	x						x	x									x
Instrument Lab Support	x	x					x	x			x	x	x	x	x	x	x	x	
Astronomer Optical									x	x									x
Astronomer - Radio						x	x	x			x	x	x	x	x	x	x	x	
Geologist	x																		
Geochemist	x																		
Geophysicist	x																		
Microbiologist	x																		
Plant Biologist																			
Zoologist																			
Housekeeping Services																			
Heavy Equip. Operations																			
Logistics Scheduling																			
Civil Engineer																			
Suit Technician																			

Skill/Specialty	Geology-Geochemistry										Geophysics						Part. & Fields Lunar Atmos.			
	4032	4033	4037	4038	4039	4048	4057	4059	4060	4061	4044	4045	4046	4049	4058	4088	4050	4051	4053	4055
Commander/Planetologist																				
Electronics Engineer	x	x						x		x	x	x	x	x	x	x				
Aeronautical/Mech. Engineer		x			x	x	x		x				x					x		x
Electronics Technician	x	x						x		x	x	x	x	x	x	x				
Electromechanical Technician		x			x	x	x		x				x					x		x
Pilot Eng. - Tug Flyer																				
Medical																				
Cook - Dietitian																				
Photo Lab Support	x																		x	
Geo/Chem. Lab Support		x	x			x			x	x										
Optical Lab Support	x			x	x				x	x										
Instrument Lab Support	x			x	x		x	x	x	x	x	x	x	x	x	x	x	x		x
Astronomer Optical																				
Astronomer - Radio																				
Geologist	x	x	x		x	x		x	x	x	x					x			x	
Geochemist		x	x	x	x	x	x			x										
Geophysicist						x	x	x	x	x	x	x	x	x	x		x	x	x	x
Microbiologist																				
Plant Biologist																				
Zoologist																				
Housekeeping Services																				
Heavy Equip. Operations		x																		
Logistics Scheduling																				
Civil Engineer																				
Suit Technician																				

Skill/Specialty	Engineering Technology												
	4064	4066	4071	4074	4075	4078	4079	4081	4082	4084	4085	4086	4087
Commander/Planetologist													
Electronics Engineer							x						
Aeronautical/Mech. Engineer			x	x	x	x		x	x	x	x		
Electronics Technician							x						
Electromechanical Technician			x	x	x	x		x	x	x	x		
Pilot Eng. - Tug Flyer													
Medical													
Cook - Dietitian													
Photo Lab Support	x	x											
Geo/Chem. Lab Support													
Optical Lab Support													
Instrument Lab Support													
Astronomer Optical													
Astronomer - Radio													
Geologist				x	x								
Geochemist					x								
Geophysicist						x							
Microbiologist													
Plant Biologist		x											
Zoologist	x												
Housekeeping Services													
Heavy Equip. Operations				x									
Logistics Scheduling													
Civil Engineer				x								x	x
Suit Technician													

Function: Stationkeeping

Skill/Specialty	Base Operations	Base Expmt. Opns.	Base Maint. Opns.	Base Housekeeping	Base Facility Opns.	Base Buildup	Rover Operations	Rover Maint. Opns.	Rover Expmt. Opns.	Rover Housekeeping	Flyer Operations	Flyer Maintenance	Tug Operations	Tug Maintenance
Commander/Planetologist	x	x			x	x								
Electronics Engineer		x	x		x			x	x			x		x
Aeronautical/Mech. Engineer		x	x		x	x		x	x					
Electronics Technician		x	x		x			x	x			x		x
Electromechanical Technician		x	x		x	x		x	x			x		x
Pilot Eng. - Tug Flyer	x	x			x						x		x	
Medical	x	x		x			x			x				
Cook - Dietitian	x			x						x				
Photo Lab Support		x							x					
Geo/Chem. Lab Support		x							x					
Optical Lab Support		x							x					
Instrument Lab Support		x	x					x	x			x		x
Astronomer Optical		x												
Astronomer - Radio		x												
Geologist		x							x					
Geochemist		x							x					
Geophysicist		x							x					
Microbiologist		x							x					
Plant Biologist		x												
Zoologist		x												
Housekeeping Services		x		x						x				
Heavy Equip. Operations						x	x							
Logistics Scheduling	x	x		x			x		x	x				
Civil Engineer	x					x								
Suit Technician	x	x	x		x	x	x	x	x		x	x	x	x

It is the purpose of this chart (Table 4.8-2) to show the areas of greatest skill/specialty need. The skills/specialties are listed down the left hand side of the chart with science and stationkeeping functions listed across the top. The experiments are broken out by discipline and experiment number. Stationkeeping is depicted by gross functions such as base operation, base experiment operations, etc. By reading across the chart from a given skill/specialty, each check mark flags a need for that particular experiment and/or stationkeeping function. Final crew selection will determine the level of training for a given discipline and the amount of cross-training each will need to fully support base requirements.

To provide more insight into the crew skill requirements, each of the skills/specialties have been briefly described to illustrate the basic need. For those where the need is relatively small, some indication as to how they may be combined has been provided.

Skill/Specialty Definitions

Base Commander. Management and command capability are required along with a background in science or engineering. The optimum situation would be a science-oriented man in either geological or planetological research. This skill/specialty carries full responsibilities for both base and science operations.

Electronics Engineer. Background and training in electronics/electrical engineering with extensive field experience, plus the responsibility for base and experiment electrical/electronics equipment operation and maintenance. This skill also provides technical direction and consultation with support personnel performing operation and maintenance tasks.

Aeronautical - Mechanical Engineer. Requires background and training in aeronautical engineering with extensive design and field experience in aeronautical and space equipments. This skill/specialty carries the responsibility for operation and maintenance of base subsystems, remote sortie equipment, including support for experiment mechanical equipment. He also provides direction and consultation for support personnel performing assembly and maintenance tasks.

Electronics Technician. Requires background and training in engineering design of electrical/electronics subsystems and equipment with extensive field experience in testing, calibration, maintenance and operation of such systems and equipment. This skill would be considered as interchangeable with the electronics engineer.

Electro/Mechanical Technician. Requires a background very similar to that of the aeronautical engineer with extensive field experience in testing, calibration, maintenance and operation of electrical, mechanical, pneumatic and hydraulic subsystems and equipments. This skill could be considered as interchangeable with the aeronautical engineer.

Pilot Engineer. Requires flight skills for tug and flyer operations but not necessarily that of a military or engineering test pilot. Equipment sophistication of the 1980 time period should preclude the need for very highly trained pilots. He should have a background in aeronautical or electronics engineering or possibly in one of the associated science disciplines.

Medical. A preliminary analysis of mission operations including stationkeeping, deep drilling and astronomy experiments, and the requirements for remote sortie operations indicate a very limited requirement for a full-time medical doctor (MD). The aerospace medicine and bioscience experiments presently proposed do not impose a primary requirement for an MD.

A recent innovation in the medical world that utilizes the experience and training of Armed Services medical corpsmen after completion of their service tour, is helping to fill a need in civilian medical coverage. This approach provides an excellent means of extending medical care and services to areas with too few doctors, or to remote areas where there are none. These medical corpsmen or Medex, as they are now called, are given additional training to update their service training and to specialize in the medical services needed in the demographic area where they will serve. The Medex is always under the supervision of an MD although he may not necessarily be under direct surveillance because of his remote location (Reference 10).

Therefore, in place of the MD, it is proposed that this concept be utilized for the LSB. Utilization of this level of medical capability appears to satisfy the rather minimal requirements for crew care and to provide for the expected minor illnesses and injuries that may occur during lunar surface operations. Additional utilization of the Medex for laboratory support, sanitation and contamination control, food management, plus other housekeeping functions, would appear to provide effective integration of available crew skills for those functions.

Crew selection which includes a thorough assessment of both physiological and psychological characteristics of every crewman chosen for lunar operations makes these personnel a very select group that is much above the norm in physical condition. Thus, utilizing a Medex rather than a full-time MD appears to be acceptable when the following factors are given consideration:

1. Availability of the crewman's complete medical history and background acquired during the selection process and subsequent training

2. The required physical conditioning for each crewman prior to flight

3. The relatively short tours of duty presently projected for LSB operations (each tour, one year maximum, and not more than 2 tours total; final definition depending on Skylab experience)

4. The requirement for autonomous operation with highly automated base subsystems and experiment systems which, in turn, reduces crew exposure to hazardous situations

The Medex who will be utilized for LSB operations will need to be familiar with current space operations, the medical equipment of his duty station, and the medical and emergency procedures associated with lunar surface operations. Their performance capabilities must include:

1. The use of X-ray equipment to determine the extent of injury

2. The care and surgical procedures necessary for dressing open wounds

3. The care and treatment of sprains and dislocations

4. Care and treatment of simple fractures and the stabilization and care of patients with compound fractures prior to more comprehensive treatment

5. Limited dental and periodontal care

6. The administration of medication for pain, minor ailments, and infections that may occur

7. The preparation of an injured or sick patient for transport back to earth

8. The diagnostic capability to provide his earth-based medical consultants with the best possible description of the case (TV may be a great aid for consultation purposes)

Utilization of the Medex to support the day-to-day medical needs of the crew appears to fulfill the basic requirements for lunar surface operations.

Cook - Dietitian. Regardless of the duty assignment concept, training and experience on this skill/specialty is required. The medical technician could be assigned this responsibility because of the very close relationship between the care and feeding of man.

Photo Lab Support. Requires training and experience in photography and photographic processing as related to astronomical observatory operations, and to support other experiment photographic processing requirements. This skill could be combined with any of the following skills: medical technician, optical laboratory, and geological laboratory technicians.

Geology/Chemical Laboratory Support. Requires training and background in chemistry and laboratory techniques and equipment as related to geological research and exploration, including the laboratory techniques necessary for detecting and isolating the life forms that may be associated with lunar surface materials.

<u>Optical Laboratory Support</u>. Requires training and background in the operation, maintenance, and calibration of the optical elements associated with astronomy, and other laboratory research equipment utilizing optical sensors.

<u>Instrument Laboratory Support</u>. Requires training and background in the servicing and repair of the various electrical, electronic, and mechanical sensors and recorders associated with LSB subsystems, base laboratory, and experiment equipment. Depending on experiment equipment complexity, this skill could be assigned to the principal investigators with electronics and electro/mechanical technician support.

<u>Astronomer - Optical</u>. Requires high level training in astronomy with emphasis on observatory procedures and operation, including X-ray, advanced stellar and solar work, plus UV and IR and gamma ray research.

<u>Astronomer - Radio</u>. Requires training and background in radio astronomy with a degree in electronics engineering and extensive experience with radio astronomy installations and equipment. The electronics engineering is of prime importance for lunar surface radio astronomy since the data being gathered is relayed directly back to earth for storage and analysis. The need is for knowledge of the equipment and how to maintain it and how to make modifications to meet experiment requirements plus knowing that the data being collected is of acceptable quality. This skill could very well be assumed by an electronics engineer supported by an electronics technician with cross training in the field of radio astronomy.

<u>Geologist</u>. Requires high level training in geology with extensive field work. Primary emphasis should be placed on the broad aspects of the science as related to lunar exploration with specific attention to the fields of petrology and surficial geology.

<u>Geochemist</u>. Requires high level training in geochemistry with extensive field work. Primary emphasis should be placed on study of the lithosphere as related to lunar surface exploration including the abundance of elements and their evolution.

<u>Geophysicist</u>. Requires high level training in geophysics with extensive field work. Primary emphasis should be placed on the study and application of the techniques of seismology, volcanology, magnetism, and geodesy as related to lunar exploration.

<u>Microbiologist</u>. Requires training and background in microbiology with emphasis on viable life forms and dormant spores as related to lunar surface geological exploration. This skill requires both field and laboratory operations and could be accomplished by the medical technician through proper design of experiment equipment and operational procedures.

<u>Plant Biologist</u>. Requires training and background in plant physiology, genetics, cytology, botany, etc., including laboratory and research experience. The very low requirement for this skill will probably preclude assigning one

for LSB operations. This requirement can be supplied through cross training and appropriate experiment design. Candidate skills are the microbiologist and/or medical technician.

Zoologist. This is a high level specialty requiring background in behavior and neurophysiology, genetics, etc., of vertebrate and invertebrate animals. Because of related skills and background, the tasks could possibly be assigned to the medical technician or microbiologist if the experiments are properly designed and cross training given.

Housekeeping Services. Requires training and background in food management, health, and sanitation requirements. One crewman should have the responsibility in this area with assistance by all crewmen on a rotating basis for galley and cleaning tasks. This rotation of crewmen to accomplish the ever present housekeeping chores would apply to the remote sortie operations as well as base operations. Stateroom cleanliness is the responsibility of the occupant. The medical technician appears to be the logical choice to receive this training because of his closely related background.

Heavy Equipment Operators. Requires training and background in operation and maintenance of construction equipment such as a bulldozer, backhoe, crane hoist, and transportation of heavy equipment (base modules) over minimum prepared unsurfaced lunar roads. The construction equipment needed for lunar base buildup will consist of adaptations and accessories attached to and operated from the lunar surface prime mover. The training for this skill could be combined with the civil engineering skill for utilization during base buildup.

Logistics Scheduling. Requires training on the equipment used for planning and recording logistics resupply needs for LSB operations including the scheduling of remote sortie logistic needs. This will probably be semi-automated with computer and printout facilities to reduce the manpower loading and provide a running summary of base logistic needs. The responsibility for this skill should be delegated to one individual with assistance provided by others doing base administrative work when and if required because of interfering schedules.

Civil Engineer. Requires training and background in civil engineering with emphasis on facility layout and construction beginning with site surveying, site preparation, and assembly of modular base facilities, including base landing sites, power plants, garages and shops, living quarters, communications equipment, and scientific facilities consisting of astronomical observatories, radio telescope networks, and deep core drilling sites.

Suit Technician. Requires training and background in the handling, maintenance and operation of space suits used for EVA operations. The lunar base requires a space suit maintenance facility that is capable of performing at the organizational level with the appropriate skills. Maintenance authorized at this level will encompass modular replacement of major components. This, in general, does not mean replacement of components that are secured by adhesives, stitches, or welds. Examples of replaceable modules are those components which are attached with screws, clamps, zippers, and similar devices. Only standard hand tools and shop equipment are necessary to accomplish the maintenance at this level. This skill could be combined with the electromechanical technician.

4.8.2 Crew Work Shifts

For purposes of this study, the LSB crew size to be evaluated will range from 6 to 12 crewmen with the nominal crew assumed to be 12, to provide 120 man-hours daily for scheduling to obtain operational work loading. This manpower level would provide for a 4-man remote sortie crew and 8 crewmen full-time at the LSB for science and stationkeeping. The crew work day is ten hours, six days per week, with a potential four to five hours work for required functions on the seventh day. The ten-hour day is not excessive considering that no time is spent going to and from work, and that most professional employees frequently work longer than eight hours. In addition, both the longer day and longer week in challenging job activities will tend to reduce the mental fatigue which results from insufficient activity.

The present concept of utilizing concurrent work and sleep periods for the total crew represents the most efficient application of crew time, and improves the availability of appropriate skills for multiman tasks. However, it can be expected that the normal scheduled work shift will have to be modified on occasions to take care of emergencies and specific time requirements for certain experiments where exposure or run times must be continuous until completion.

Manpower Criteria for Work Scheduling

EVA Workshifts. It was assumed that all EVA operations would be conducted by the buddy system, or a minimum of two crewmen for any EVA operation. The following criteria have been used throughout for all manpower requirements.

One workshift = 6.5 hours available for work outside the airlock per day*

One man month = 169 man-hours (26 days)

One man year = 2028 man-hours

*NOTE: The remaining 3.5 hours of the normal 10-hour shift is utilized in pre- and post-EVA operations and debriefing.

Shirtsleeve (IVA) Work Shifts.

One workshift = 10 hours available for work per day

One man month = 270 man-hours or 26 days plus minor additional scheduling

One man year = 3250 man-hours

Crew Duty and Personal Time Scheduling

Preliminary studies suggest that, for extended periods, the safest course is to plan for conventional, earth-based schedules unless the particular type of mission or remote sortie strongly demands alternative scheduling. This means that crews should normally maintain (1) a regular, diurnal schedule, (2) more than 7 hours of sleep per day, (3) work should not exceed 10 hours per day, and (4) the work week should not exceed 6 days with some limited scheduling possible on the seventh day. When an atypical cycle is imposed, man's physiological rhythms may be expected to show some adaptation to the non-24-hour periodicity -- but adaptation is not likely to be complete nor to be uniform for all individuals. This underscores the desirability of pre-adaptation to a given schedule if that schedule is to differ significantly from the normal regime of 16 hours of wakefulness and 8 hours of sleep. Additionally, the scheduling of crew activities must not merely avoid gross overload; it must be structured to combat gradual degradations in interest and capacity. Sleep periods should be arranged so they will come at essentially the same time each day so that adjustments to the circadian rhythms will be facilitated.

The duty cycles for all lunar operations (shelter, remote sorties, and orbit, if any) should be on the same time base and scheduled concurrently because of (1) the limited number of crewmen and the relatively small size of the LSB and remote sortie facilities where noise could seriously degrade sleeping, (2) crewmen can be rotated from one operation to another without disturbing their daily scheduling, and (3) this would also foster better utilization of both crewmen and facilities. As an example, inter-operation communications would otherwise have to be rigidly scheduled to avoid disruption and inconvenience for everyone concerned.

Daily crew scheduling should utilize the following crew duty cycle criteria for LSB operations.

	Hours
Sleep	8.0
Eating	2.5
Recreation, medical and exercise	2.5
Personal hygiene	1.0
Workshift	10.0
Total	24.0

Utilization of the above criteria will allow for greater flexibility of scheduling, and permits contingency time encroachment without causing undue crew stress. Rigid scheduling and/or allocation of crew personal time is not intended under any circumstances because of personal preferences and differences in physiological requirements between individuals. As an example, there are some men who only require four to five hours sleep per day where others may require eight or more.

Eating. Meal periods should be shared by the crew to the maximum extent possible because it provides a relaxed atmosphere for social contact between crewmen and also provides for group discussion on subjects of common interest. Time has been allocated for three eating periods in line with normal earthside eating habits, and allows 30 minutes for breakfast, 45 minutes for lunch, and 75 minutes for the evening, or end of the normal workshift, meal.

Recreation and Exercise. Time has been allotted for recreation, medical care and exercise to assist in maintaining the morale and efficiency of the LSB crew. Approximately 2.5 man-hours have been allocated to cover these functions. Whether a definite exercise regimen will be required for physical conditioning of the LSB crewman is dependent on two things: (1) the scheduled workload imposed, and (2) the medical results from experiments conducted on earlier space missions and precursor lunar surface missions. The probability that normal work loading will provide the total necessary physical conditioning is presently considered rather remote. Therefore, provisions have been included for equipment and use of the medical facility as an exercise area.

Medical monitoring of each crewman on a regular scheduled basis (monthly) should provide for timely and adequate indications of any physiological deconditioning. The medical monitoring would consist of a complete physical, limited only by the available base medical capability.

The recreational facilities should be capable of providing a sufficient variety to permit shifts in interest during the normal tour of duty. Base facilities should include book, film, TV and educational provisions. Probably the most important morale factor is the provision for relatively private communications with families at home.

Personal Hygiene. A nominal value of one hour per man per day has been allotted for personal hygiene activities. Although the frequency of bathing in Western civilization is much greater than is directly justifiable for physical health reasons, regular bathing is recommended on long-duration missions to assure social acceptability and for the individual satisfaction it provides. The LSB has the capability to provide a shower per man/day. When the lunar dust problem and EVA operations are considered, the base shower capability will probably be most welcome. Sufficient quantities of expendable hygiene items (soaps, body wipes, bactericides, dentifrice, and deodorants) must be provided.

4.8.3 Crew Staytime and Duty Tours

Because of current staytime uncertainties, past practices, and improvement in efficiency and coordination, it is anticipated that rotating half the crew at one time will assist in improving the overall crew performance level because of the carryover training from the previous crew. However, specific skill requirements may be rotated in accordance with program needs and logistic capabilities. Total elapsed crew staytime from the time a given crew leaves the earth until they return could go as high as 12 months, based on assumed satisfactory staytimes from Skylab and Earth Orbit Space Station of 56 and 180 days, respectively, and the non-zero gravity environment and increased personnel mobility.

Based on experience with Antarctic bases, nuclear submarines, and previous space missions, it seems that design planning might consider two tours of duty per crewman (on the average) for initial missions. This, of course, assumes the crewman desires additional duty tours and that there are a minimum of ill effects experienced by the crewman upon returning to earth after the first tour. The problem of achieving performance effectiveness, however, tends to generate program requirements towards either longer staytimes, partial crew exchange, repeat tours of duty (into more senior positions), extended mission preparation, or some combination of these. Each of these influences should be examined separately. (Reference 11)

5.0 MISSION ANALYSIS

The overall LBS mission can be divided into two separate elements: lunar surface element - remote sorties, drilling operations, and the observatory program; and the earth-moon logistics element.

The logistics mission parameters and vehicle capabilities were selected from current in-house NASA-funded study results developed, for example, in the Earth Orbit Shuttle, Reusable Space Tug, the Chemical Shuttle, and Reusable Nuclear Shuttle analyses.

The lunar surface missions, on the other hand, were extensively analyzed in this study to develop optimized systems for exploration and exploitation.

The purpose of this analysis was to define quantitative mission performance requirements which must be satisfied by the crew and equipment utilized to perform that mission. These requirements "size" the crew and equipment for the job to be accomplished. To facilitate the identification of these requirements a procedure was followed which organized the problem-solution process.

For both classes of missions, generalized concepts were defined as presented in Section 4.0. Each of these concepts was analyzed to determine the important functions and these were sequenced in chronological order on functional flow diagrams. The top level diagram identifies the inter-relationships between the various programs which make up the overall Lunar Exploration Program. One function from this diagram, "Perform Lunar Surface Base Program," is expanded into its major functions on the first level diagram, No. 4.0. Similarly, the key function on Diagram 4.0, "Perform Lunar Surface Base Operations", No. 4.24, is expanded into its most critical functions on the second level diagram No. 4.24. All functions need not be analyzed in a Phase A study as the objective is to define an optimum concept from many alternate concepts. Only functions which strongly affect the concepts and therefore can significantly affect the accuracy of the study results require detailed investigation. For this reason many of the functions can be bypassed but all are shown in order to select the most important ones.

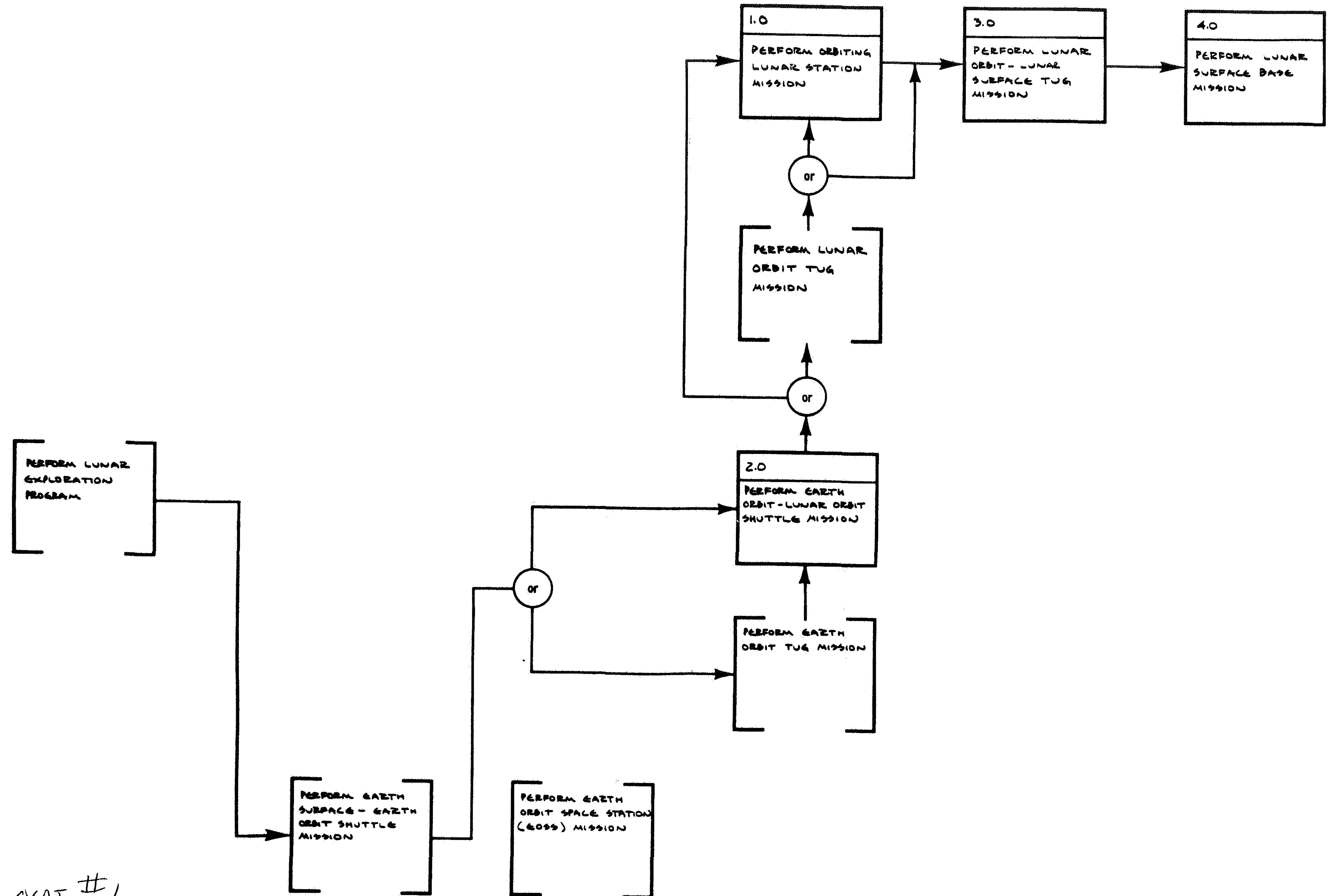
In addition to the mission concept definitions and functional analyses, time lines were prepared for individual functions and for complete flow diagrams as their importance directs. For example, individual functions in the remote sortie diagrams were time-lined in order to build up the total remote sortie duration. The overall LSB program time line is prepared for the top-level function, perform lunar surface base program, Function 4.0. This time line contains a day-by-day scheduling of tasks for over four years. This level of detail is required in order to integrate all program elements into an effective total plan. The program time line is discussed in Part 2, Section 3.0.

Requirement Analysis Sheets (RAS) were prepared based on the functional analysis of the surface missions to assist in the identification of requirements. RAS's were not prepared for the logistic mission because experience had already indicated the requirements drivers (payload characteristics, flight frequency, and number of vehicles required) and these were analyzed directly. All RAS's are included in Appendix C.

The top level functional diagram, Figure 5.0-1, defines the role of the LSB in the lunar exploration program. The lines connecting the individual functions indicate that hardware and/or information can flow in either direction between the functions.

The first level diagram, No. 4.0, Figure 5.0-2, defines all the major functions of the LSB program but particularly the earth-moon logistics mission. This mission is shown in two phases: first, the delivery of the basic shelter (Shelter Mission) which includes the module structure and all internal subsystems; and second, the delivery and return of all additional equipment and the crew (Up Payload and Down Payload). Implicit in the latter phase are all resupply missions which are not shown because the basic functions are identical to the initial mission. These functional requirements are analyzed later to define the logistics mission performance requirements.

The second level diagram, No. 4.24, Figure 5.0-3, expands the function "Perform Lunar Surface Base Operations" from the first level diagram to depict the major functional requirements of the LSB. These can be divided into two classes: the basic shelter functions required to operate and maintain the facility; and the functions the shelter performs to support the scientific sorties. The key functions here are those associated with the scientific sorties. In the next sections, Functions 4.24.1 "Perform Remote Sorties," 4.24.2 "Perform Observatory Operations," and 4.24.4 "Perform Drilling Operations" are analyzed in greater detail. Function 4.24.3 "Perform Shelter Experiments Program" covers a number of simple non-site-dependent experiments which are performed in and about the shelter a great number of times. The manpower, storage, and electrical power requirements are not as complex as the other sorties and were not functionally analyzed.



LEGEND

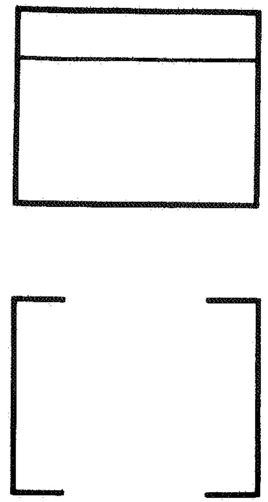
NOTES

Fig

THIS PRINT REDUCED 50%

DSG BY T.J. Dole
DR BY
APPROVED
REVISION A
REVISION B
REVISION C
REVISION D

FOLD-OUT #1



DENOTES ESSENTIAL PROGRAM FUNCTION

DENOTES REFERENCE PROGRAM FUNCTION

LEGEND

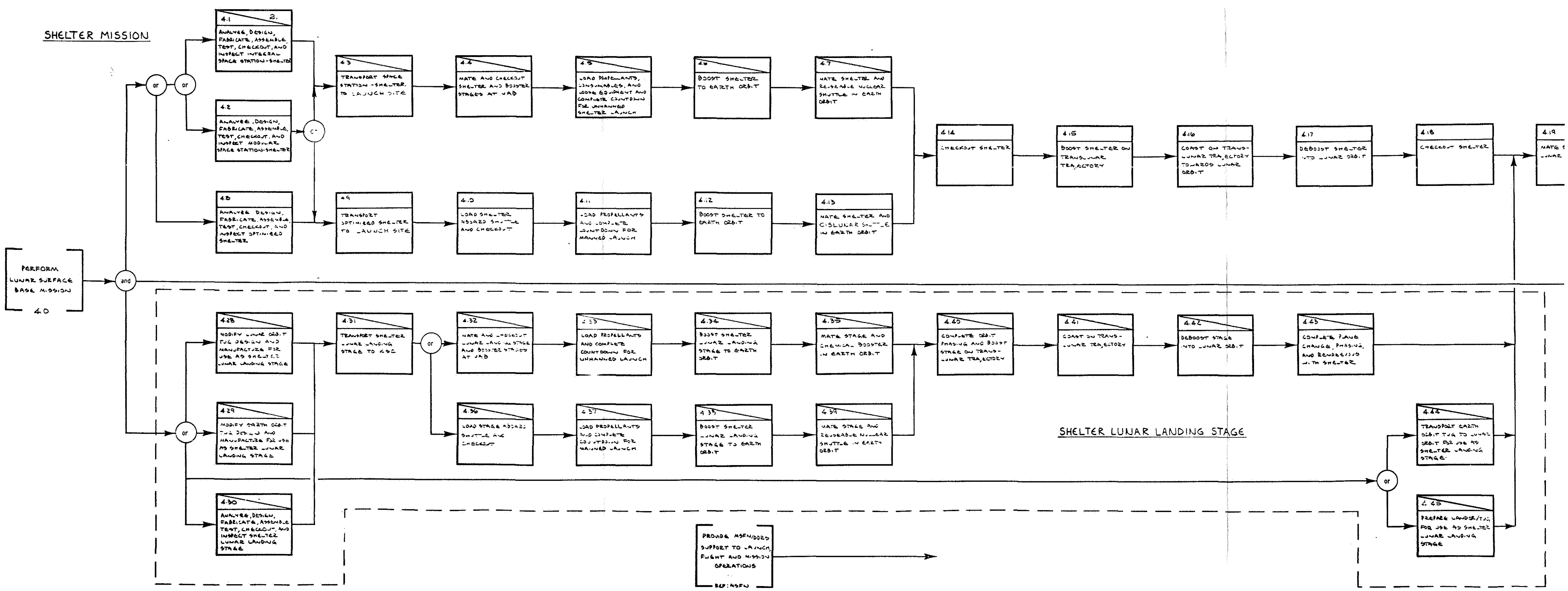
FOLD-OUT #2

NOTES

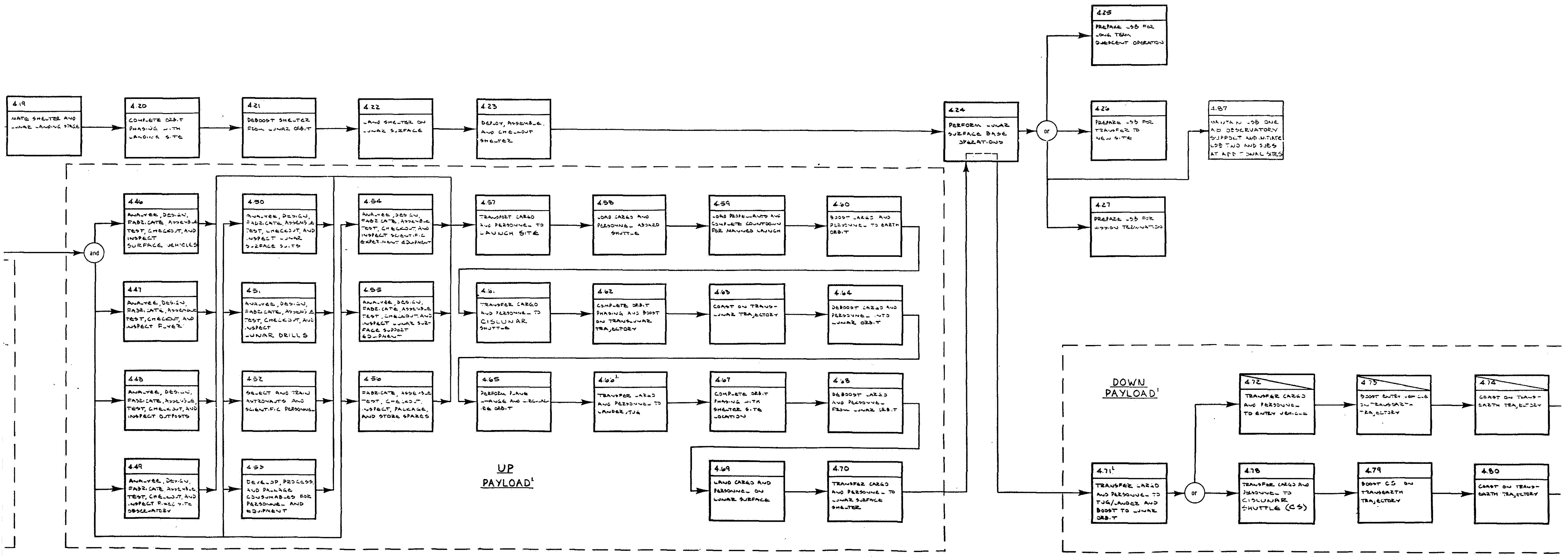
Figure 5.0-1 1-5-3, 1-5-4 SD 71-477

DSG BY T.J. Dole	31 AUG 70	SPACE DIVISION NORTH AMERICAN ROCKWELL CORPORATION 12214 LAKEWOOD BOULEVARD, DOWNEY, CALIFORNIA	[redacted]
DR BY			
APPROVED BY		LUNAR EXPLORATION PROGRAM FUNCTIONAL FLOW DIAGRAM	
REVISION A	TJD 8 OCT 70		
REVISION B	TJD 12 APR 71		
REVISION C		CODE IDENT NO. 03953	TOP LEVEL
REVISION D		SCALE	SIZE / SHEET 1 OF 1

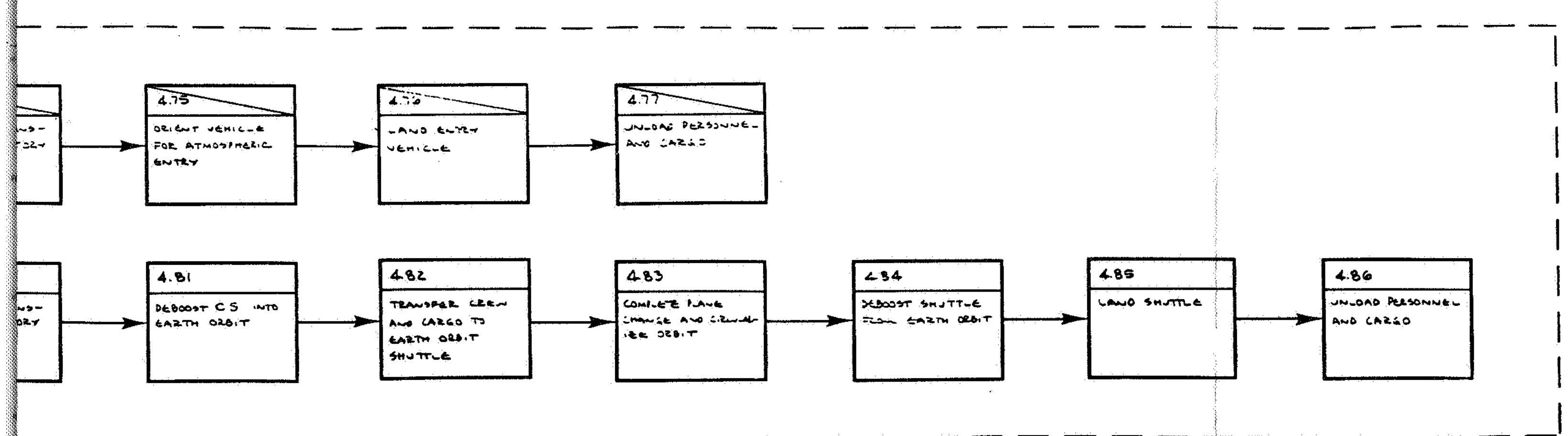
FORM 2930-V NEW 3-63

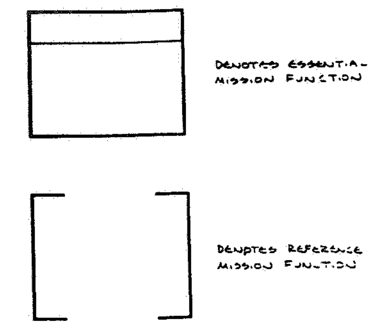

SHELTER MISSION
PERFORM LUNAR SURFACE BASE MISSION
4.0
4.1 ANALYZE, DESIGN, FABRICATE, ASSEMBLE, TEST, CHECKOUT, AND INSPECT INTEGRAL SPACE STATION-SHELTER
4.2 ANALYZE, DESIGN, FABRICATE, ASSEMBLE, TEST, CHECKOUT, AND INSPECT MODULAR SPACE STATION-SHELTER
4.8 ANALYZE, DESIGN, FABRICATE, ASSEMBLE, TEST, CHECKOUT, AND INSPECT OPTIMIZED SHELTER
4.3 TRANSPORT SPACE STATION-SHELTER TO LAUNCH SITE
4.4 MATE AND CHECKOUT SHELTER AND BOOSTER STAGES AT VAB
4.5 LOAD PROPELLANTS, CONSUMABLES, AND LOOSE EQUIPMENT AND COMPLETE COUNTDOWN FOR UNMANNED SHELTER LAUNCH
4.6 BOOST SHELTER TO EARTH ORBIT
4.7 MATE SHELTER AND REUSEABLE NUCLEAR SHUTTLE IN EARTH ORBIT
4.9 TRANSPORT OPTIMIZED SHELTER TO LAUNCH SITE
4.10 LOAD SHELTER ABOARD SHUTTLE AND CHECKOUT
4.11 LOAD PROPELLANTS AND COMPLETE COUNTDOWN FOR MANNED LAUNCH
4.12 BOOST SHELTER TO EARTH ORBIT
4.13 MATE SHELTER AND CISLUNAR SHUTTLE IN EARTH ORBIT
4.14 CHECKOUT SHELTER
4.15 BOOST SHELTER ON TRANSLUNAR TRAJECTORY
4.16 COAST ON TRANSLUNAR TRAJECTORY TOWARDS LUNAR ORBIT
4.17 DEBOOST SHELTER INTO LUNAR ORBIT
4.18 CHECKOUT SHELTER
4.19 MATE
SHELTER LUNAR LANDING STAGE
4.28 MODIFY LUNAR ORBIT TUG DESIGN AND MANUFACTURE FOR USE AS SHELTER LUNAR LANDING STAGE
4.29 MODIFY EARTH ORBIT TUG DESIGN AND MANUFACTURE FOR USE AS SHELTER LUNAR LANDING STAGE
4.30 ANALYZE, DESIGN, FABRICATE, ASSEMBLE, TEST, CHECKOUT, AND INSPECT SHELTER LUNAR LANDING STAGE
4.31 TRANSPORT SHELTER LUNAR LANDING STAGE TO KSC
4.32 MATE AND CHECKOUT LUNAR LANDING STAGE AND BOOSTER STAGES AT VAB
4.33 LOAD PROPELLANTS AND COMPLETE COUNTDOWN FOR UNMANNED LAUNCH
4.34 BOOST SHELTER LUNAR LANDING STAGE TO EARTH ORBIT
4.35 MATE STAGE AND CHEMICAL BOOSTER IN EARTH ORBIT
4.36 LOAD STAGE ABOARD SHUTTLE AND CHECKOUT
4.37 LOAD PROPELLANTS AND COMPLETE COUNTDOWN FOR MANNED LAUNCH
4.38 BOOST SHELTER LUNAR LANDING STAGE TO EARTH ORBIT
4.39 MATE STAGE AND REUSEABLE NUCLEAR SHUTTLE IN EARTH ORBIT
4.40 COMPLETE ORBIT PHASING AND BOOST STAGE ON TRANSLUNAR TRAJECTORY
4.41 COAST ON TRANSLUNAR TRAJECTORY
4.42 DEBOOST STAGE INTO LUNAR ORBIT
4.43 COMPLETE PLANE CHANGE, PHASING, AND RENDEZVOUS WITH SHELTER
4.44 TRANSPORT EARTH ORBIT TUG TO LUNAR ORBIT FOR USE AS SHELTER LANDING STAGE
4.45 PREPARE LANDER/TUG FOR USE AS SHELTER LUNAR LANDING STAGE
PROVIDE MSFN/DDRS SUPPORT TO LAUNCH, FLIGHT AND MISSION OPERATIONS
REF: MSFN
and
or
or
or
or
or
or

FOLD-OUT #1


4.19 MATE SHELTER AND LUNAR LANDING STAGE
4.20 COMPLETE ORBIT PHASING WITH LANDING SITE
4.21 DEBOOST SHELTER FROM LUNAR ORBIT
4.22 LAND SHELTER ON LUNAR SURFACE
4.23 DEPLOY, ASSEMBLE, AND CHECKOUT SHELTER
4.24 PERFORM LUNAR SURFACE BASE OPERATIONS
or
4.25 PREPARE LSB FOR LONG TERM QUIESCENT OPERATION
4.26 PREPARE LSB FOR TRANSFER TO NEW SITE
4.27 PREPARE LSB FOR MISSION TERMINATION
4.87 MAINTAIN LSB ONE AD OBSERVATORY SUPPORT AND INITIATE LSB TWO AND SUBS AT ADDITIONAL SITES
and
4.46 ANALYZE, DESIGN, FABRICATE, ASSEMBLE, TEST, CHECKOUT, AND INSPECT SURFACE VEHICLES
4.47 ANALYZE, DESIGN, FABRICATE, ASSEMBLE, TEST, CHECKOUT, AND INSPECT FLYER
4.48 ANALYZE, DESIGN, FABRICATE, ASSEMBLE, TEST, CHECKOUT, AND INSPECT OUTPOSTS
4.49 ANALYZE, DESIGN, FABRICATE, ASSEMBLE, TEST, CHECKOUT, AND INSPECT FIXED SITE OBSERVATORY
4.50 ANALYZE, DESIGN, FABRICATE, ASSEMBLE, TEST, CHECKOUT, AND INSPECT LUNAR SURFACE SUITS
4.51 ANALYZE, DESIGN, FABRICATE, ASSEMBLE, TEST, CHECKOUT, AND INSPECT LUNAR DRILLS
4.52 SELECT AND TRAIN ASTRONAUTS AND SCIENTIFIC PERSONNEL
4.53 DEVELOP, PROCESS AND PACKAGE CONSUMABLES FOR PERSONNEL AND EQUIPMENT
4.54 ANALYZE, DESIGN, FABRICATE, ASSEMBLE, TEST, CHECKOUT AND INSPECT SCIENTIFIC EXPERIMENT EQUIPMENT
4.55 ANALYZE, DESIGN, FABRICATE, ASSEMBLE, TEST, CHECKOUT AND INSPECT LUNAR SURFACE SUPPORT EQUIPMENT
4.56 FABRICATE, ASSEMBLE, TEST, CHECKOUT, INSPECT, PACKAGE, AND STORE SPARES
4.57 TRANSPORT CARGO AND PERSONNEL TO LAUNCH SITE
4.58 LOAD CARGO AND PERSONNEL ABOARD SHUTTLE
4.59 LOAD PROPELLANTS AND COMPLETE COUNTDOWN FOR MANNED LAUNCH
4.60 BOOST CARGO AND PERSONNEL TO EARTH ORBIT
4.61 TRANSFER CARGO AND PERSONNEL TO CISLUNAR SHUTTLE
4.62 COMPLETE ORBIT PHASING AND BOOST ON TRANSLUNAR TRAJECTORY
4.63 COAST ON TRANSLUNAR TRAJECTORY
4.64 DEBOOST CARGO AND PERSONNEL INTO LUNAR ORBIT
4.65 PERFORM PLANE CHANGE AND CIRCULARIZE ORBIT
4.66 TRANSFER CARGO AND PERSONNEL TO LANDER/TUG
4.67 COMPLETE ORBIT PHASING WITH SHELTER SITE LOCATION
4.68 DEBOOST CARGO AND PERSONNEL FROM LUNAR ORBIT
4.69 LAND CARGO AND PERSONNEL ON LUNAR SURFACE
4.70 TRANSFER CARGO AND PERSONNEL TO LUNAR SURFACE SHELTER
UP PAYLOAD
DOWN PAYLOAD
4.71 TRANSFER CARGO AND PERSONNEL TO TUG/LANDER AND BOOST TO LUNAR ORBIT
or
4.72 TRANSFER CARGO AND PERSONNEL TO ENTRY VEHICLE
4.73 BOOST ENTRY VEHICLE ON TRANSEARTH TRAJECTORY
4.74 COAST ON TRANSEARTH TRAJECTORY
4.78 TRANSFER CARGO AND PERSONNEL TO CISLUNAR SHUTTLE (CS)
4.79 BOOST CS ON TRANSEARTH TRAJECTORY
4.80 COAST ON TRANSEARTH TRAJECTORY

FOLD-OUT #2





LEGEND

2. DIAGONAL LINE IN FUNCTION BOX TOP DENOTES FUNCTION DELETED FROM BASELINE MISSION

1. BASELINE MISSION ASSUMED FOR THIS ANALYSIS REQUIRES UTILIZATION OF TUG/LANDERS IN LUNAR ORBIT

NOTES

1-5-5, 1-5-6

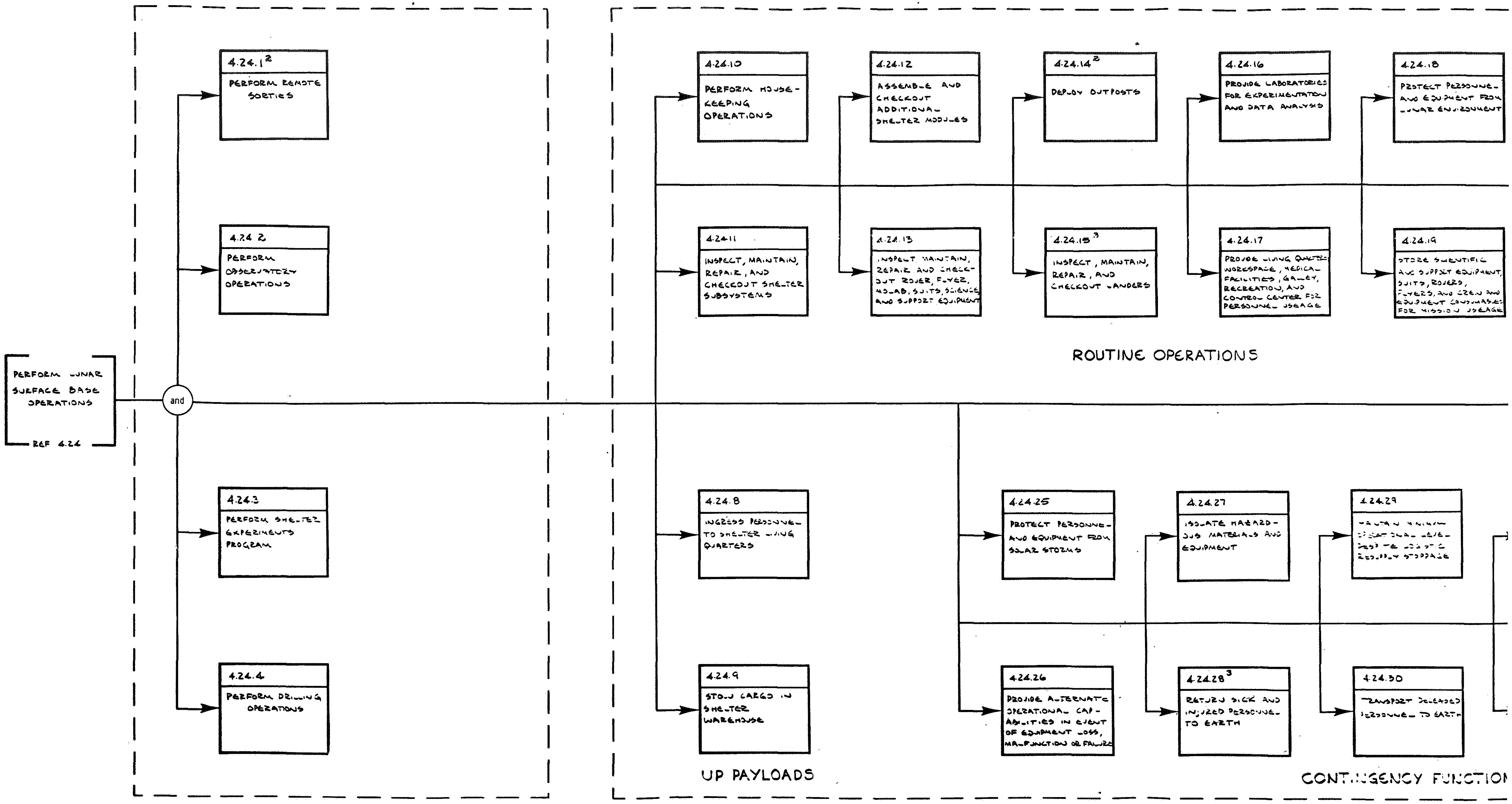
Figure 5.0-2

SD 71-477

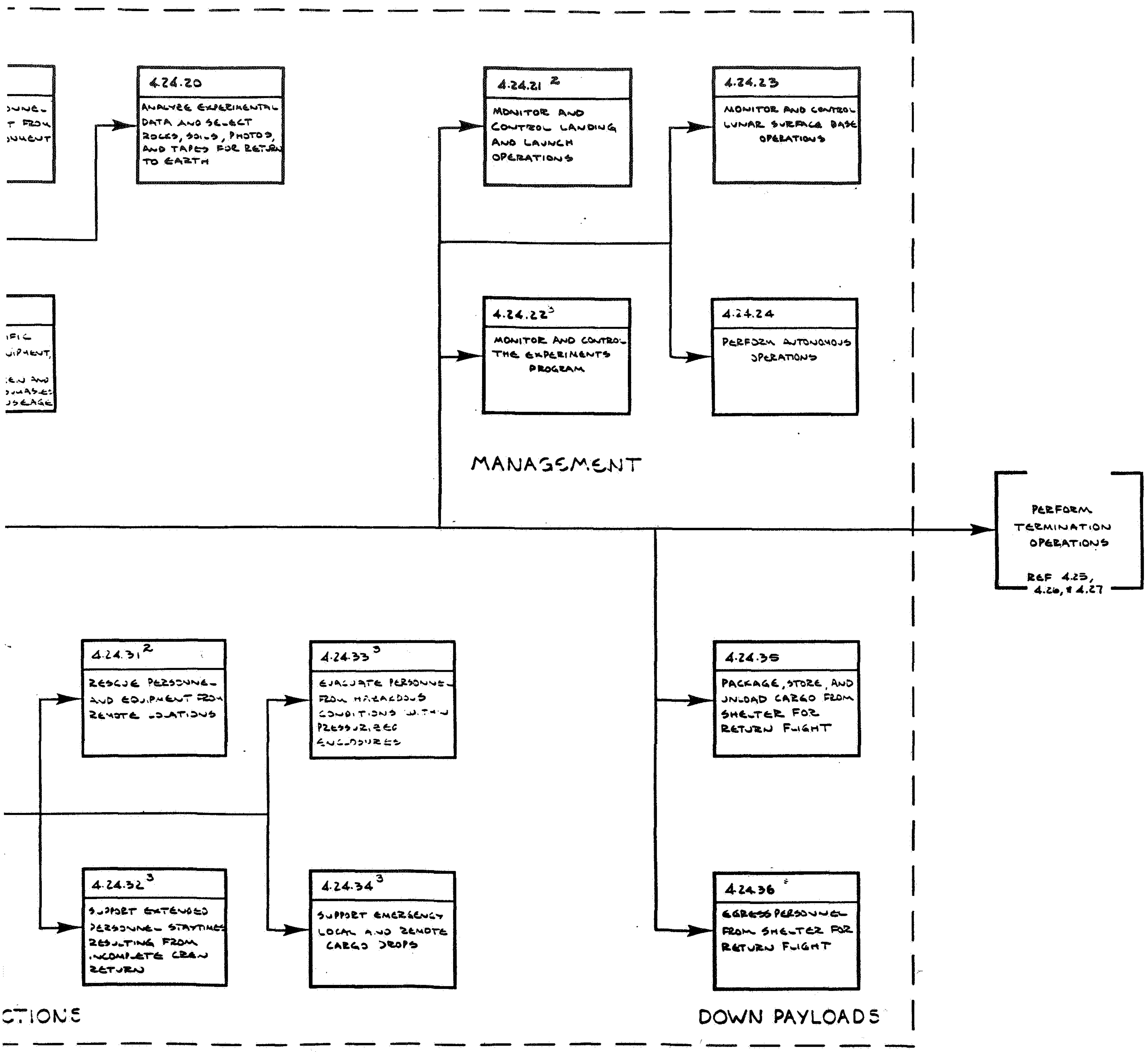
DSG BY T.J. Dolan 31 AUG 70	NORTH AMERICAN ROCKWELL CORPORATION 12214 LAKEWOOD BLVD., DOWNEY, CALIFORNIA	
DR BY		
APPROVED BY	LUNAR SURFACE BASE MISSION FUNCTIONAL FLOW DIAGRAM	
REVISION A TJD 30 OCT 70		
REVISION B TJD 12 APR 71		
REVISION C	CODE IDENT NO. 03953	FIRST LEVEL - 4.0
REVISION D	SCALE	SIZE / SHEET 1 OF 1

THIS PRINT REDUCED 50%

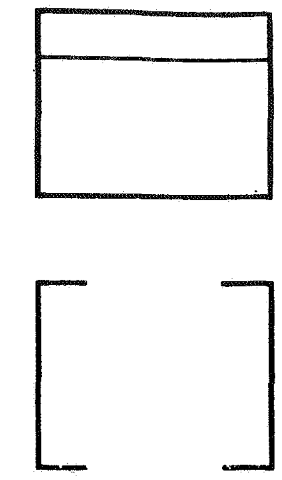
FOLD-OUT #3



FOLD-OUT #1 SCIENTIFIC SORTIES SHELTER FUNCTIONS



FOLD-OUT #2



LEGEND

4. DELETED FUNCTIONS 4.24.5, 4.24.6 & 4.24.7 ... REVISION A
3. DENOTES LSB OPERATIONS WHICH CAN BE SIMPLIFIED BY SUPPORT FROM THE OLS
2. DENOTES SURFACE MISSIONS WHICH CAN BE PERFORMED FROM EITHER THE LSB OR THE OLS
1. UNCODED FUNCTIONS DENOTE MISSIONS AND OPERATIONS TO BE PERFORMED BY LSB ASSUMING THE ORBITING LUNAR STATION (OLS) IS NOT UTILIZED IN THE LUNAR EXPLORATION PROGRAM.

NOTES

Figure 5.0-3 1-5-7, 1-5-8

SD 71-477

THIS PRINT REDUCED 50%

DSG BY T. J. Dolan		NORTH AMERICAN ROCKWELL CORPORATION 12214 LAKEWOOD BLVD., DOWNEY, CALIFORNIA
DR BY		
APPROVED BY		LUNAR SURFACE BASE OPERATIONS FUNCTIONAL FLOW DIAGRAM
REVISION A	TJD 30 OCT 70	
REVISION B	TJD 12 APR 71	
REVISION C		CODE IDENT NO. 03953 — SECOND LEVEL 424
REVISION D		SCALE — SIZE — SHEET 1 OF 1

5.1 REMOTE EXPLORATION MISSION ANALYSIS

In the exploration of space a major scientific goal is the determination of the origin and history of the terrestrial planets. The moon offers a unique opportunity for investigating many problems relating not only to its own origin and history but to those of the earth and other planets of the solar system.

Some of the fundamental questions asked in searching for the origin and history of a planet are related to its composition and the chemical and physical distributions of its mass. These questions cannot be answered entirely by orbital observations or by random local landing investigations. In the case of a non-homogenous planet, a general understanding must be developed of the body and this requires studying the processes that have caused and may yet be causing a redistribution of materials within it. Only if the processes are understood can valid general conclusions be made regarding the significance of specific measurements or findings. The experiment plan proposed in this study is designed to lead to a sound understanding of geologic processes rather than cosmological considerations because it is not possible to proceed from the specific to the general without the geologic knowledge.

The dominant visible features of the moon are the dark maria, the lighter, highland areas, arcuate mountain rings commonly concentric about circular maria, and of course, the craters.

According to our current state of knowledge, the maria are large basins partially filled with basaltic lava, and mantled by a regolith of soil and breccia formed by long-continued meteoric impact. Layers of pyroclastic material such as tuff or volcanic ash may lie interbedded with the basalt flows, but they have not yet been detected in our limited surface investigations. Discovery of such material and more stratigraphy in general requires subsurface drilling and field studies of deep mare craters such as Copernicus or Kepler.

The highlands, which make up about half of the near side surface and virtually all of the far side of the moon, are currently considered crustal segregations of lower density rock differentiated from and resting upon higher density basalt or gabbroic material. This concept is essentially an earth analog, for our "highlands" are continental plates of silicous rock resting on a submass of heavier basic material. Even before an Apollo landing in the highlands, important evidence regarding the composition of the highlands has been found by landings in mare areas. Apollo 11 and 12 both returned sparse fragments of anorthosite, a calcic feldspar rock, less basic and less dense than the mare basalt. The anorthosite is thought to have been scattered over the mare and incorporated in the regolity by high energy bolide impacts in the highlands.

Arcuate and ring structures include gross features such as the Carpathian-Apennine mountain chain to less conspicuous concentric ridges such as those with Marie Imbrium, Humorum and Crisium. Examination of the more numerous and well-developed ring structures on the far side, the most notable of which is Mare Orientale, have shown that they are typical of the moon and indicative of internal structure and processes. Some geo-scientists consider these as normal volcanic calderas; others have postulated the rings are heaped up impact ejecta; but more recent studies support massive impacts in a layered, plastic subcrust, producing giant tidal waves which froze to form the arcuate ranges. Widespread volcanic effusions followed the events, filling in the low areas with smooth-surfaced mare basalt.

After centuries of study, the lunar craters still remain a subject of debate. Most selenologists have interpreted them as impact features. Others, including the majority in the USSR, regard them as volcanic. No large craters have yet been directly studied on the lunar surface, but the mare landings and the acquisition of superior imagery is solidifying a compromise view - that of impact with induced volcanism. Hence the central peaks, lava flows, and volcanos seen in many craters were likely formed by volcanism re-establishing equilibrium following impacts which shattered the crust, imparted immense energy in the form of heat, and excavated material to a depth of, or approaching, fluid material. The object of studying craters in situ is not only to determine their manner of origin, but to obtain a wide range of lunar rocks including deepseated ejecta bearing on lunar differentiation processes, and to study layering and structures exposed in the crater walls. The wall exposures will reveal much more general information relating to succession eruption or impact succession and former existence of water, ice, and plutonic activity.

Many smaller geologic features which require understanding have been enumerated by IITRI and in many other recent reports. Examples include wrinkle ridges, rilles, domes, fault scarps, and others as listed in Table 5.1-1 which is a list adapted from an IITRI study. Many specific examples are sited and proposed as experiment sites in the LSB experiment plans.

Some of the features, e.g., dimple and secondary craters, are now of interest mainly as curiosities because they are unusual and not well understood. Others, such as sinuous rilles and sites of transient activity, are of obvious interest not just as curiosities but as phenomena caused by processes that have an important bearing on the evolution of the moon and which may relate to the finding of water or other exploitable material. For example, study of sinuous rilles should reveal important evidence relating to the former existence or non-existence of water. Difficult as it is to conceive in light of other studies indicating a past and present paucity of water on the moon, the meandering nature of the rilles, particularly those with median sinuous rilles entrenched along the bottom, strongly suggest a fluvial origin. Some students of the subject postulate that they are collapsed lava tubes. Sinuous rilles provide not only the opportunity for genetic study but the deep exposures on the sides may be valuable for observing and interpreting subsurface structures, stratigraphy, geologic history, signs of former permafrost, and mineralization. Some, notably Schroter's Valley, are also loci of observed transient activity and there may be gaseous emanations of value in interpreting differentiation and other internal lunar processes. The steep slopes and possible presence of volatile matter in lunar rilles may also be exploited for shelter and consumption by an LSB.

Table 5.1-1. Specific Lunar Geologic Features and their Principal Interest

	Origin or Dynamic Process	Geologic History	Tectonics	Water	Shelter	Minerals
Ash flow deposit	X	X				
Other pyroclastic deposits	X	X				
Base surge deposit	X	X				
Coarse, hummocky facies	X					
Chevron facies	X					
Distal facies	X					
Lava flows	X	X		X	X	
Craters						
With central peak or plane	X	X		X		X
With smooth floors, young	X	X				X
With smooth floors, old	X	X				X
Rayed and haloed	X	X				
Small, primary	X				X	
Secondary	X				X	
Dimple	X					
Ghost	X	X				
Wrinkle ridge	X					X
Dome	X	X	X	X		
Transient phen. sites	X		X	X	X	X
Outgassing areas	X		X	X	X	X
Radioactive anomaly	X					
Mass concentration	X	X	X			
Seismic zone	X	X	X			
Concentric ring	X	X	X			
Arcuate structure	X	X	X			
Fault scarp		X	X	X	X	X
Crater chains	X			X	X	
Linear rille	X	X	X	X	X	X
Sinuous rille	X	X	X	X	X	X
Median rille	X	X		X		
Diatreme		X	X			X
Steptoe	X	X				
Patterned ground	X		X	X	X	
Major lineation	X	X	X			
Mare-highland contact		X				
Stratigraphic exposure	X	X	X	X	X	X
Permanently shaded areas	X	X			X	X

The Surveyor V and VI spacecrafts' alpha scattering data, which indicated basalt at the landing sites on the lunar mare was confirmed by study of returned Apollo specimens. The lunar basalts are unlike terrestrial rocks in many respects, particularly in their high concentrations of refractory elements, low contents of volatile elements, and the unusually high titanium and iron content, concentrated largely in ilmenite. They are similar enough to terrestrial basalts, of course, to be classified as basalt, dolarite, gabbro, peridotite, and troctolite, and the non-fragmental rocks are recognizable as volcanic or at least igneous in origin. These rocks exhibit a wide range of textures essentially identical to their terrestrial counterparts, and their mineralogic composition, largely glass, plagioclase, pigeonite and subcalcic augic, olivine, crystobalite, ilmenite and sanidine, are familiar also in terrestrial volcanic rocks. Some less abundant minerals, troilite, native iron, and the iron analog of pyroxmangite are not normal in terrestrial rocks.

The breccias and finer fragmental rocks are more distinctive physically, mainly because of the abundance of glass, which occurs as fragments, blobs, minute sphericles and dumb-bell-shaped particles. The bulk of the regolith material consists of mineral fragments of the same species mentioned above, and foreign rock fragments. These rocks resemble volcanic breccia in some respects but evidence such as the glass spherules and blobs and the abundance of glass-lined pits on lunar surface material indicates that the regolith was formed by long-continued bombardment by high-energy meteoroids. The influence of solar wind bombardment is also shown by high contents of noble gases and unusual $^{4}He/^{3}He$ and $^{20}Ne/^{22}Ne$ ratios.

One of the most striking findings of the recent studies is the apparent lack of water in the returned samples, and the presence of native iron, which suggests that even at the time of eruption, relatively early in the moon's history, the lavas were essentially devoid of water. Terrestrial volcanic rocks commonly contain approximately two percent water of magmatic origin, and glassy rocks from three to five percent. In terrestrial pitchstones and perlitic glasses, water, mainly of meteoric origin, commonly makes up ten percent by weight.

The Apollo 11 and 12 landings were on mare materials considered to be among the youngest rocks of the moon. Consequently, there was surprise when the Tranquility Base rocks were determined radiometrically to be 3.7×10^9 years old. The Apollo 12 rocks from Mare Procellarum were dated by potassium-argon at 2.6×10^9 years, but this figure was corrected to 3.4×10^9 by more reliable rubidium-strontium and lead-uranium-thorium methods. Hence, one of the last of the major surface-changing events on the moon, the formation of the mare basins and effusion of immense volumes of volcanic materials occurred relatively early in lunar history. At this time the earth's surface was in an early form of development. Only one or two large proto continents existed, and little is known regarding the state of the oceans and atmosphere. The ultimate age of the moon and the solar system in general is assumed to be 4.6×10^9 years, based upon radiometric dating of meteorites. The period of lunar history between 3.6 and 4.6 billion years will hopefully be explained by age dating and geologic studies of the highlands and/or far side regions.

Explanation of the history of the shaping of the surface, from the present time back to, presumably, four billion years, requires examination and interpretation of lunar stratigraphy and morphology. Considerable progress has been made in establishing a sequence of events by the lunar geologic mapping program of the U.S. Geological Survey. Using earth-based telescopic studies and conventional photogeologic principles and methods, geologic systems, e.g., Copernican, Eratosthian, Imbrian, and Pre-Imbrian, have been established. Each system represents a major event or series of related events, such as the formation of rayed craters, or formation of large circular maria and peripheral deposits. Rock formations have also been established and mapped on the face of the moon. This work is highly qualitative, however, and basically sets the stage for detailed, in situ investigations of lunar morphologic features and stratigraphic sections, supplemented by earth-based laboratory studies including more radiometric age determinations.

Knowledge of the lunar interior is only rudimentary. Astronomic data reveal that the moon's moment of inertia is close to that of a homogenous sphere. This implies the absence of a heavy metallic core analogous to that of the earth. Further evidence for the absence of a core is the very weak static magnetic field of the moon measured by orbiting spacecraft and the Apollo 12 magnetometer.

Other evidence of the absence of a heavy core is the calculated bulk density of the moon ($\sim$ 208.5 lb/cu ft) which puts a significant constraint on speculations regarding the internal structure. The average density of the Apollo 11 rocks is about 206 lb/cu ft and the Apollo 12 rocks are only slightly less. Thus, the density of the surface mare rocks is not appreciably less than that of the moon as a whole, leaving little likelihood of a general increase with depth, as in the earth.

Seismically, the moon is inactive compared to the earth, but an apparent lack of tectonic type "moonquakes" during the brief period of seismic observation has not resulted in a lack of interest in lunar seismology. Seismic signals received from the Apollo 11 and 12 seismometers are very puzzling. They are exceptionally prolonged, of the order of 30 to 60 minutes, with gradual buildup and decrease in signal amplitude. This implies transmission with very low attenuation and intense wave scattering, conditions which are mutually exclusive on the earth. So far, the early stage seismic experiments have not yielded any information on the structure of the deep interior, for the recorded events appear to have occurred at relatively short ranges. If strong events have occurred on the lunar far side, they have not been recorded and would indicate that the lunar interior is highly attenuating for seismic waves. The nearby events that have been recorded and studies show that the near-surface zone of self-compaction is about 12.4 miles thick and it exhibits very low attenuation. Seismic wave velocities corresponding to the first arrival were measured between 9,850 and 12,400 feet/second on the Apollo 12 instrument.

These results indicate a need for further experimentation over a wide extent of the lunar surface. A program of generalized exploration over the entire surface coupled with specific and detailed exploration at one or more discrete sites would considerably advance our knowledge of the moon, the earth, and the solar system.

5.1.1 Experiment Site Selection

Since the objective of this study was to provide a preliminary design for an LSB to be operational in the 1980's and capable of being located anywhere on the moon, only generalized performance requirements were required. To accomplish this, seven potential LSB sites were analyzed to define requirements such as distance to be traveled by a flyer or a surface vehicle, mission duration, terrain to be encountered, payload characteristics, and so on. From all these data, parameter distributions were developed to define a mathematical model of a "typical" LSB site. General mission performance requirements encompassing 95 percent of the data were taken from the model. Equipment sized to meet these requirements are expected to be capable of accomplishing the requirements of the surface missions at any site. A wide variety of LSB locations were deliberately selected to provide a broad range of inputs to the model. The location and extent of these sites are shown in Figure 5.1-1 along with the approximate exploration routes around the shelter site.

The approach for selection of the potential LSB sites was based on the availability at specific lunar locations of the geologic features which are related to providing answers to the primary scientific questions on the origin and evolution of the moon (See Table 5.1-1). Also, a centralized location for the shelter at these sites is desirable in order to support all three missions - remote sorties, deep drilling, and the observatory. For remote exploration sorties the site criteria include features located within a reasonable distance from a centralized shelter location consisting of favorable rock exposures and special geological, geophysical, or geochemical formations or events. For suitable deep drilling locations the site criteria are: promising stratigraphic sections near the surface; suspected zones of subsurface permafrost; and anomalous heat flow, devolatilizing or geophysical features. Observatory site criteria will be treated in detail in Part 2.

There are a multitude of sites which meet these criteria and are worthy of detailed, advanced study. Those of this study were chosen for a number of reasons, the most important being the presence of sufficient features or conditions of scientific interest accessible from the base to allow the maximum in scientific return from a relatively modest logistic effort.

Mare Orientale

Despite its name, Mare Orientale (Figure 5.1-2) is perhaps more of a highland than a mare site. Its primary interest lies in its gigantic and well-formed ring structure. Several analogous but more poorly formed ring structures occur on the far side. The importance of the process and conditions requisite for formation of the ring structures is evident when studying analogous features on the near side. That is, the lunar ring structures are not just isolated curiosities, but are present in all quadrants of the moon, and point to pre-existing crustal conditions that are peculiar to ring formation.

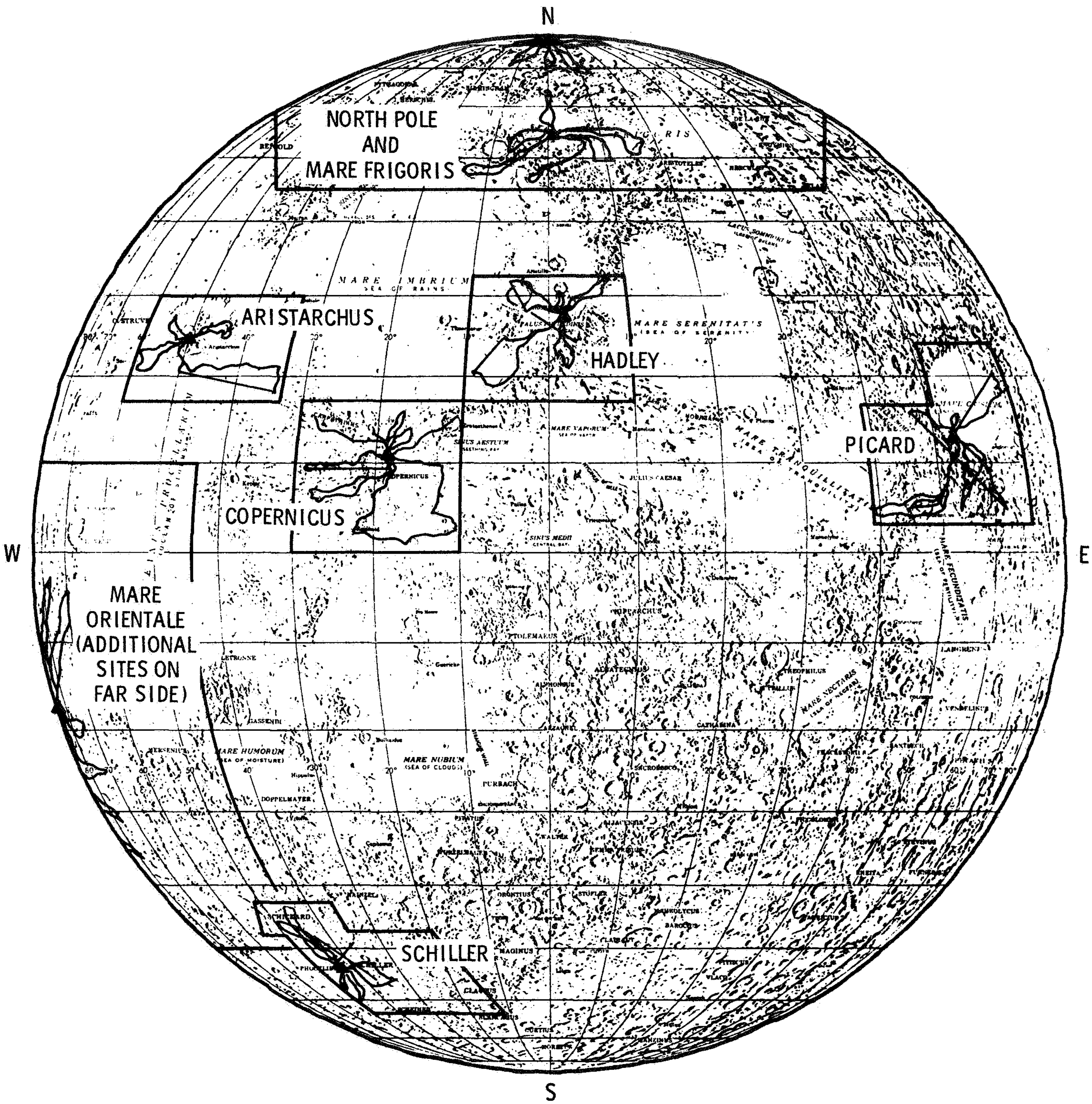


Figure 5.1-1. Potential LSB Sites Analyzed

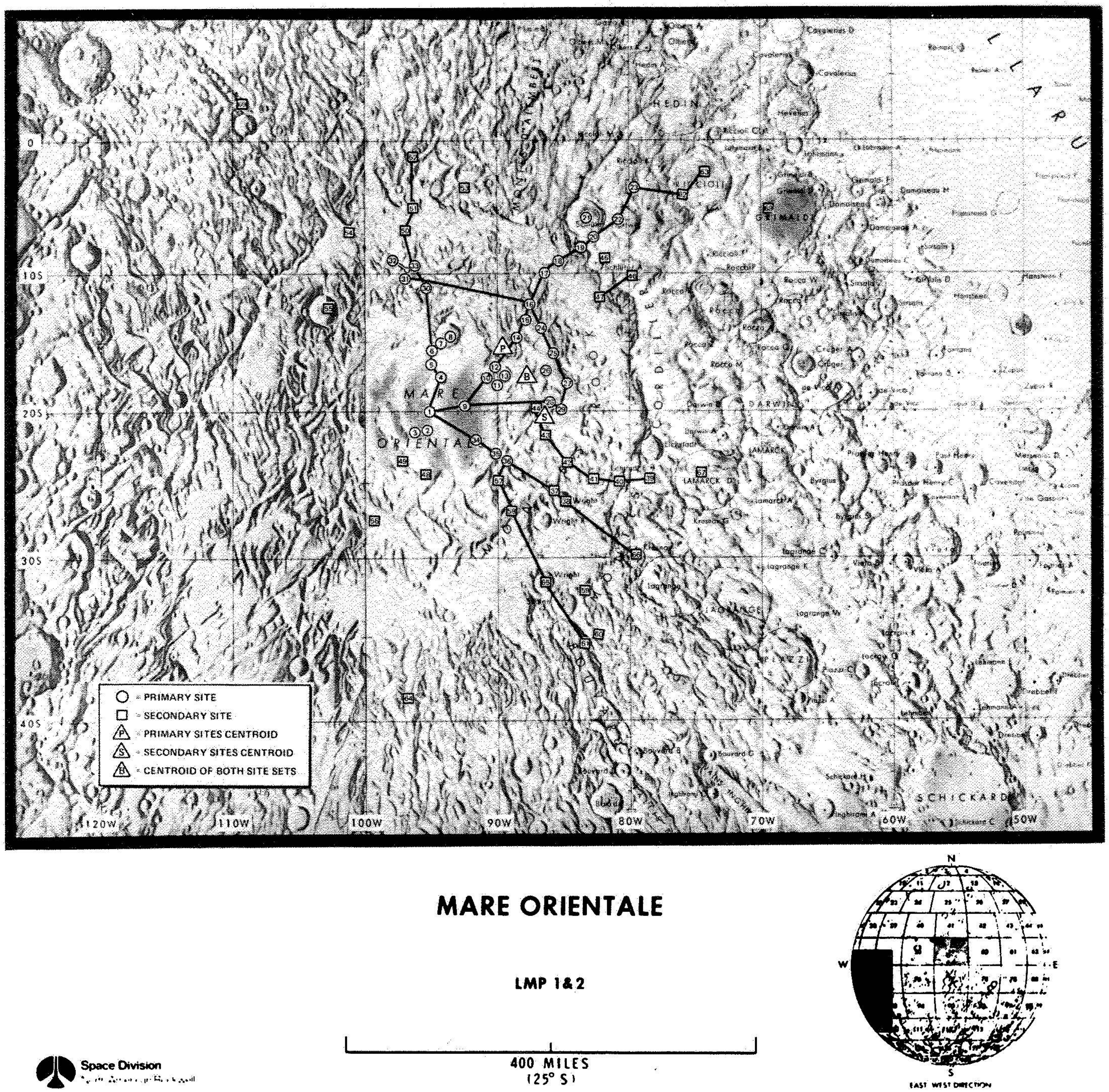


Figure 5.1-2. Mare Orientale LSB SITE

The topography around Mare Orientale shows an unusual radial pattern suggestive of deposition by a massive base surge or density flow process. Hence most of the pre-mare rocks may exist as breccia and fine material deposited by an impact cataclysm, and pre-existing highland bed rock may be difficult to find except as xenoliths in mare lavas that were extruded in the later stages of the cataclysm.

Mare Frigoris

The Frigoris site (Figure 5.1-3) was selected as an excellent location for studying typical highland petrology and structures because in the northern portion it appears to have been free of major brecciation and subsidence processes. Its features of major interest are the narrow and presumably shallow Mare Frigoris, Alpine Valley, a straight, wide valley bisected by a sinuous rille, and the relatively unstudied polar region, pock-marked by old craters, some of which contain areas of permanent shade which may hold relatively volatile minerals not present in sunlit areas of the moon. Also of major interest are a variety of craters including Aristoteles and the Alpine Mountain chain which is part of a Mare Imbrium ring structure.

Picard

The Picard LSB site (Figure 5.1-4), at the southwest margin of Mare Crisium, has several major features of great interest:

Mare Crisium, a "circular mare" with buried "mascon."

Picard, a small volcanic-appearing crater with relatively high walls and prominent central peak.

Arcuate highland mass bordering Mare Crisium with polygonal tectonic grain caused by linear valleys and ridges.

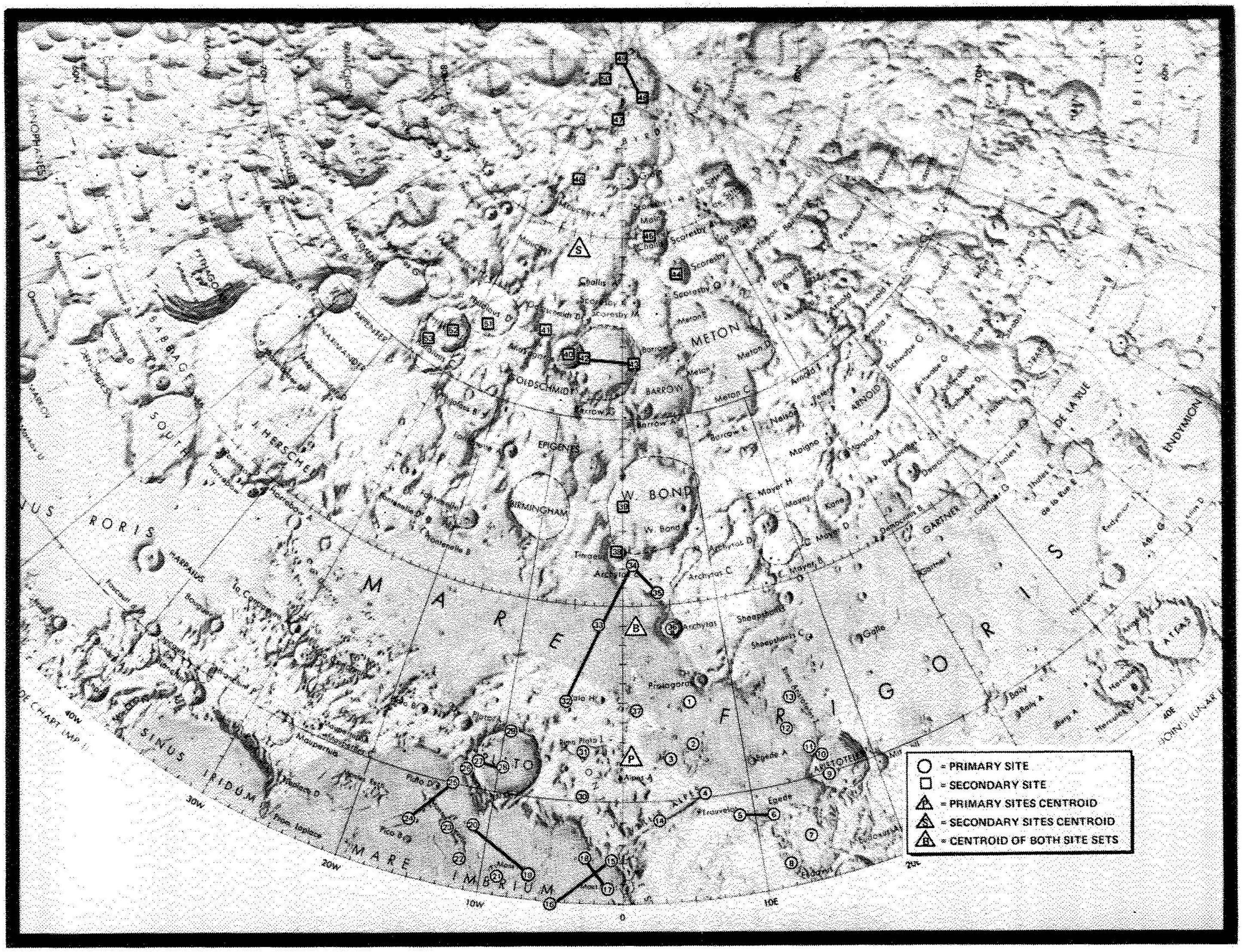
Taruntius, a crater situated on the northeast margin of the Mare Fecunditatus with concentric internal structures.

The Mare Fecunditatus boundary zone with overlapping of highland basement, the wide, straight Cauchy rilles, and the intersection with highland material.

Sinuous rilles south of Cauchy.

Mare Crisium is of special interest, for it resembles Mare Imbrium and many other circular mare, yet is small enough to allow geophysical and geological study by surface crews. Special features of interest are the central mass concentration revealed by Lunar Orbiter tracking and the concentric ridges along its margin. The latter may mark buried shoulders of the rim structure, or buried mountain rings such as those exposed about Mare Orientale.

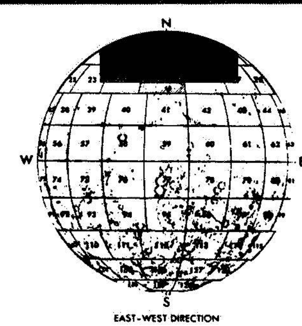
Crisium may be a relatively easy area for a long-range geophysical traverse utilizing gravity, magnetic, and spot seismic and geological



MARE FRIGORIS & NORTH POLE

LMP 3

400 MILES
(65°N)



Space Division
North American Rockwell

Figure 5.1-3. Mare Frigoris LSB Site

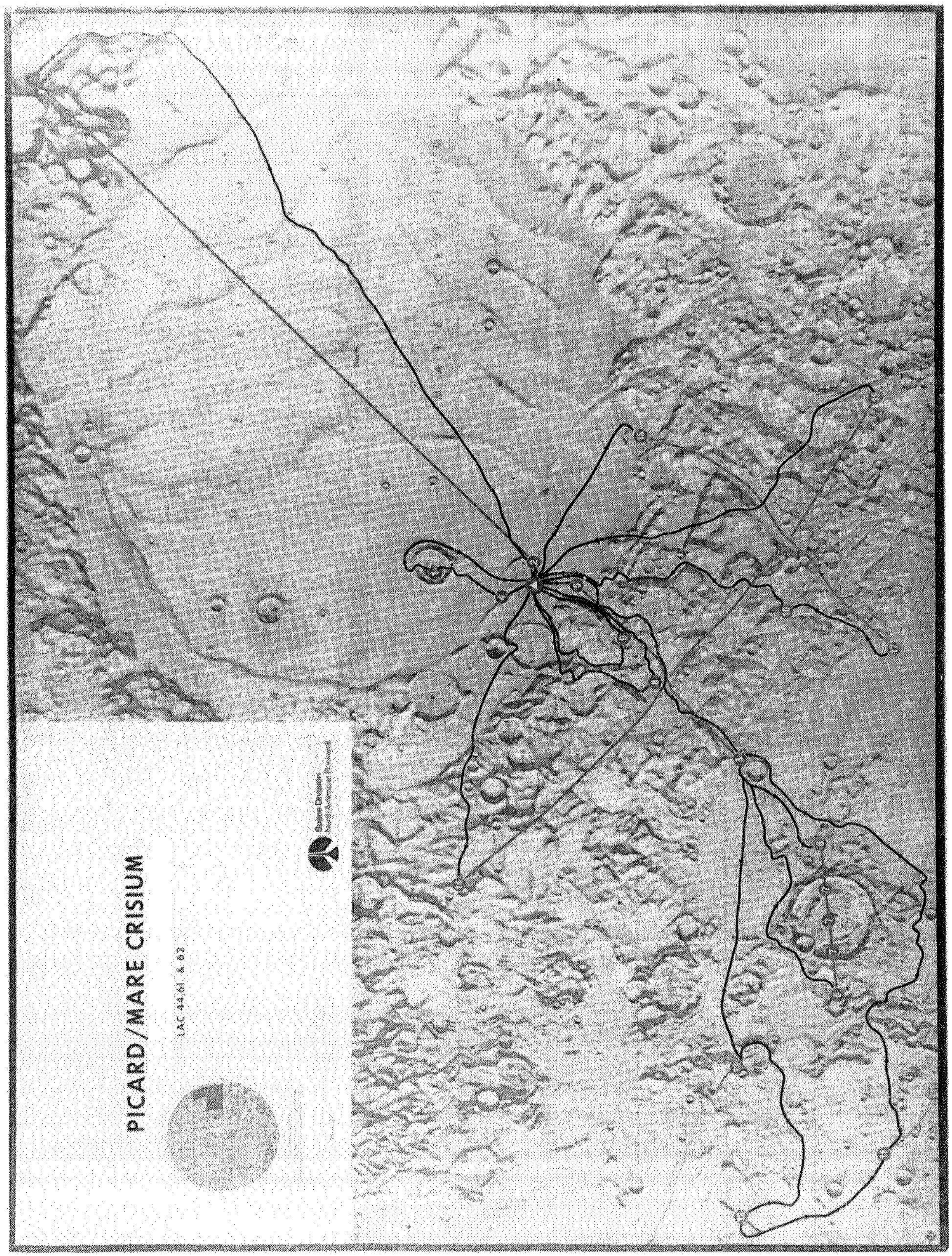


Figure 5.1-4. Picard LSB Site

surface investigations to determine the nature of the underlying mascon, mare shelf, and highland-border relations.

The surrounding "highland" area may prove not to be in situ continental material as in Alphonsus or Tycho areas, but a massive surface deposit of ejecta thrown out and heaped up by the impact that formed Mare Crisium, and perhaps, Fecunditatus before it. The linear ridges and valleys prominent in the high country will provide important clues to the nature of tectonic evolution of the lunar surface. Long geophysical traverses here should reveal regional trends in parameters such as the gravity and magnetic fields and support more meaningful interpretation of the Crisium traverse data, and of course, local anomalies found in the other areas.

Picard Crater is a young, exceptionally well-formed small crater with an asymmetric somma-ring and a central peak. It is very like a volcano nested in a cauldera. In contrast are the nearby Yerkes and Lick craters, which appear to be older impact features, post-dating the Crisium impact but predating the lavas which have filled the Mare basin.

Schiller

Schiller (Figure 5.1-5) is a relatively low latitude site (54^{o}S) located in a large highland mass. The area contains an abundance of craters, ejecta land forms, and valleys of apparent tectonic origin, but because of its location near the limb of the lunar face, it has not been studied as intently, nor mapped as well as many more centrally located sites.

Of primary interest at this site are:

Schiller Crater, a long, elliptical, distinctive lunar crater.

Highland topography and country rock.

Ejecta deposits and possible landforms from Tycho and Orientale events.

Tectonically-oriented valley and ridge patterns, trending predominantly northwest and northeast.

Schiller basin, a low area east of Schiller, partially flooded with ejecta or lava.

Schiller is an uncommonly elongated crater that gives the impression that it may have been created by a very low-angle bolide impact. Its size (320 miles long by 100 miles wide) has prompted some observers to refer to it as a "walled plain" or a "graben structure." Close examination of it in Lunar Orbiter photographs reveals that it is a relatively fresh, steep walled structure in which three more nearly circular features can be recognized. A full understanding of the origin of Schiller and the reasons

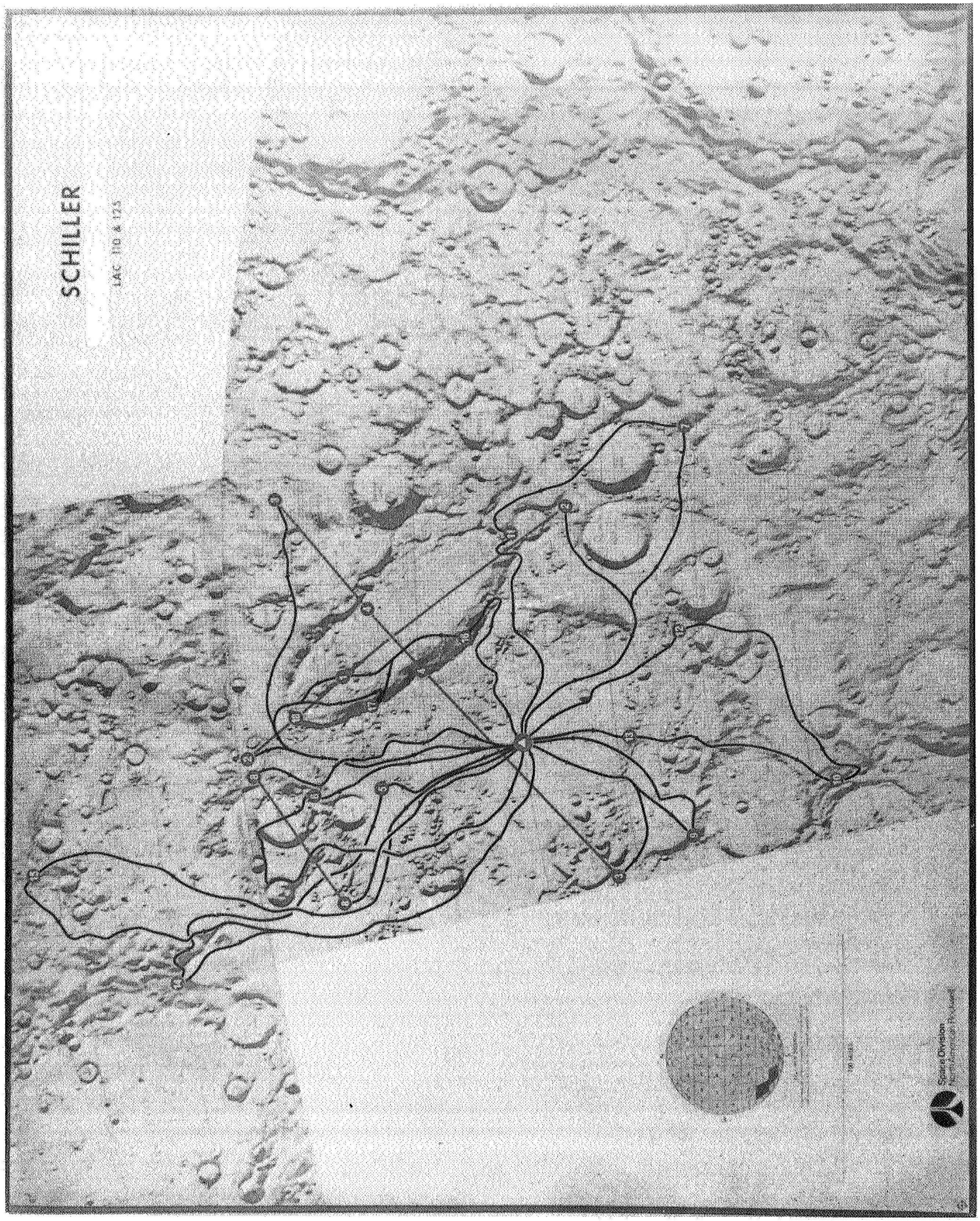


Figure 5.1-5. Schiller LSB Site

for the paucity of similar craters on the moon will result from the proposed geologic study of the region and the geophysical traverses across this complex crater.

Hadley

The Hadley LSB (Figure 5.1-6) will allow study of an area of extremes in both scientific interest and geographic relief. The area is at the southeast margin of Mare Imbrium, and includes Mt. Hadley and other high peaks of the Appenines. Specific features to be investigated are:

Hadley Rille and Valley, a very prominent sinuous rille at the foot of the Apennines.

The Mare Imbrium - Apennine contact.

Highland topography and pre-Imbrium rocks of the Apennines.

Palus Putredinis, a shallow bay of Imbrium northwest of Hadley Rille.

Archimedes, a prominent, old, flat-floored crater in Mare Imbrium.

Mass deficiency area near Wallace Crater.

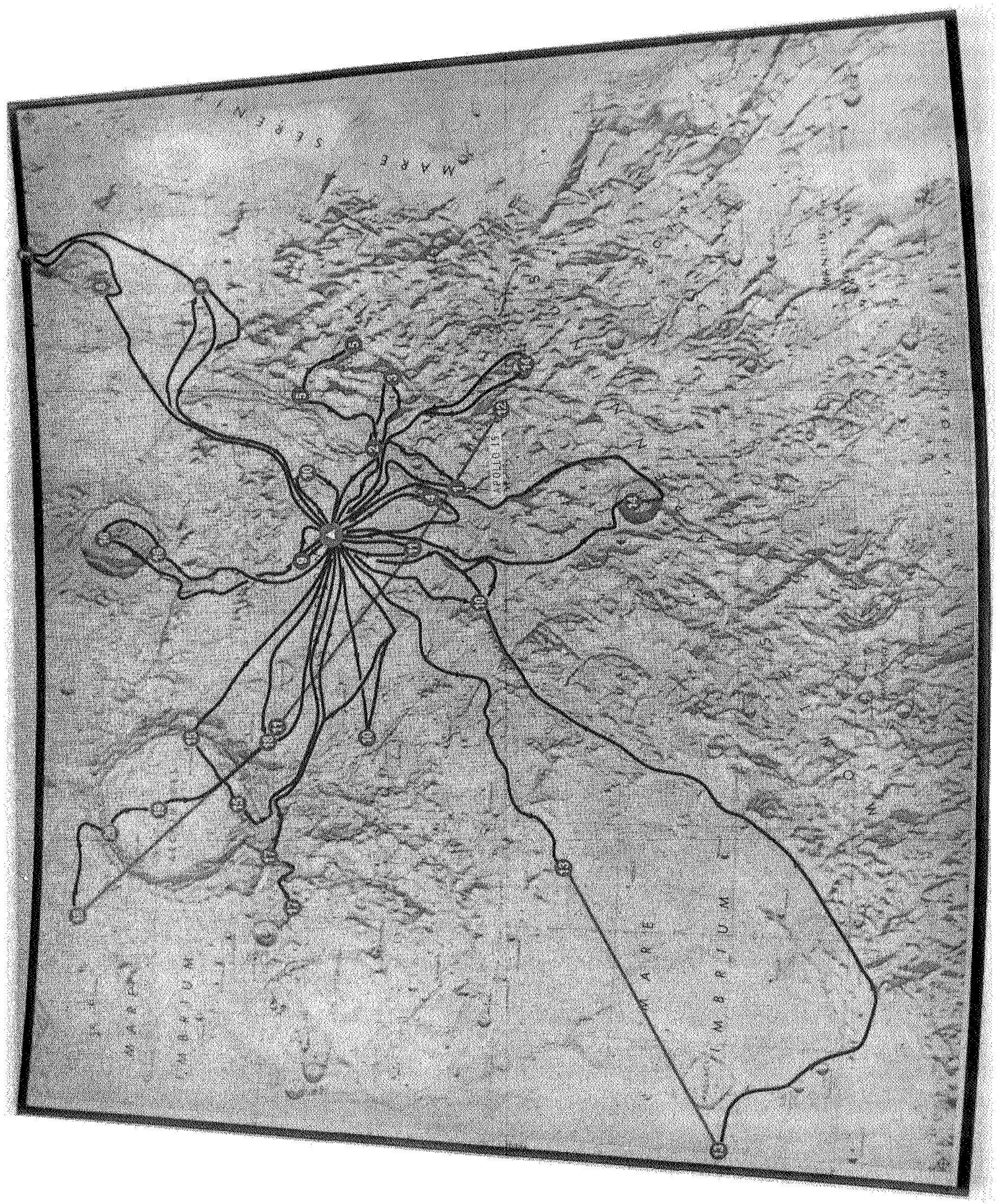
Numerous rilles, straight and sinuous, radial and concentric to Mare Imbrium.

Hadley Rille is a V-shaped rille about 600 feet deep and a half mile wide that roughly parallels the arcuate Apennine - Mare Imbrium boundary in its eastern part. It originates as an elongated depression in an area of domes of probably volcanic origin, and meanders northward in a wide valley for about 60 miles where it merges with a second rille. The origin of lunar sinuous rilles is unknown but important, for it is possible that water or other volatile material had a part in their formation. There is an unusual abundance of rilles in the Putredinis area.

The Apennine mountains at Mt. Hadley rise about 1100 feet above the rilles and contain ancient rock exposed or possibly deposited during excavation of the Imbrium basin.

Aristarchus

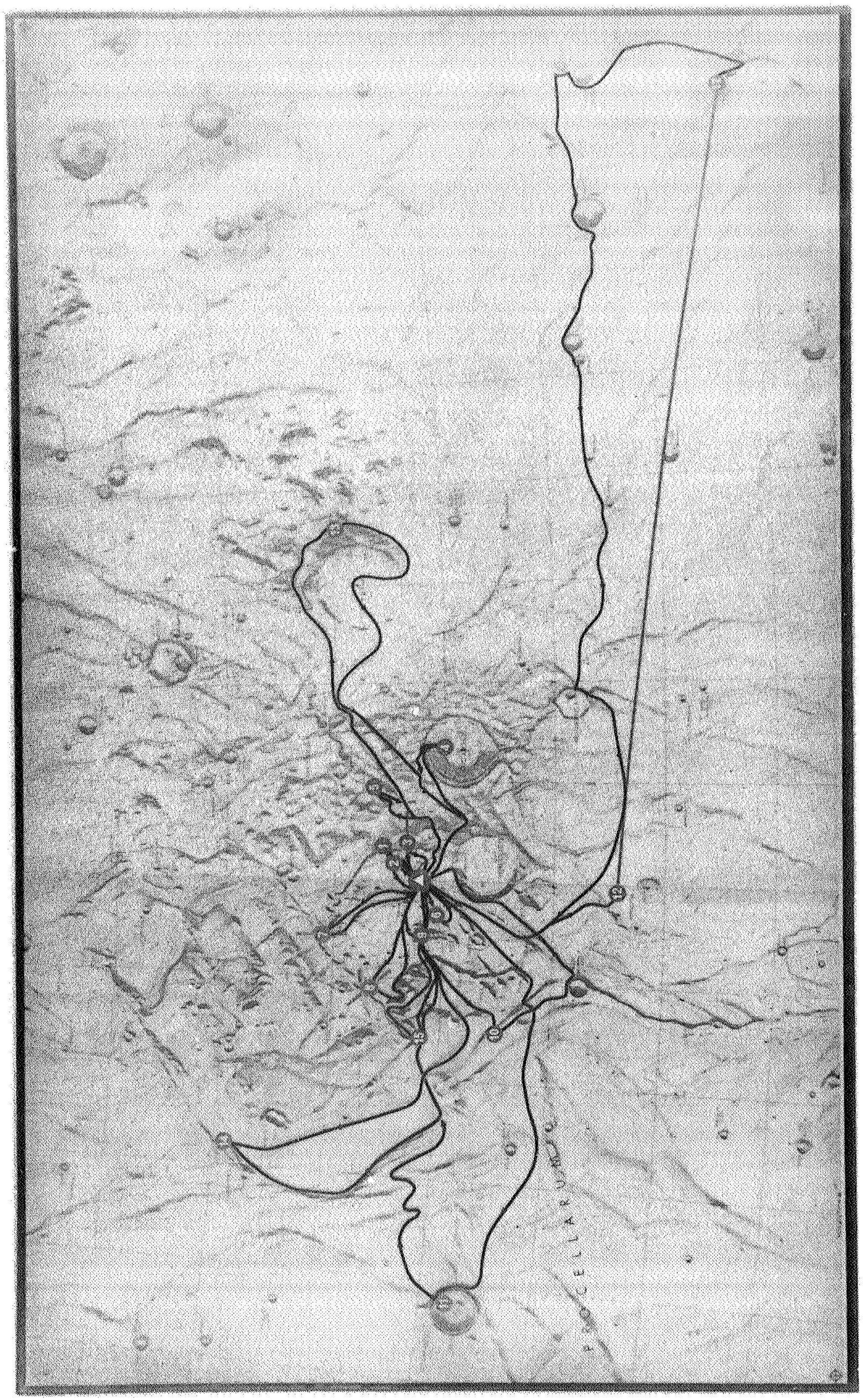
The Aristarchus plateau (Figure 5.1-7) is exceptionally rich in features some of which have been the subject of scientific inquiry for more than a century. The area appears to be a cratered volcanic plateau isolated in Mare Procellarum. Of historic interest to observers are Aristarchus, a high-albedo crater with central peak, and Schröter's Valley, a large sinuous rille which terminates abruptly in a crater or amphitheater-like feature called the "Cobra Head." Transient events resembling glowing lights or



HADLEY RILLE

LAC 41

Figure 5.1-6. Hadley LSB Site



ARISTARCHUS

LAC 38 & 39

Figure 5.1-7. Aristarchus LSB Site

eruptions of clouds have been seen by telescope in these areas. Schröter's Valley is perhaps the strangest of the lunar sinuous rilles. On its bottom is a subsidiary median rille which meanders much like a low gradient stream bed on earth, strongly suggestive of the former existence of flowing surface water on the moon. The plateau area "Woodspot" is well-known for its low albedo and luminescence. The cause of the low luminescence has been attributed to possible sulfide mineralization or simply to the presence of relatively young, dark basalt lava.

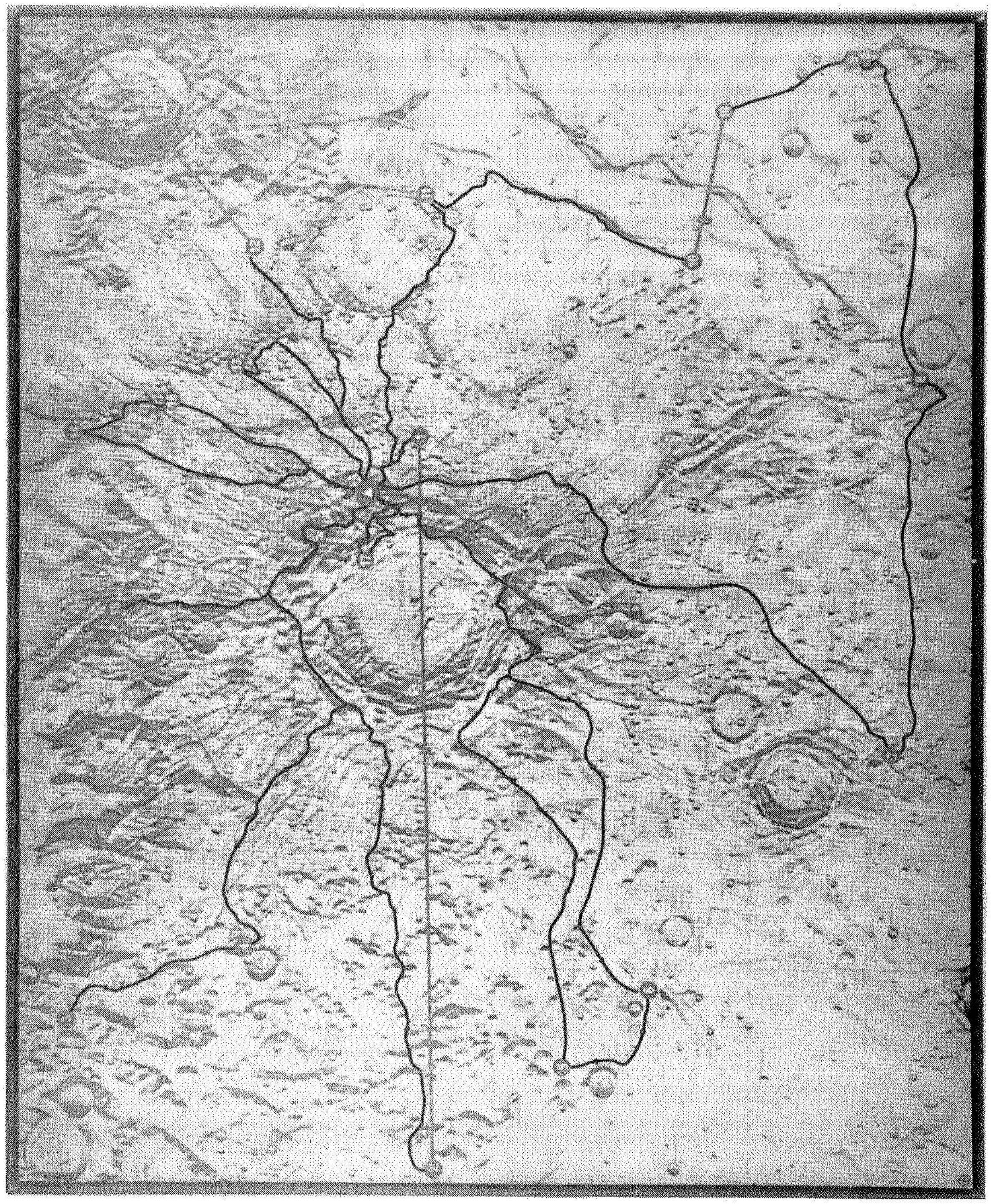
Smaller scale features of interest include many rilles, ridges, apparent fault scarps and depressions, many of which have preferred orientations forming a regional pattern caused by former crustal stresses. Craters and ejecta of all types may be expected and various types of slopes and slump phenomena provide useful subjects for erosion or mass wasting studies. The area is one of the richest in suspected sources of outgassing and active volcanism; hence, it may be well suited for the study of dynamic lunar processes. Stratigraphic relations and rocks important for absolute age dating are well exposed in the walls and ejecta of Aristarchus Crater and Schröter's Valley, which is extremely steep-walled and locally more than 2,500 feet deep.

Copernicus/Eratosthenes

The Copernicus site (Figure 5.1-8) is located on the near side and close to the equator. Two major craters focus attention on this site - Copernicus and Eratosthenes. Copernicus is probably the most famous lunar landmark, in part due to its enormous size, about 50 miles in diameter, and in part due to the bright rays emanating from it. Principal interest lies in the possible mare and highland stratigraphy exposed on the 15,000-foot-high undulating walls and on outcrops of the 12,000-foot central peak. The crater floor is level although the high resolution Lunar Orbiter photographs indicate that it is extremely rough. Eratosthenes is another deep crater about 38 miles in diameter with an extremely rough floor and many irregular central peaks. Stratigraphy on the walls and peaks and rock samples from the floor constitute desirable measurements.

In addition to these craters, other features to be investigated on this large site include: the circular crater with somma ring at Tobias Mayer C; the domes north of Hortensius; the long bifurcating wrinkle ridge below Eratosthenes; and a crater chain on the rim of Stadius.

Table 5.1-2 summarizes the availability of the desired lunar features for the five sites analyzed in detail. None of these sites contain all the desired features. It should also be noted that several visits will probably need to be made to the more complex features to understand them completely. This may call for repeated surface missions following the initial data analysis or missions to other similar features not found at the LSB site. It is concluded that the sites selected, including Orientale and Frigoris which are far larger and equally rich in formations, are satisfactory sites for the purposes of this study.



COPERNICUS/ERATOSTHENES

LAC 58

Figure 5.1-8. Copernicus LSB Site

Space Division
North American Rockwell

A comparison of the area covered in a typical LSB site may be made using Figure 5.1-9. This map (original scale at 1:1,000,000) covers about the same surface area as the lunar site maps presented earlier. This map covers a large part of the state of Nevada and portions of California. Reference points include Lake Tahoe (upper left) and Las Vegas - Lake Mead in the lower right corner. Extreme slopes on some of the lunar craters such as Aristarchus and Copernicus correspond directly with contours shown on this map between Death Valley and Telescope Peak and between the valley floor and White Mountain Peak. Alternatively, slopes on the eastern Sierras are considerably steeper than lunar slopes - over a comparable horizontal distance.

5.1.2 LSB Site Measurement Plans

Each of the above LSB sites was analyzed in detail using USAF-NASA LAC-series charts scaled at 1:1,000,000 (or 1:5,000,000 for Orientale and Frigoris) to define the local experiment sites and traverses desirable to explore the features at the LSB site completely.

Activities at individual experiment sites include a number of different experiments, usually five to ten, require up to 400 hours duration (1,600 man-hours for a four-man crew), and local exploration travel up to 150 miles.

Surface traverses are scheduled to obtain wide area coverage along a relatively constant heading. They involve continuous measurements and the constant repetition of a few EVA and IVA experiments requiring full stops of the vehicle every 1-5 miles throughout the trip for rock samples and magnetometer and gravimeter surveys.

To maximize the data return from all surface sorties, certain baseline geophysical data measurements such as gamma ray and mass spectrometry will normally be made whenever the vehicles are in motion to provide a network of data which can be used to "connect" geologically interesting sites. The primary difference between these data and those of the traverse are that no EVA experiments such as active seismic surveys are performed nor are any stops made en route. These differences are shown more clearly on the functional diagrams for these sorties.

The geoscience features of interest at each of the LSB sites were identified on the respective maps, as shown by the numbered circles on Figures 5.1-2 through 5.1-8, and a series of experiments based on the type of features present were specified. The site experiment plans shown in Tables 5.1-3 through 5.1-9 list the features, the experiments (by an identifying number) at each feature, the estimated travel distance required to fully explore the features, the weight of rock and soil samples to be returned to the shelter, and the suitability of the site for deployment of a remote geophysical monitor (RGM) which is an automatically operated set of experiments to measure and transmit data over several years of operation on passive seismic events. Also listed are the recommendations for additional site visits, particularly for observations of day/night and random transient phenomena. Finally, an estimate of the time required to complete all the

Table 5.1-2. Availability of Lunar Features at LSB Sites

LUNAR FEATURES	ARISTARCHUS	PICARD/ MARE CRISIUM	SCHILLER	HADLEY	COPERNICUS
LAVA FLOW	X	X			
ASH DEPOSIT	X				
FAULT SCARP		X	X	X	X
CRATER WALL	X	X	X	X	X
CONE		X			
BULBOUS DOME	X				X
LOW DOME					X
LTP SITE	X				
MARE-UPLAND CONTACT		X		X	
DIATREME					
RIMLESS CRATER		X	X		
SOFT MARE CRATER	X				
GRID LINEAMENT	X	X	X	X	
RADIAL LINEAMENT	X	X			X
CONCENTRIC SCARP		X			
LINEAR RILLE	X	X	X	X	X
CRATER FLOOR	X	X	X	X	X
PATTERNED GROUND	X	X			
EJECTA BLANKET		X	X		X
RIFT AREA		X	X		
WRINKLE RIDGE	X		X		X
SINOUS RILLE	X		X	X	X
MARE	X	X		X	
CENTRAL PEAK	X	X		X	X
EXPOSED RING					
MANTLED RING					X
GHOST RING	X				
<20 Km SMALL YOUNG CRATER	X	X		X	X
>50 Km LARGE YOUNG CRATER	X	X	X	X	X
STREWN ROCK CRATER			X		

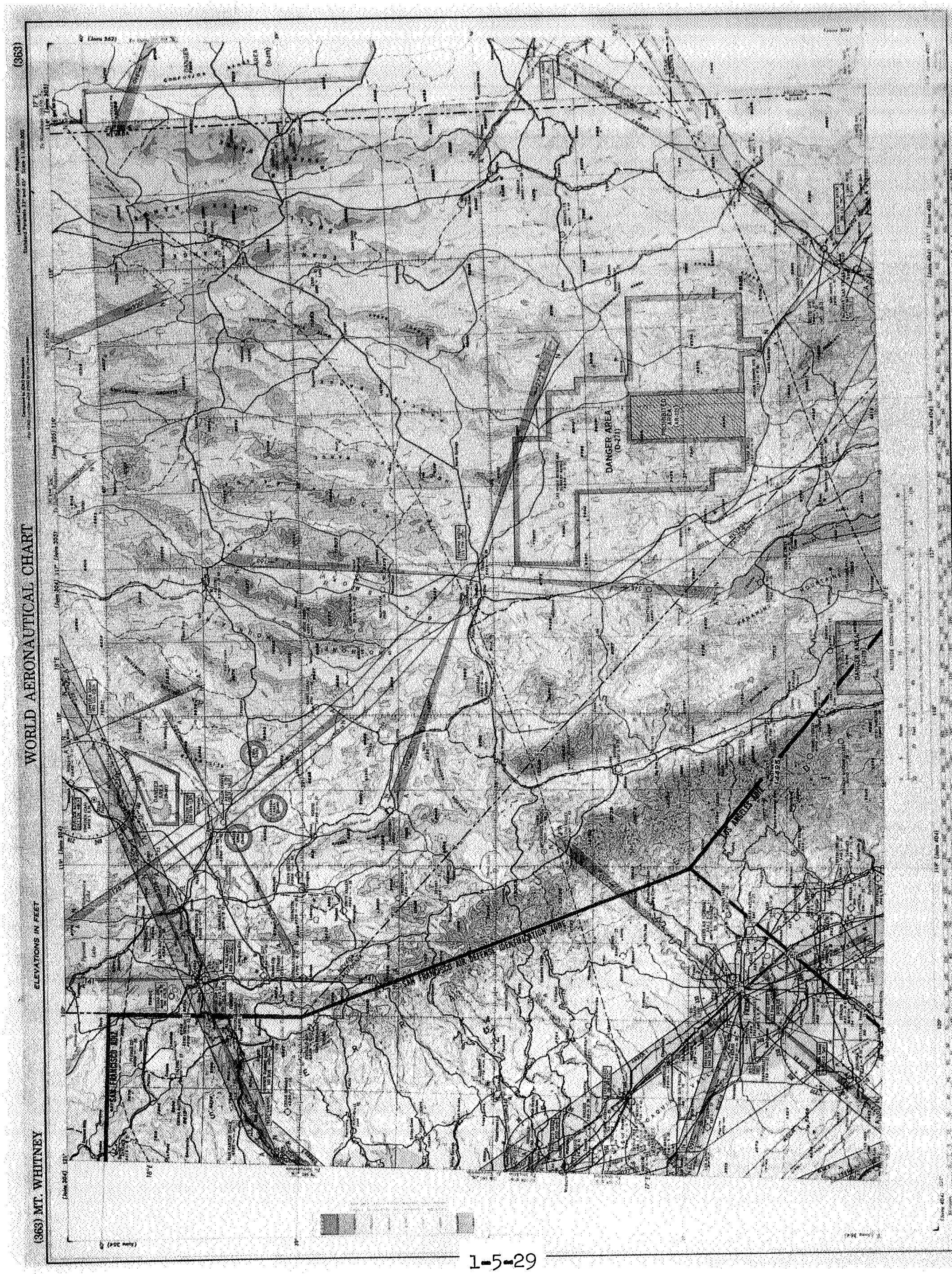


Figure 5.1-9. Example of Comparable Exploration Area on Earth

Table 5.1-3. Experiment Plan, Orientale LSB Site

-FIRST LEVEL REMOTE SITES-

Experiment Site	Features	Preferred Experiments	Experiment Site Mobility (SM)	Rock Sample Pickup (lb)	Deploy RGM	Return Visits	Duration of Experiment Operation
1	Central Mare wrinkle ridge and hills (central peak analogue)	4001, 4032, 4033 (3), 4038, 4039, 4044, 4045, 4046, 4047, 4053, 4057, 4058, 4059, 4088	35	75	4039 - 4047	Optional	Minimum: 27 hrs; Maximum: 85 hrs
2	Steptoe and subsidence ring. Mare and pre-Mare stratigraphy	4032, 4033 (2), 4038, 4045, 4046, 4053, 4057, 4058, 4059	10	50	No	Optional	Minimum: 25 hrs; Maximum; 70 hrs
3	Open Mare fissure, Mare stratigraphy	4001, 4032, 4038, 4045, 4047, 4058	5	75	No	Optional	Minimum: 13 hrs; Maximum: 30 hrs
4	Light, Maar-type crater	4032, 4038, 4046, 4053, 4057	5	25	No	Optional	Minimum: 4 hrs; Maximum: 16 hrs
5	Distal crater deposits, base-surge chevron facies(?) and secondary craters	4032, 4033 (1), 4038, 4046, 4058, 4059	0	25	No	Optional	Minimum: 12 hrs; Maximum: 18 hrs
6	Smooth - surface crater deposits	4032, 4045, 4058	0	25	No	Optional	Minimum: 6 hrs; Maximum: 12 hrs
7	Very young impact crater rim and crater wall stratigraphy	4032, 4038, 4044, 4053, 4057	5	75	4039	Optional	Minimum: 12 hrs; Maximum: 24 hrs
8	Central Peak and crater floor of young impact crater	4032, 4038, 4039, 4044, 4053, 4057	5	25	4039	Optional	Minimum: 6 hrs; Maximum: 50 hrs
9	Open fissures in Mare stratigraphy	4001, 4032, 4038, 4039, 4044, 4045, 4046, 4053	25	100	4039	Optional	Minimum: 18 hrs; Maximum: 50 hrs
10	Hummocky Terrain (Montes Rook Fm)	4032, 4033 (2), 4038, 4045, 4046, 4053, 4057, 4058, 4059	5	45	No	No	Minimum: 12 hrs; Maximum: 48 hrs
11	Elongate gash in crater rim slope. Smooth crater rim deposit	4032, 4038, 4045, 4046, 4058, 4039	0 to 10	30	4039	Optional	Minimum: 12 hrs; Maximum: 36 hrs
12	Rim and crater walls of possible volcanic crater	4032, 4038, 4057	0 to 40	150	No	No	Minimum: 12 hrs; Maximum: 36 hrs
13	Fissured crater floor	4032, 4038, 4057,	0 to 10	30	4039	Optional	Minimum: 6 hrs; Maximum: 36 hrs

Table 5.1-3. Experiment Plan, Orientale LSB Site (continued)

-FIRST LEVEL REMOTE SITES-

Experiment Site	Features	Preferred Experiment	Experiment Site Mobility (SM)	Rock Sample Pickup (lb)	Deploy RGM	Return Visits	Duration of Experiment Operation
14	Large radial rift and intersecting N-S rift Central Basin Plains Fm.	4001, 4032, 4033 (2), 4038, 4044, 4045, 4046, 4053, 4057, 4058, 4088	20	100	No	Optional	Minimum: 24 hrs; Maximum: 48 hrs
15	Mare Veris and concentric fault in Central Basin Plains fm. Structurally dropped ring	4001, 4032, 4033 (2), 4038, 4057, 4059, 4088	5	75	No	No	Minimum: 12 hrs; Maximum: 36 hrs
16	Mountain of Pre-Orientale terra material, Inner Rook Rng.	4001, 4032, 4033 (1), 4038, 4045, 4057, 4058, 4059	25	100	No	No	Minimum: 16 hrs; Maximum: 48 hrs
17	Head of Mare Veris arm, pre-Orientale terra mtn.	4032, 4033 (2), 4038, 4058, 4046, 4057, 4059, 4088	10	40	No	No	Minimum: 16 hrs; Maximum: 60 hrs
18	Montes Rook Formation Hummocky Outer Ring	4001, 4032, 4033 (1), 4038 4045, 4046, 4057, 4088	0	40	No	No	Minimum: 16 hrs; Maximum: 60 hrs
19	Outer Ring - Cordillera Fault Scarp. Cordillera Fm. stratigraphy & structure	4001, 4032, 4038, 4046, 4057	0 to 25	200	No	No	Minimum: 16 hrs; Maximum: 60 hrs
20	Schlüter Crater. Shoulder and crater wall stratigraphy. Cordillera Formation	4001, 4032, 4038, 4039, 4044, 4045, 4046, 4047	30	150	Yes (4047 & 4039)	Optional	Minimum: 18 hrs; Maximum: 80 hrs
21	Central Peak, Schlüter and crater floor. Evidence of recent activity	4032, 4038, 4039, 4053, 4057, 4058, 4059	25	100	Yes (4039)	Optional	Minimum: 16 hrs; Maximum: 80 hrs
22	Hartwig old crater mantled with Cordillera deposits	4001, 4032, 4033 (1), 4038, 4045, 4046, 4058, 4088	0 to 25	20	No	Optional	Minimum: 16 hrs; Maximum: 24 hrs
23	Braided Cordillera Fm. Base surge deposits?	4032, 4045, 4046, 4058	0 to 10	20	No	No	Minimum: 8 hrs; Maximum: 16 hrs
24	Mare Veris, southern basin edge	4001, 4032, 4033, 4045, 4046, 4058, 4059, 4088	0 to 15	25	No	No	Minimum: 16 hrs; Maximum: 36 hrs
25	Central Basin Plains fm. Concentric fault, Mare Veris onlap	4032, 4033, 4045, 4046, 4058, 4059, 4088	20	35	No	No	Minimum: 26 hrs; Maximum: 40 hrs

Table 5.1-3. Experiment Plan, Orientale LSB Site (continued)

-FIRST LEVEL REMOTE SITES-

Experiment Site	Features	Preferred Experiment	Experiment Site Mobility (SM)	Rock Sample Pickup (lb)	Deploy RGM	Return Visits	Duration of Experiment Operation
26	Fissured Lobate Hill in Central Basin Plains material	4001, 4032, 4038, 4045, 4046, 4057, 4058	10	50	No	Optional	Minimum: 8 hrs; Maximum: 24 hrs
27	Domes (Steptoes?) in Mare Veris	4032, 4033, 4045, 4046, 4058, 4059	0 to 10	10	No	Optional	Minimum: 8 hrs; Maximum: 24 hrs
28	Crater containing tholoid or flow in center	4032, 4038, 4045, 4058, 4039	0	30	Possibly (4039)	Optional	Minimum: 8 hrs; Maximum: 24 hrs
29	Mountain of pre-Orientale material	4032, 4038, 4045, 4058, 4044	0 to 10	25	No	No	Minimum: 8 hrs; Maximum: 24 hrs
30	Inner Ring Mountains, north	4032, 4038, 4045, 4058, 4044	0 to 10	25	No	No	Minimum: 8 hrs; Maximum: 24 hrs
31	Dark Halo Crater in western Mare Veris	4032, 4033, 4038, 4045, 4047, 4059	0 to 10	25	No	No	Minimum: 8 hrs; Maximum: 24 hrs
32	Rook Mts. Central fault scarp. Pre-Orientale or Montes Rook stratigraphy	4032, 4038, 4047	0 to 20	150	No	No	Minimum: 24 hrs; Maximum: 48 hrs
33	Sinuous Rille; stratigraphy, rille genesis, geophysics	4001, 4032, 4033, 4038, 4045, 4046, 4047, 4058, 4059, 4088	0 to 20	150	Yes (4047)	No	Minimum: 48 hrs; Maximum: 200 hrs
34	Central Mare, fresh crater	4032, 4033, 4038, 4045, 4046, 4057, 4059, 4088	0 to 10	35	No	No	Minimum: 16 hrs; Maximum: 24 hrs
35	Innermost Rook Mtn. fault scarp. Hummocky terrain	4032, 4038, 4047	0 to 10	75	No	No	Minimum: 8 hrs; Maximum: 24 hrs
36	Highly fractured mountain terrain of inner Rook range. Trafficability nearly impossible	4032, 4038, 4045, 4046, 4057, 4058	0 to 10	40	No	No	Minimum: 12 hrs; Maximum: 36 hrs
	-ALTERNATIVE OR SECOND LEVEL REMOTE SITES-						
37	Veris fault scarp, Montes Rook contacts between pre-Orientale, Central Basin, Montes Rook and younger crater materials.	4001, 4032, 4033, 4038, 4045, 4047, 4050, 4059, 4088	10 to 50	150	Yes (4047)	No	Minimum: 160 hrs; Maximum: 250 hrs

Table 5.1-3. Experiment Plan, Orientale LSB Site (continued)

-ALTERNATIVE OR SECOND LEVEL REMOTE SITES-

Experiment Site	Features	Preferred Experiment	Experiment Site Mobility (SM)	Rock Sample Pickup (lb)	Deploy RCM	Return Visits	Duration of Experiment Operation
38	Wright S volcanic (?) crater interior and wells	4032, 4038, 4039, 4045, 4046, 4057, 4058	5	25	Perhaps (4039)	Optional	Minimum: 20 hrs; Maximum: 80 hrs
39	Lineated and patterned surface of Cordillera fm. Eichstädt E	4001, 4032, 4038, 4045, 4046, 4057, 4058	5 to 10	25	Yes (4047)	Optional	Minimum: 20 hrs; Maximum: 80 hrs
40	Cordillera Fault Scarp Stratigraphy of Cordillera and older rocks	4032, 4038, 4045, 4046, 4057, 4058	10 to 20	75	No	Optional	Minimum: 24 hrs; Maximum: 56 hrs
41	Chaotic terrain of Montes Rook fm.	4032, 4038, 4045, 4046, 4057, 4058	0 to 10	25	No	Optional	Minimum: 8 hrs; Maximum: 16 hrs
42	Veris fault scarp. Montes Rook & older stratigraphy	4001, 4032, 4038, 4044, 4045, 4046, 4057, 4058	0 to 10	50	No	Optional	Minimum: 16 hrs; Maximum: 25 hrs
43	Small sinuous rille in southern area of Mare Veris	4001, 4032, 4033(2), 4038, 4045, 4046, 4058, 4059, 4088	0 to 20	150	No	Optional	Minimum: 36 hrs; Maximum: 200 hrs
44	Inner Rook Mt. fault scarp, pre-Rook stratigraphy	4032, 4038, 4047	0 to 10	75	No	No	Minimum: 8 hrs; Maximum: 24 hrs
45	Schlüter A crater	4001, 4032, 4038, 4039 4044, 4045, 4046	20	75	No	Optional	Minimum: 8 hrs; Maximum: 40 hrs
46	Lineated & patterned surface of Cordillera fm.	4001, 4032, 4038, 4045, 4046, 4057, 4058	5 to 10	25	Yes	No	Minimum: 20 hrs; Maximum: 80 hrs
47	Gentle slope across Cordillera Scarp, slumping, Mare contact	4001, 4032, 4038, 4046, 4057	0 to 20	150	No	Optional	Minimum: 16 hrs; Maximum: 60 hrs
48	Deep fractures, concentric and oblique, bordering Central Mare	4001, 4032, 4038, 4045, 4047, 4058	25	75	No	Optional	Minimum: 13 hrs; Maximum: 30 hrs
49	Border graben, central Mare	4032, 4033 (2), 4038, 4045, 4046, 4053, 4057, 4058, 4059	50	50	Optional (4047)	Optional	Minimum: 25 hrs; Maximum: 65 hrs

-THIRD LEVEL REMOTE EXPERIMENT SITES

Table 5.1-3. Experiment Plan, Orientale LSB Site (continued)

Experiment Site	Features	Preferred Experiments	Experiment Site Mobility (SM)	Rock Sample Pickup (lb)	Deploy RGM	Return Visits	Duration of Experiment Operation
50	Outer facies, Montes Rook fm.	4001, 4032, 4033 (1), 4038, 4045, 4046, 4057, 4088	0	40	No	No	Minimum: 12 hrs; Maximum: 50 hrs
51	Cordillera Fault Scarp Cordillera fm. and older stratigraphy	4032, 4038, 4044, 4045, 4046, 4057, 4058	10 to 20	75	No	No	Minimum: 8 hrs; Maximum: 80 hrs
52	Braided "Chevron" terrain of Cordillera fm. Base surge study	4032, 4045, 4046, 4047, 4058	0 to 10	25	Yes (4047)	No	Minimum: 12 hrs; Maximum: 24 hrs
53	Montes Rook overlap area, geophysical and stratigraphic study	4032, 4045, 4046, 4058	0	45	No	No	Minimum: 8 hrs; Maximum: 24 hrs
54	Intersection, major NW rift with Cordillera scarp. Mare contact, far side	4001, 4032, 4033, 4038, 4045, 4046, 4058, 4059, 4088	50	50	Optional (4047)	No	Minimum: 28 hrs; Maximum: 90 hrs
55	Far side Central Peak Crater	4001, 4032, 4038, 4039, 4058	0 to 10	50	Optional (4039)	No	Minimum: 12 hrs; Maximum: 40 hrs
56	Faulted pre-Orientale Crater old, high mt. scarp	4001, 4032, 4038, 4044, 4045, 4046, 4057, 4058	0 to 20	50	Optional (4047)	No	Minimum: 16 hrs; Maximum: 40 hrs
57	Highly fissured terrain	4032, 4038, 4045, 4046, 4057, 4058	0 to 10	40	No	Optional	Minimum: 12 hrs; Maximum: 24 hrs
58	Central Basin Plains deposits and middle Rook fault scarp	4001, 4032, 4038, 4044, 4045, 4046, 4057, 4058	0 to 20	50	Optional (4047)	No	Minimum: 16 hrs; Maximum: 24 hrs
59	Cordillera scarp, southeast border of outer ring	4032, 4038, 4045, 4046, 4057, 4058	10 to 20	17	No	Optional	Minimum: 24 hrs; Maximum: 56 hrs
60	Cordillera deposits, outer rim	4001, 4032, 4038, 4044, 4045, 4046, 4057, 4058	5 to 10	25	No	No	Minimum: 20 hrs; Maximum: 80 hrs
61	Bouvard-Vallis Baade, major radial rift	4001, 4032, 4033, 4038, 4045, 4046, 4058, 4059, 4088	10 to 50	250	Optional (4047)	No	Minimum: 40 hrs; Maximum: 160 hrs
62	Riccioli Crater Walls mod. old crater, partially mantled	4001, 4032, 4038, 4039, 4044, 4045, 4046	10	100	No	No	Minimum: 16 hrs; Maximum: 40 hrs

Space Division
North American Rockwell

-THIRD LEVEL REMOTE EXPERIMENT SITES-

Table 5.1-3. Experiment Plan, Orientale LSB Site (continued)

Experiment Site	Features	Preferred Experiments	Experiment Site Mobility (SM)	Rock Sample Pickup (lb)	Deploy RGM	Return Visits	Duration of Experiment Operation
63	Riccioli Crater floor, basalt and younger Cordillera, distal base surge deposits (?)	4001, 4032, 4033 (1), 4038, 4045, 4046, 4058, 4088	25 to 50	75	Yes (4047)	Optional	Minimum: 16 hrs; Maximum: 80 hrs
64	Major radial rift	4001, 4032, 4033, 4036, 4045, 4046, 4058, 4059, 4088	10 to 50	200	Optional (4047)	No	Minimum: 40 hrs; Maximum: 140 hrs
65	Wright Crater, interior domes	4032, 4038, 4039, 4044, 4045, 4046, 4057, 4058	0 to 5	60	No	No	Minimum: 20 hrs; Maximum: 80 hrs
66	Krasnov Crater (w/central peak)	4001, 4032, 4038, 4039, 4044, 4045, 4046	10	100	No	No	Minimum: 16 hrs; Maximum: 48 hrs
67	Lamarck D, Distal Cordillera fm. structures	4001, 4032, 4033 (1), 4038, 4045, 4046, 4058, 4088	20 to 30	75	Optional (4047)	No	Minimum: 16 hrs; Maximum: 80 hrs
68	Grimaldi, Rim and basalt floor	4001, 4032, 4038, 4039, 4044, 4045, 4046	10	100	Yes (4047)	No	Minimum: 16 hrs; Maximum: 65 hrs
69	Major radial crater chain	4001, 4032, 4038, 4039, 4044, 4045, 4046, 4058,	50	200	Yes (4039)	No	Minimum: 40 hrs; Maximum: 120 hrs

Table 5.1-3. Experiment Plan, Orientale LSB Site (continued)

No.	Experiment Sites	Preferred Experiments	Duration of Experiment Operation
	GEOPHYSICAL TRAVERSES		
	1st Level		
T.1	1-9-10-12-14-15-16-17-18-19-20-22-23	4045 & 4058 at periodic stops every 1 to 10 km of 5 minutes maximum duration; Shirtsleeves 4053 & 4057 in transit; continuous monitoring; shirt-sleeves 4046 and other EVA experiments at numbered sites as indicated or at intermediate sites as dictated by data analysis control group	Duration based upon transit speed of 3 to 4 km/hour and 15% additional for topographic obstacles. Five-minute stops every 1 to 10 km for 4045 and 4058, rest stops, and EVA stops at remote experiment sites.
T.2	1-4-5-6-30-33	Same as above	Same as above
T.3	1-9-28-29	Same as above	Same as above
	2nd Level		
T.4	39-40-41-42-43-44	Same as above	Same as above
T.5	46-47	Same as above	Same as above
T.6	29-27-25-24-16-31	Same as above	Same as above
T.7	1-34-35-36-36-38-66	Same as above	Same as above
T.8	1-34-35-36-57-58-65-61	Same as above	Same as above
T.9	33-50-51-52 (continuation of T.2)	Same as above	Same as above
T.10	23-62-63 (continuation of T.1)	Same as above	Same as above

Table 5.1-4. Experiment Plan, Mare Frigoris LSB Site

FIRST LEVEL EXPERIMENT SITES

Experiment Site	Features	Preferred Experiments	Experiment Site Mobility (SM)	Rock Sample Pickup (lb)	Deploy RGM	Return Visits	Duration of Experiment Operation
1	Crater chain in Mare Frigoris	4001, 4032, 4033, 4038, 4045, 4046, 4058, 4059, 4088	35	50	No	Optional	Minimum: 18 hrs; Maximum: 40 hrs
2	Highland steptoes or inliers in Mare	4001, 4032, 4033, 4038, 4045, 4046, 4058, 4059, 4088	50	120	No	Optional	Minimum: 18 hrs; Maximum: 40 hrs
3	Rime Archytas and Mare boundary	4001, 4032, 4033, 4038, 4045, 4046, 4058, 4059, 4088	40	80	No	Optional	Minimum: 18 hrs; Maximum: 48 hrs
4	Head of Alpine Valley, search for evidence of origin	4001, 4032, 4033, 4038, 4045, 4046, 4058, 4059, 4088	75	150	No	Optional	Minimum: 30 hrs; Maximum: 200 hrs
5	Egede, polygonal crater, locally breached	4001, 4032, 4033, 4038, 4044, 4046, 4088	50	100	No	Optional	Minimum: 20 hrs; Maximum: 48 hrs
5-6	Geophysical traverse	4045, 4046, 4058, 4053	0	30	No	Optional	Traverse Criteria *
6	Egede crater rim	4032, 4038, 4057	10	40	No	Optional	Minimum: 4 hrs; Maximum: 12 hrs
7	Rudementary ring structure	4032, 4033, 4038, 4045, 4046, 4058, 4059, 4088	150	100	No	Optional	Minimum: 18 hrs; Maximum: 150 hrs
8	Summit craters on rim of ring structure	4032, 4038, 4045, 4058	10	60	No	Optional	Minimum: 6 hrs; Maximum: 18 hrs
9	Crater Aristoteles, floor structures & alteration effects	4001, 4032, 4038, 4045, 4046, 4057, 4058	25	50	No	Optional	Minimum: 6 hrs; Maximum: 18 hrs
10	Wall stratigraphy and slump structures, Aristoteles	4032, 4038, 4057	20	150	No	No	Minimum: 6 hrs; Maximum: 36 hrs
11	Coarse crater rim material	4032, 4038, 4044, 4057	0	35	No	No	Minimum: 6 hrs; Maximum: 12 hrs
12	"Braided" facies, base surge deposits	4032, 4038, 4057	0	35	No	Optional	Minimum: 6 hrs; Maximum: 12 hrs
13	Pima Aristoteles: Mare stratigraphy, surface distal base surge deposits & RGM site	4001, 4032, 4033, 4038, 4045, 4046, 4053, 4058, 4059, 4088	15	200	Yes	Optional	Minimum: 40 hrs; Maximum: 120 hrs
14	Alpine Valley & Alpine Highland study	4032, 4038, 4045, 4046, 4053, 4057, 4058	40	140	No	Optional	Minimum: 18 hrs; Maximum: 48 hrs
15	Alpine Valley, end and Mare Imbrium contact	4032, 4033, 4038, 4045, 4046, 4058, 4059, 4088	30	100	No	Optional	Minimum: 18 hrs; Maximum: 60 hrs

*See Orientale Experiment Plan

Table 5.1-4. Experiment Plan, Mare Frigoris LSB Site (continued)

FIRST LEVEL EXPERIMENT SITES

Experiment Site	Features	Preferred Experiments	Experiment Site Mobility (SM)	Rock Sample Pickup (lb)	Deploy RGM	Return Visits	Duration of Experiment Operation
15-16	Geophysical traverse, edge of Imbrium Mare & mascon, Longitudinal to Alpine Valley	4045, 4046, 4053, 4058	0	25	No	Optional	Traverse criteria (70 miles)
17-18	Geophysical traverse on Mare Transverse to Alpine Valley	4045, 4046, 4053, 4058	0	25	No	Optional	Traverse criteria (35 miles)
19	Wrinkle ridge, rim of ghost ring	4032, 4033, 4038, 4045, 4046, 4058, 4059, 4088	5	100	No	Optional	Minimum: 18 hrs; Maximum: 40 hrs
19-20	Geophysical traverse, ghost crater	4045, 4046, 4053, 4058	0	30	No	Optional	Traverse criteria (70 miles)
21	Mons Pico, steptoe, high albedo material	4032, 4033, 4038, 4045, 4046, 4058, 4059, 4088	10	150	No	Optional	Minimum: 12 hrs; Maximum: 48 hrs
22	Mare exposures, Imbrium	4032, 4033, 4038, 4045, 4046, 4058, 4059, 4088	0	40	No	Optional	Minimum: 12 hrs; Maximum: 30 hrs
23	Teneriffe Mts., steptoes possible transient activity	4032, 4038, 4039, 4045, 4046, 4057, 4058	15	150	Optional	Optional (4039)	Minimum: 12 hrs; Maximum: 25 hrs
24	Marginal rilles, wrinkle ridges, seismic RGM	4001, 4032, 4033, 4038, 4046, 4047, 4059, 4088	15	120	Yes (4047)	Optional	Minimum: 18 hrs; Maximum: 36 hrs
24-25	Geophysical traverse, Imbrium border	4045, 4053, 4058	0	0	No	No	Traverse criteria (70 miles)
25	Sinuous Rille	4001, 4032, 4033, 4038, 4045, 4046, 4053, 4058, 4059, 4088	50	200	Optional	Optional	Minimum: 36 hrs; Maximum: 120 hrs
26	Outer rim of Plato, termination of sinuous rille, structure & stratigrafic exposures	4001. 4032, 4033, 4038, 4039, 4044, 4045, 4046, 4053	40	150	Optional (4039)	Optional	Minimum: 30 hrs; Maximum: 150 hrs
27	Inner walls of Plato and low albedo floor	4032, 4038, 4039, 4057	4	75	Yes (4039)	No	Minimum: 13 hrs; Maximum: 25 hrs
27-28-29	Geophysical traverse	4045, 4046 as req., 4053, 4058	0	50	No	Optional	Traverse criteria
30	Rima Plato II, rille network Alpine stratigraphy	4001, 4032, 4033, 4038, 4039, 4044, 4045, 4046, 4053	50	150	No	Optional	One to six Loci. Each: Minimum: 18 hrs Maximum: 45 hrs

Table 5.1-4. Experiment Plan, Mare Frigoris LSB Site (continued)

FIRST LEVEL EXPERIMENT SITES

Experiment Site	Features	Preferred Experiments	Experiment Site Mobility (SM)	Rock Sample Pickup (lb)	Deploy RGM	Return Visits	Duration of Experiment Operation
31	Rima Plato I, rille investigations, tectonic pattern	4001, 4032, 4033, 4038, 4044, 4045, 4046, 4053	10	100	No	Optional	Minimum: 18 hrs; Maximum: 45 hrs
32	Alpine lithology & tectonic lineations	4032, 4038, 4051, 4057	0	100	Optional	No	Minimum: 6 hrs; Maximum: 18 hrs
32-34	Geophysical traverse - Mare Figoris	4045, 4046, 4053, 4057, 4058	0	30	Optional	No	Traverse criteria
33	Mare Figoris - wrinkle ridges	4032, 4033, 4045, 4046, 4059, 4088	2	40	No	No	Minimum: 13 hrs; Maximum: 19 hrs
34	Archytas-Band rim. RGM site, Highland terrain	4001, 4032, 4033, 4038, 4044, 4047, 4053, 4059, 4088	0	100	Yes (4047)	Optional	Minimum: 18 hrs; Maximum: 50 hrs
34-35	Geophysical traverse, subdued crater, alternate RGM site at 35	4045, 4046, 4047, 4053, 4058	0	40	Optional	Optional	Traverse criteria
36	Archytas, young crater with central peak	4032, 4038, 4045, 4046, 4057, 4058	10	75	No	No	Minimum: 12 hrs; Maximum: 38 hrs
36a	Protagoras, young crater with central peak	4032, 4038, 4045, 4046, 4057, 4058	10	75	No	No	Minimum: 12 hrs; Maximum: 38 hrs
37	Intersection of: Mare-Alpine contact, Rima Archytas I and "highland" crater chain	4001, 4032, 4033, 4038, 4045, 4046, 4058, 4059	25	150	No	No	Minimum: 40 hrs; Maximum: 80 hrs
SECOND LEVEL OR ALTERNATIVE EXPERIMENT SITES							
38	Timaeus Crater, central peak, nearly breached	4032, 4038, 4045, 4046, 4057, 4058	5	40-80	No	No	Minimum: 6 hrs; Maximum: 18 hrs
39	W. Bond, ancient or subdued crater, possible caldera	4032, 4033, 4038, 4045, 4046, 4058, 4059, 4088	0	30-60	No	No	Minimum: 18 hrs; Maximum: 30 hrs
40	Anaxagoras, bright rayed crater elongate central range	4032, 4038, 4045, 4046, 4057	40	75	Optional	Optional	Minimum: 12 hrs; Maximum: 75 hrs
41	Ray material and base surge study	4032, 4038, 4045, 4046, 4057	40	75	Optional	Optional	Minimum: 6 hrs; Maximum: 18 hrs
42-43	Goldschmidt geophys. traverse	4045, 4046, 4053, 4058	0	25	No	Optional	Traverse criteria
44	Scoresby, symetrical central peak crater, highland terrain	4001, 4032, 4038, 4045, 4058	0	75	No	Optional	Minimum: 12 hrs; Maximum: 37 hrs

Table 5.1-4. Experiment Plan, Mare Frigoris LSB Site (continued)

SECOND LEVEL OR ALTERNATIVE EXPERIMENT SITES

Experiment Site	Features	Preferred Experiments	Experiment Site Mobility (SM)	Rock Sample Pickup (lb)	Deploy RGM	Return Visits	Duration of Experiment Operation
45	Median rim, Main and Challis twin craters	4001, 4032, 4038, 4045, 4058	10	50	No	No	Minimum: 12 hrs; Maximum: 30 hrs
46	N-S tectonic lineations, possible permanently shaded areas	4001, 4032, 4033, 4038, 4045, 4046, 4057, 4059, 4088	30	75	Optional	No	Minimum: 24 hrs; Maximum: 80 hrs
47	Linear segment of Byrd Crater rim	4001, 4032, 4033, 4038, 4045, 4046, 4057, 4059, 4088	0	50	Optional	No	Minimum: 20 hrs; Maximum: 60 hrs
48	Peary crater rim, permanently shaded sub crater	4001, 4032, 4033, 4038, 4045, 4046, 4057, 4059, 4088	0	200	Optional	Optional	Minimum: 30 hrs; Maximum: 100 hrs
49	North Pole	4001, 4032, 4033, 4038, 4044, 4045, 4046, 4047, 4050, 4051, 4053, 4055, 4057, 4059, 4088	50	150	Yes (4047)	Optional	Minimum: 50 hrs; Maximum: 200 hrs
50	Tectonic pattern, deep, shaded crater	4001, 4032, 4033, 4045, 4046, 4058, 4059, 4088	20	40	No	No	Minimum: 20 hrs; Maximum: 40 hrs
51	Philolaus Northeast; lunar transient phenomena and tectonic lineations	4001, 4032, 4033, 4039, 4045, 4046, 4058, 4059, 4088	40	50	Yes (4039)	Optional	Minimum: 18 hrs; Maximum: 40 hrs
52	Philolaus crater floor and central peak	4032, 4038, 4045, 4046, 4057, 4058	30	40	No	No	Minimum: 12 hrs; Maximum: 20 hrs
53	Crater wall and rim, slump blocks	4032, 4038, 4039, 4045, 4046, 4057, 4058	5	50	No	No	Minimum: 12 hrs; Maximum: 20 hrs

Table 5.1-5. Experiment Plan, Picard LSB Site

Experiment Site	Features	Preferred Experiments (Critical Experiments Underlined)	Experiment Site Mobility (SM)	Rock Sample Pickup (Lbs.)	Deploy RGM	Return Visits	Duration of Experiment Operation (Based on 3-4 Man Field Crew)
1	Picard Crater (Assymetric double crater with central peak)	<u>4032</u>, 4038, <u>4039</u>, 4044, 4057, 4058	31	150	No	1 Night	Minimum: 20 hrs. Maximum: 60 hrs.
2	Linear Rille terminating at craters	4001, <u>4032</u>, 4033, 4038, <u>4039</u>, 4045, 4046, 4057, <u>4058</u>, 4059, <u>4088</u>	6	25	No	Optional	Minimum: 18 hrs. Maximum: 50 hrs.
2-3	Mare Crisium Mascon Geophysical Traverse	<u>4032</u>, 4038, 4044, <u>4045</u>, <u>4046</u>, <u>4047</u>, 4053, <u>4057</u>, <u>4058</u>	None	300	Yes	No	IVA stop every 2 Km for instrument measurements (5 min.). On return trip (to base) seismic refraction (4046) at problem sites (approx. 4) 4 hrs. each (EVA). RGM at midpoint of traverse.
4	Concentric Faults	4001, 4032, 4033, 4038, 4044, 4045, 4053, 4057, 4058, 4059, 4088	31	35	No	No	Minimum: 36 hrs. Maximum: 80 hrs.
5-5	Concentric Highland Rim Geophysical Traverse	<u>4032</u>, 4038, 4044, <u>4045</u>, <u>4046</u>, 4053, 4057, <u>4058</u>	6	100	No	No	IVA stop every Km for instrument measurements (5 min.). On return trip, seismic refraction experiments (4046) at 3 problem areas, EVA.
6-6	Taruntius Crater Geophysical Traverse	<u>4045</u>, 4053, <u>4058</u>	12	150	No	No	IVA stop every 2 Km for instrument measurements (5 min.). EVA investigations on crater walls and central peak (Experiment Site 7's)
7	Tarantius Crater, concentric inner structures and central peak	4001, <u>4032</u>, 4033 (optional, shallow), 4038, 4039, <u>4044</u>, 4046, <u>4047</u>, 4057	31	150	Yes (1 only)	Optional (3 locations)	Minimum: 50 hrs. Maximum: 200 hrs. } at each location
8	Irregular shaped depressions	<u>4032</u>, <u>4033</u>, 4038, <u>4045</u>, 4056, 4058, 4059, <u>4088</u>	43	75	No		Minimum: 60 hrs. Maximum: 200 hrs.

Table 5.1-5. Experiment Plan, Picard LSB Site (continued)

Experiment Site	Features	Preferred Experiments (Critical Experiments Underlined)	Experiment Site Mobility (SM)	Rock Sample Pickup (Lbs.)	Deploy RGM	Return Visits	Duration of Experiment Operation (Based on 3-4 Man Field Crew)
9	Structures radial to Mare Crisium	4032, 4033, 4038, 4045, 4058, 4059, 4088	12	75	No	May be repeated at different locations	Minimum: 30 hrs. Maximum: 100 hrs.
10	Ridges and rilles concentric to Crisium	4032, 4033, 4038, 4045, 4058, 4059	47	300	No	May be repeated at different locations	Minimum: 30 hrs. Maximum: 100 hrs.
11	Crater Chain	4032, 4038, 4045, 4057, 4058	None	25	No	No	Minimum: 30 hrs. Maximum: 60 hrs.
12*	Cauchy Rille (Tectonic rift)	4001, 4032, 4033, 4038, 4044, 4045, 4047, 4057, 4058, 4059	25	50	No	Optional	Minimum: 50 hrs. Maximum: 75 hrs.
13	Intersection (breach) of Taruntius M and Cauchy I Rille	4032, 4038, 4045, 4058	6	75	No	No	Minimum: 24 hrs. Maximum: 80 hrs.
14	Low relief highland RGM site	4032, 4038, 4047, 4057	None	25	Yes	No	Minimum: 6 hrs. Maximum: 12 hrs.
14-15	Geophysical Traverse, longitudinal	4038, 4045, 4046, 4058			No	Local returns for active seismic expt.	Stops every 5 Km for measurement of regional fields.
15	Highland RGM Site	4001, 4032, 4038, 4047, 4057	None	250	Yes	No	Minimum: 6 hrs. Maximum: 40 hrs.
16-17	Geophysical Traverse Transverse to Structure	4032, 4038, 4044, 4045, 4046, 4053, 4057, 4058	6 @ #16 6 @ #17	10 @ #16 200 @ #17	No	No	IVA stops for instrument measurements (5 min.). On return trip, seismic refraction experiments (4046) at 3 problem areas, EVA.

* Traverse May Be Unmanned

Table 5.1-6. Experiment Plan, Schiller LSB Site

Experiment Site	Features	Preferred Experiments (Critical Experiments Underlined)	Experiment Site Mobility (SM)	Rock Sample Pickup (Lbs.)	Deploy RGM	Return Visits	Duration of Experiment Operation (Based on 3-4 Man Field Crew)
1	Interior Crater and Median Ridge	4001, 4032, 4038, 4044	37	150	No	Optional	Minimum: 48 hrs. for strat. studies; Maximum: 350 hrs. for geologic mapping
2-2'	Geophysical Traverse across Schiller	4032, 4033, 4038, 4044, 4045, 4046, 4053, 4057, 4058, 4059, 4088		300	No	Optional	Seismic refraction at 4 sites, 4 hrs. each. Drill core samples at 4 sites, 24 hrs. each. Stops (IVA) every 3 Km for gravity and magnetic measurements; every 1 Km at local anomalies.
3-3'	Geophysical Traverse perpendicular to 2-2'	4032, 4033, 4038, 4044, 4045, 4046, 4053. 4057, 4058, 4059, 4088		400	Yes, 2 locations	Optional	Seismic refractions at 2 sites, 4 hrs. each. Drill core samples at 2 sites, 24 hrs. each. Stops (IVA) every 3 Km for gravity and magnetic measurements; every 1 Km at local anomalies. One RGM at each end of the traverse.
4	Crater Wall	4001, 4032, 4038, 4057	12 at each of 2 sites.	75 at each of 2 sites.	No	Optional	Minimum: 6 hrs. Maximum: 60 hrs. } at each of 2 sites
5	Irregular Ridges	4001, 4032, 4033, 4038, 4044, 4057, 4059	9	50	No	Optional	Minimum: 18 hrs. Maximum: 30 hrs.
6	Noggerath Crater Rim (Linear fault features)	4001, 4032, 4033, 4037, 4038, 4044, 4088	25	60	No	Optional	Minimum: 100 hrs. Maximum: 250 hrs. for reconnaissance and drilling.
7	Pre Imbrian Hills south of Crater Rost.	4001, 4032, 4033, 4038, 4044, 4047, 4057	37	80	Yes	Optional	Minimum: 80 hrs. Maximum: 150 hrs. for surface reconnaissance
8-8'	Geophysical Traverse across Noggerath	4032, 4033, 4039, 4044, 4045, 4046, 4057 4058, 4059, 4088		150	No	Optional	Seismic refraction and drill samples at 4 sites. 28 hrs. total each. Stops (IVA) every 1 Km for gravity and magnetic measurements.
9	Wide Sinuous Ridge originating at Segner	4001, 4032, 4033, 4038, 4044, 4056, 4059	19	50	No	Optional	Minimum: 50 hrs Maximum: 250 Hrs.
10	Slump Features on size of Zuchius	4001, 4032, 4038, 4059	None	50	No	Optional	Minimum: 12 hrs. Maximum: 36 hrs.

Table 5.1-6. Experiment Plan, Schiller LSB Site (continued)

Experiment Site	Features	Preferred Experiments (Critical Experiments Underlined)	Experiment Site Mobility (SM)	Rock Sample Pickup (Lbs.)	Deploy RGM	Return Visits	Duration of Experiment Operation (Based on 3-4 Man Field Crew)
11	Rost B - Schiller Alignment	4001, <u>4032</u>, 4033, 4038, 4044, 4057, 4059	50	150	No	Optional	<u>Minimum:</u> 48 hrs. <u>Maximum:</u> 150 hrs.
12	Weigel D Tectonic Lineation	4001, <u>4032</u>, 4033, 4038, 4044, 4059, 4088	19	100	No	Optional	<u>Minimum:</u> 36 hrs. <u>Maximum:</u> 150 hrs.
13	Northwest Treading Lineation across the Schiller Basin	<u>4032</u>, 4033, 4038, 4053, 4057	62	80	No	Optional	<u>Minimum:</u> 38 hrs. <u>Maximum:</u> 65 hrs.
14	Linear Fault Scarp Feature	4001, <u>4032</u>, 4033, 4039, 4044, <u>4047</u>, 4057	16	200	Yes	Optional	<u>Minimum:</u> 60 hrs. <u>Maximum:</u> 200 hrs.
15	Drebel G (Linear Tectonic Features)	4001, <u>4032</u>, 4033, 4038, 4044, 4059, 4088	19	100	No	Optional	<u>Minimum:</u> 80 hrs. <u>Maximum:</u> 250 hrs.
16	Crater Wall	4001, <u>4032</u>, 4038, 4057	12	75	No	Optional	<u>Minimum:</u> 6 hrs. <u>Maximum:</u> 60 hrs.
17	Crater Wall	4001, <u>4032</u>, 4038, 4057	12	75	No	Optional	<u>Minimum:</u> 6 hrs. <u>Maximum:</u> 60 hrs.
18	Crater Wall	4001, <u>4032</u>, 4038, 4057	12	75	No	Optional	<u>Minimum:</u> 6 hrs. <u>Maximum:</u> 60 hrs.

Table 5.1-7. Experiment Plan, Hadley LSB Site

Experiment Site	Features	Preferred Experiments (Critical Experiments Underlined)	Experiment Site Mobility (SM)	Rock Sample Pickup (LBS)	Deploy RGM	Return Visits	Duration of Experiment Operation (Based on 3-4 Man Field Crew)
1	Rima Hadley (sinuous rille)	4001, 4032, 4038, 4039, 4057	None	200	No	Optional for LTA	Minimum: 20 hrs Maximum: 200 hrs
2	Terminations of Rima Hadley	4032, 4033, 4038, 4039, 4045, 4046, 4057, 4058, 4059, 4088	31	120	No	No	Minimum: 48 hrs Maximum: 250 hrs
3	Mt. Hadley & Range & Geol. traverse up valley from (2)	4001, 4032, 4039, 4044, 4053, 4057	62	200	Yes	No	Minimum: 60 hrs Maximum: 200 hrs
4	Front ridge, west of Rima Hadley	4032, 4033, 4038, 4044, 4057	25	50	No	No	Minimum: 20 hrs Maximum: 60 hrs
5	Structural features: linear ridges & fracture patterns	4032, 4033, 4038, 4045, 4057, 4058, 4088	62	150	No	No	Minimum: 40 hrs (2 sites) Maximum: 140 hrs
6	Caucasus Range, General geology and structure	4001, 4032, 4038, 4045, 4047, 4057, 4058	19	120	Yes	No	Minimum: 10 hrs Maximum: 60 hrs
7	Caucasus Range. Fault to the north	4001, 4032, 4038, 4045, 4057, 4058	19	75	No	No	Minimum: 10 hrs Maximum: 60 hrs
8	Mare rocks & stratigraphy NW Mare Serenetatus	4001, 4032, 4033, 4038, 4044, 4045, 4046, 4088	None	100	No	No	Minimum: 80 hrs Maximum: 230 hrs
9	Palus Putredinis, Mare rocks & stratigraphy	4001, 4032, 4033, 4038, 4044, 4045, 4046, 4088	None	100	No	No	Minimum: 80 hrs Maximum: 230 hrs
10	Rilles, straight, structural features	4001, 4032, 4038, 4045, 4058	None	75	No	No	Minimum: 80 hrs; Maximum 200 hrs each site (NOTE: 3 sites)
11-11'	Small mascon, geophysical traverse	4032, 4038, 4044, 4045, 4046, 4047, 4053, 4058	None		Yes	No	Stop every 1 Km for IVA. Emplace passive seismic station at 11. RGM at SE end of Traverse
11 & 11'	At traverse end points	4033, 4039 (Two 100-ft drill holes on traverse) 4088				No	Minimum: 50 hrs; Maximum 70 hrs for EVA

Table 5.1-7. Experiment Plan, Hadley LSB Site (continued)

Experiment Site	Features	Preferred Experiments (Critical Experiments Underlined)	Experiment Site Mobility (SM)	Rock Sample Pickup (LBS)	Deploy RGM	Return Visits	Duration of Experiment Operation (Based on 3-4 Man Field Crew)
11'-12	Mare-Appenine Mt. Front Geophysical Survey	<u>4033</u>, 4038, <u>4044</u>, <u>4045</u>, <u>4058</u>, <u>4046</u>, 4053, <u>4088</u>	None	75	No	No	5-10 min. stops each Km for IVA
13-13'	Mass Deficiency Southeast Mare Imbrium	<u>4038</u>, <u>4045</u>, <u>4047</u>, <u>4053</u>, 4057, 4058			Yes	Single Traverse	5 or 10 min. IVA stops each Km. Smooth terrain, RGM at SW end of traverse.
13 & 13'	Traverse end points	4032, <u>4033</u>, 4038, <u>4044</u>, <u>4046</u>, <u>4059</u>, <u>4088</u>					2 boreholes 100 ft deep & 2 seismic refraction/reflection (expt. 4046) at problem sites on traverse. <u>Minimum</u>: 40 hrs; <u>Maximum</u>: 240 hrs.
14	Highland Craters, Coron & Aratus	4032, 4038, 4047, 4057, 4058	None	50	Yes	No	<u>Minimum</u>: 28 hrs; <u>Maximum</u>: 60 hrs. (2sites)
15	Crater Rim & Floor, Archimedes, (2 or more sites)	<u>4001</u>, <u>4032</u>, <u>4038</u>, 4057	None	150	No	No	<u>Minimum</u>: 12 hrs. <u>Maximum</u>: 60 hrs. (2 sites)
16	Crater Rim & Interior Autolycus, (2 or more sites)	<u>4001</u>, <u>4032</u>, <u>4038</u>, 4057	None	150	No	No	<u>Minimum</u>: 12 hrs. <u>Maximum</u>: 60 hrs. (2 sites)
17*	Fault Scarp, structural lineoments (with transverse goephysical traverse)	4001, 4032, 4038, <u>4045</u>, <u>4046</u>, <u>4053</u>, <u>4057</u>, <u>4058</u>	47	50	No	No	<u>Minimum</u>: 28 hrs. <u>Maximum</u>: 60 hrs. (2 sites)
18-18'	Archimedes geophysical traverse	4032, 4038, <u>4044</u>, <u>4045</u>, <u>4046</u>, <u>4058</u>	None	200	No	Optional	Same requirements as traverse 11-11'
19	Archimedes crater floor	4032, 4038, 4039, 4044, <u>4047</u>	None	20	Yes	No	<u>Minimum</u>: 6 hrs. <u>Maximum</u>: 12 hrs.
20	Archimedes, NW Wall	<u>4032</u>, 4038, 4057	62	200	No	No	<u>Minimum</u>: 18 hrs. <u>Maximum</u>: 60 hrs.

* Traverse May Be Unmanned

Table 5.1-8. Experiment Plan, Aristarchus LSB Site

Experiment Site	Features	Preferred Experiments (Critical Experiments Underlined)	Experiment Site Mobility (SM)	Rock Sample Pickup (LBS)	Deploy RGM	Return Visits	Duration of Experiment Operation (Based on 3-4 Man Field Crew)
1	Schroeters Valley, Upper (Sinuous rille and incised rille)	4001, <u>4032</u>, 4033, 4038, 4039	30	200 (200 more on subsequent visits)	No	Optional	<u>Minimum</u>: 36 hrs for stratig. studies <u>Maximum</u>: 300 hrs for mapping upper valley walls
2	Plateau, west of Schroeter's Valley (Volcanic plateau)	4001, 4033, 4038, 4044, 4088	0	25	No	Optional	<u>Minimum</u>: 48 hrs
3*	Cobra Head (Crater-like point of origin of Schroeter's Valley)	4001, <u>4032</u>, 4033, <u>4039</u>, 4045, 4046, 4047, 4057, <u>4058</u>, 4088	15	200	Yes		Four Operations: (1) Geo. in Cobra Head: <u>Minimum</u>: 36 hrs, <u>Maximum</u>: 200 hrs; (2) Instrument emplacement: <u>Minimum</u>: 2 hrs; (3) Geophys. traverse west plateau: <u>Minimum</u>: 12 hrs; (4) Geophys. traverse east plateau: <u>Minimum</u>: 12 hours
4	Aristarchus Crater (Med. large crater w/central peak)	4001, <u>4032</u>, 4038, <u>4039</u>, 4057, 4044, 4045, 4046, 4047, <u>4058</u>	100	250	Yes	Include 1 night sortie	<u>Minimum</u>: 40 hrs; <u>Maximum</u>: 200 hrs
5	Aristarchus Hills (Patterned upland topography north of Aristarchus)	4001, <u>4032</u>, 4038, 4058, 4045	40	200	No	Optional	<u>Minimum</u>: 80 hrs; <u>Maximum</u>: 400 hrs in the ridge and rille country
6	Domes of the Aristarc. Plat. (Elongate domes of volcanic plat.)	4001, <u>4032</u>, <u>4033</u>, <u>4038</u>, 4059	40	250	No	Include 1 night sortie	<u>Minimum</u>: 80 hrs; <u>Maximum</u>: 150 hrs, drilling and surface reconnaissance
7*	Middle Schroeter's Valley (Wide sinuous rille)	4001, <u>4032</u>, 4033, 4057, 4045, 4046, 4059	90	300	No	Optional	<u>Minimum</u>: 28 hrs; <u>Maximum</u>: 100 hrs
8*	Lower Schroeter's Valley (Low linear/sinuous rille)	4001, 4032, 4033, 4038, 4057, 4045, 4046, 4047, 4058, 4059, 4088	150	250	Yes	Include 1 night sortie	<u>Minimum</u>: 28 hrs; <u>Maximum</u>: 100 hrs
9	Structural patterns and irregular depressions	4001, 4032, <u>4033</u>, 4038, 4044, 4045, 4046, 4057, 4058, 4059	20	150	No	Optional	<u>Minimum</u>: 40 hrs; <u>Maximum</u>: 200 hrs
10	Wrinkle ridges and structures	4001, 4032, 4033, 4044, 4045, 4046, 4053, 4057, 4058, 4059, 4088	None	125	No	Optional	<u>Minimum</u>: 24 hrs; <u>Maximum</u>: 40 hrs

* Traverse May Be Unmanned

Table 5.1-8. Experiment Plan, Aristarchus LSB Site (continued)

Experiment Site	Features	Preferred Experiments (Critical Experiments Underlined)	Experiment Site Mobility (SM)	Rock Sample Pickup (LBS)	Deploy RGM	Return Visits	Duration of Experiment Operations (Based on 3-4 Man Field Crew)
11	Crater with volcanic Somma Ring	<u>4032</u>, 4038, 4039, 4045, 4046, 4058	None	150	No	Optional	<u>Minimum</u>: 12 hours
12-12'	Geophysical traverse across Mascon	4038, 4044, <u>4045</u>, <u>4046</u>, <u>4058</u>, <u>4047</u>, 4053, <u>4057</u>	None	250	Yes (2 locations)	Optional	430 Km one way, 3 Km/hr. Seismic refraction at 3 sites, 4 hrs each; stops (IVA) every 1 Km for grav. and mag. meas.
13	Ghost ring and pre-imbrian topography	4032, 4038, 4044, 4047, 4053, 4057	70	300	No	Optional	<u>Minimum</u>: 18 hrs; <u>Maximum</u>: 200 hrs
14	Elongate craters, depressions and winkle ridges	4032, 4038, 4039, 4044, 4045, 4058, <u>4057</u>	25	50	No	Optional	<u>Minimum</u>: 18 hrs; <u>Maximum</u>: 30 hrs
15	Tectonic rille and end of Schroeter's Valley rille	4001, <u>4032</u>, 4033, 4038, 4045, 4053, 4058, 4059, 4088	50	100	No	Optional	<u>Minimum</u>: 24 hrs; <u>Maximum</u>: 200 hrs (with drilling)

Table 5.1-9. Experiment Plan, Copernicus LSB Site

Experiment Site	Features	Preferred Experiments (Critical Experiments Underlined)	Experiment Site Mobility (SM)	Rock Sample Pickup (LBS)	Deploy RGM	Return Visits	Duration of Experiment Operation (Based on 3-4 Man Field Crew)
1-2	Geophysical traverse across Copernicus and mass deficiency area	4032, 4033, 4038, 4039, 4044, 4045, 4046, 4047, 4058, 4057, 4088, 4059	62	350	Yes (2 req'd)	None	IVA stop every 1 Km for measurements. Seismic reflections and drill cores at 2 locations, 28 hrs each. Emplace RGM on central peak bedrock and at Experiment Site #2.
3	Irregularly Shaped Fault Valley	4001, 4032, 4039, 4044	25	150	No	None	Minimum: 50 hrs; Maximum: 200 hrs
4	Tobias Mayer C (Circular crater with Somma Ring)	4001, 4032, 4039, 4044, 4033	28	150	No	None	Minimum: 20 hrs; Maximum: 80 hrs
5	Domes north of Hortensius	4001, 4032, 4033, 4039, 4044, 4045, 4046, 4057, 4088	62	200	No	1 night sortie	Minimum: 50 hrs; Maximum: 200 hrs
6	Linear, diverging ridges	4001, 4032, 4033, 4039, 4044, 4088	50	50	No	None	Minimum: 20 hrs; Maximum: 60 hrs
7	Reinhold (Peak on crater slope)	4001, 4032, 4033, 4039, 4044, 4047, 4057, 4088	6	100	Yes	1 night sortie	Minimum: 30 hrs; Maximum: 80 hrs
8	Gambart (Hexagonal crater with interesting tectonic patterns to the west)	4001, 4032, 4039, 4044	28	100		None	Minimum: 25 hrs; Maximum: 75 hrs
9	Gambart BA (Circular crater with sinuous ridges)	4001, 4032, 4039, 4044, 4047	6	80	Yes	None	Minimum: 25 hrs; Maximum: 70 hrs
10-10'	Traverse across bifurcating wrinkle ridge	4001, 4032, 4033, 4044, 4045, 4058, 4088	None	75	No	None	EVA stops required at several (8) locations for detailed terrain study. Other specs. same as 1-2.
11	Crater Chain	4001, 4032, 4039, 4044	None	75	No	None	Minimum: 30 hrs; Maximum: 80 hrs
12-12'	Geophysical traverse across Eratosthenes	4032, 4038, 4039, 4044, 4045, 4046, 4058, 4057	None	200	No	None	IVA stop for every 5 Km for measurements. Seismic reflections at 2 locations, 5 hrs each.
13	Crater Chain	4001, 4032, 4039, 4044	None	100	No	None	Minimum: 80 hrs; Maximum: 250 hrs
14	Rima Stadius, N-S trending crater chain	4001, 4032, 4039, 4044, 4047	25	150	Yes	1 night sortie	Minimum: 12 hrs; Maximum: 150 hrs
15	Intersection of N-S & NW trending rift valleys	4001, 4032, 4044	37	200	No	None	Minimum: 75 hrs; Maximum: 225 hrs
16	Rima Stadius II	4001, 4032, 4039, 4044, 4047	31	100	No	None	Minimum: 12 hrs; Maximum: 100 hrs
17	Copernicus Walls	4032, 4038, 4039, 4057	124	300+	No		Minimum: 42 hrs; Maximum: 100 hrs (4 sites)

science tasks based on a four-man crew is given. This is based on similar tasks with terrestrial field survey parties. A contingency minimum and normally desirable maximum limits are shown. All subsequent mission planning is based on the maximum times. The estimates are shown as elapsed science time required, the man-hours would be four times higher, and the total time required is a function of the crew work scheduling.

Primary sites and secondary sites are identified only for Orientale and Frigoris due to the larger number of sites which are suitable for exploration. The primary sites are those which should be explored in direct support of the mission objectives related to understanding the origin and evolution of the moon and the solar system. Secondary sites are interesting features which should be visited, once at the LSB site, in possible support of the objectives. Secondary sites alone, therefore, would not justify an LSB mission.

5.1.3 Typical Remote Site

In order to develop procedures and time lines for planning the remote site expeditions and for designing the equipment required, one of the remote sites was chosen for a more detailed study. The experiment site, Number 8 in the Aristarchus LSB plan (Table 5.1-8) is considered typical in all important respects - its experiment plan is typical, it has a typical set of geologic features to be investigated near the central location, and its distance from the LSB site and topographic problems expected are also considered typical.

Typical Experiment Group

The experiments to be performed at Aristarchus 8 include the following:

4001 Life detection
4032 Geological mapping and analysis
4033 Drilling and sampling
4038 Mineralogical and chemical analysis in situ
4045 Gravity profiling
4046 Seismic profiling
4047 In situ measurements of natural radiation spectrum
4058 Magnetic profiling
4059 Borehole logging
4088 Heat flow

The time line (Figure 5.1-10) displays experiment performance and a preferred sequence of operation. Each numbered division on the time line represents a single 10-hour work day with the activity bars to scale. Between each work day is a 14-hour period dedicated to housekeeping and sleeping. In preparing this time line, the following general ground rules were observed:

1. A mobile laboratory is used for transport.

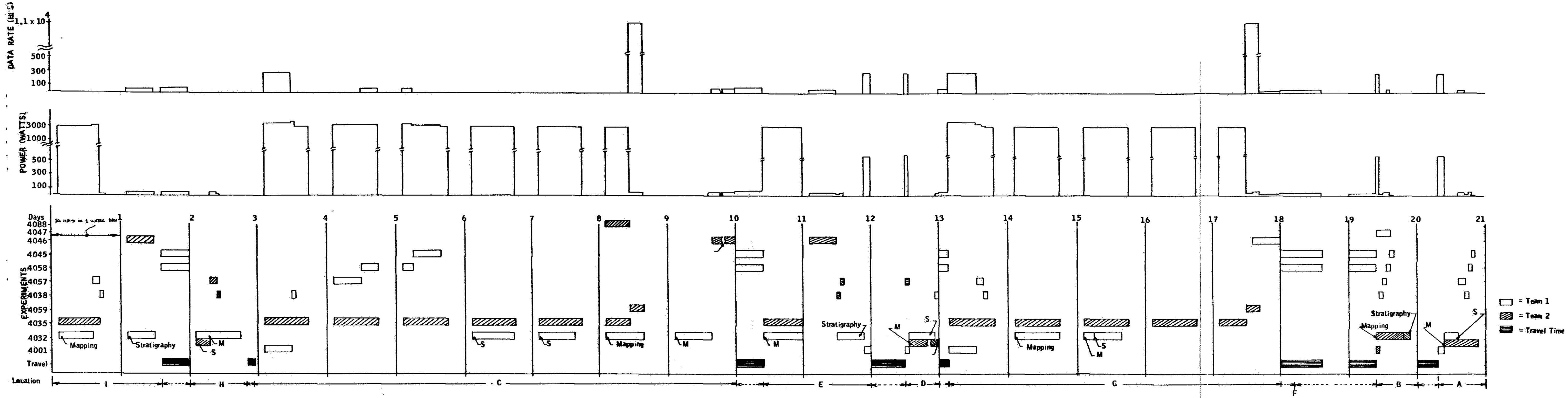


Figure 5.1-10. Typical Remote Site Exploration Timeline

2. Crew complement consists of four men in two-man teams.

3. Travel speed of the mobile laboratory is approximately two miles per hour, stopping each kilometer (0.62 miles) for a five-minute period of IVA data taking.

4. Travel time is limited to six hours per working day.

5. Normal working day consists of ten hours maximum.

6. EVA time shall be limited to six and one-half hours per day with one additional hour of preparation for each EVA.

7. Maximum power available for science is 30 kilowatt-hours per day (five kilowatts for six hours daily).

A solid bar represents travel time. Travel was limited to six hours maximum and one hour minimum. Therefore, if a work day allowed for only a one-half hour travel, no travel was scheduled until the next day. The individual experiment sites are indicated by letter and can be correlated with the experiments and path in Table 5.1-10 and Figure 5.1-11, respectively.

Table 5.1-10. Typical Remote Site Experiments

Experiments	EVA Stops									Traverses		
	A	B	C	D	E	F	G	H	I	C-E	D-F	H-I
4001 - Life Detection	X	X	X	X	X		X					
4032 - Stratig/Mapping	X	X	X	X	X		X	X	X			
4033 - Drilling			X		X		X		X			
4038 - Min/Chem Anal	X	X	X	X	X		X	X	X			
4045 - Gravity Profile	X	X	X							X	X	X
4046 - Seismic Profile			X		X		X		X			
4047 - Seismicity		X										
4057 - Natural Radiation	X	X	X	X	X		X	X	X			
4058 - Magnetic Profile	X	X	X							X	X	X
4059 - Borehole Logging			X				X					
4088 - Heat Flow			X									

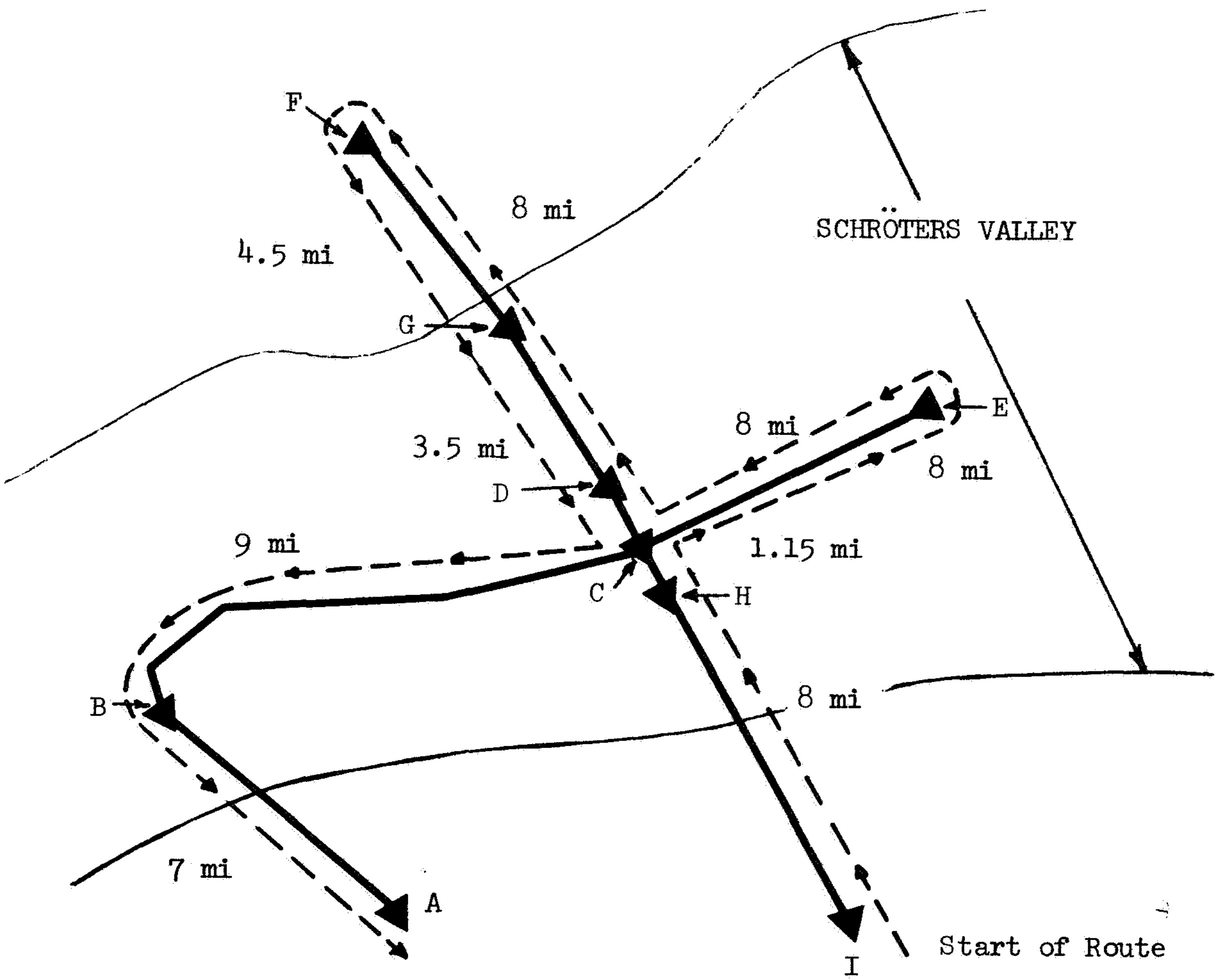


Figure 5.1-11. Typical Remote Site Exploration
(Aristarchus No. 8)

Team activity is shown as either a clear or cross-hatched bar. The significance here is that a team performs those experiments on the day for which they are designated, but there is no firm rule requiring one crew to continuously perform one experiment to its conclusion. The teams can and do relieve each other. Note that Experiment 4032 consists of two related yet distinct tasks: (1) stratigraphy; and (2) surface mapping and analysis. In certain instances such as this where two activities are performed concurrently a double time line is shown for this experiment.

In many cases, an experiment follows another directly with no time indicated for preparation. In such cases, it is assumed the total experiment time allows for preparation. The EVA work day in all cases begins with the second hour of a seven-hour period. The first hour is for EVA preparation.

This schedule, assuming the ground rules indicated, requires approximately 21 ten-hour days for this site.

Electrical power in watts and data rate in bits per second are also included above the experiment operational period. It is noted that of remote site experiments the largest power is consumed by Experiment 4033 (Subsurface Drilling and Sampling), and the largest data producer is Experiment 4059 (Subsurface Logging). At no time, however, does any requirement exceed the capability stated in the ground rules.

5.1.4 Shelter Site Selection

The preferred shelter location is shown on the site maps as a light triangle within a dark circle. The criteria for selection of the shelter site were: (1) minimum travel time and en route consumables between the shelter and the experiment sites; (2) proximity to the observatory and deep drilling sites; (3) open terrain for approach and landing by resupply vehicles; (4) smooth hard surface for landing; (5) prominent landmarks nearby for surface and flight navigation aids; and (6) favorable natural environment in terms of minimum RF noise, dust, and seismic activity.

Criterion (1) was the major factor in the general location, while the others were considered to select the precise spot. The general location was determined by computing the centroid of the experiment sites, weighting each site with its maximum science time. It was assumed that the weighted centroid would result in the minimum total distance, and hence, the minimum time and consumables. The centroid could be established to within about ± 2 miles on the map in this way. Several sites were checked for the effect of using the minimum science time and this location was found to lie within ± 10 miles of the other. The average LSB exploration area is about 400 miles in diameter. It was also found that the unweighted centroids also fell within ± 10 miles of the centroid weighted by science time indicating a degree of independence.

If the centroid location satisfied the remaining criteria that location was selected; if, for example, the centroid occurred on a mountain peak, the location was shifted to satisfy as many of the remaining criteria as possible.

5.1.5 Mission Route Selection

In order to define the performance requirements for remote exploration missions utilizing surface transportation, routes were established between the shelter and the experiment sites. The criteria for route selection fell in two categories -- the exploration philosophy and those governing path geometry.

The exploration philosophy embodies the following concepts. The exploration pattern will consist of a number of detailed explorations -- at the remote experiment sites and the shelter as an experiment site -- all interconnected into a complete LSB site network through the geophysical data gathered continuously during the enroute travel, both outbound and inbound. Each LSB site will deploy three or more RGM's as widely and equally spaced as possible about the perimeter of the site to provide the widest coverage of passive seismic events.

The path geometry criteria would ideally be limited to radial outbound and inbound legs but the lunar topography prohibits this simple route for surface vehicles. Flyers of course, would travel radially and these distances were also measured for use in the mission trade studies. For the surface vehicle transportation approach, the path geometry was selected as follows. The outbound leg was the most direct route, considering the topography, to the experiment site in order to minimize the use of consumables to the site and to provide a marked route back to the shelter for quickest emergency return. The inbound leg was considered more flexible and could proceed to additional sites if consumables permitted, could return by another route to gather additional network data, could revisit previous sites for revalidation of data, or could continue to targets of opportunity observed outbound but not covered in the experiment plan. The final path geometry criteria were to minimize contour corssings and to avoid completely any slopes greater than 30 degrees.

The routes selected are shown on the LSB site maps presented earlier in this section. An additional criterion was added after the first (Aristarchus) site analysis to further minimize the travel time. This criterion was to design all missions to basically the same total duration and to cover as many sites as possible on a single mission. Thus, after Aristarchus, most missions explore more than one experiment site thus eliminating most of one inbound and another outbound leg.

To determine the time required to explore all the remote sites at a given LSB site, the following assumptions were made: missions would be scheduled to provide a maximum of driving time under daylight conditions, but arrival at the first experiment site would occur at lunar dawn; driving would proceed at a constant average velocity through the lunar day despite sun angle and feature washout; the driving would continue at night though at a reduced speed; that successive missions would be scheduled within two weeks after completion of the previous one; and that a 10 percent increase would be added to the driving time as a contingency for enroute maintenance and repair. A preliminary assessment of the guidance and navigation concepts for lunar surface travel is contained in Appendix D.

Five of the seven LSB sites were analyzed in detail to create the data for the mathematical site model. Orientale and Frigoris were not analyzed in the same detail because the only maps available were to a five times larger scale and lacked the required resolution. The mathematical model developed from the analysis of the other five sites was used to predict probable requirements for these larger sites.

For Aristarchus, Picard, Schiller, Hadley, and Copernicus the map routes selected were analyzed in detail to determine the latitude, longitude and elevation of each shelter site and each experiment site, the outbound and inbound distances, and the radial distance. The number of miles spent on 0 to 10-degree, 10 to 30-degree, and over 30-degree slopes and the mileage on smooth (mare) and rough (highland) terrain were estimated and used to compute the adjusted travel distance, i.e., the map miles corrected for terrain and slopes. Over 100 surface missions were analyzed.

In addition, the science payload characteristics such as weight, power, volume, and data rates were defined for these missions. The results of these analyses are summarized in Table 5.1-11 for the above sites. Based on the LAC maps, some travel at slopes slightly in excess of 30 degrees seemed unavoidable. These distances are shown in Table 5.1-12. While it is clear that the surface mobility vehicles will have to have high mobility, it was basically assumed that these steep slope areas can be negotiated by careful route planning utilizing higher resolution data than that currently available.

5.1.6 LSB Site Model

These and other characteristics of the remote exploration missions were summarized in histograms and probability distributions and are contained in Appendix E to this volume. From these plots, quanitative mission performance requirements were computed from the equation

$$\int_{0}^{DP} Fx \, dx = .95 \int_{0}^{X_{max}} Fx \quad dx$$

Where Fx is the mission variable on the histogram

X_{max} is the maximum value of the variable

DP is the design point selected for the variable

This equation defines the design point to be that value of the mission variable which will permit 95 percent of the product of missions (sorties/sites) and the variables to be accomplished. It also rejects extreme variations such as unusually distant sites or lengthy experiment durations which would result in oversized consumables tanks and structures and therefore impose excessive weight on 95 percent of the missions.

Table 5.1-11. Mission Requirements for the LSB Sites

Parameter	Aristarchus	Picard	Schiller	Hadley	Copernicus
Science time (hours)	2116	1501	2181	3052	1862
Number of experiments	115	117	115	134	93
Number of experiment sites	14	16	16	27	14
Number of sorties	15	8	11	20	9
Number of traverses	1	5	3	4	3
Return payload (pounds)	3225	2395	2295	3285	2380
Travel at experiment sites (statute miles)	635	306	353	466	549
Maximum radius from shelter (statute miles)	295	304	204	237	217
Enroute distance* (statute miles)	2838	3694	3803	3940	3456
Mission duration** (days)	848	619	851	1150	714
Mission duration** (years)	2.3	1.7	2.3	3.2	2.0

* Actual map miles uncorrected for terrain roughness or slopes

** Includes driving, science, enroute maintenance, and between mission turnaround times

Table 5.1-12. Travel on Slopes Exceeding 30 Degrees

SITE	TOTAL MILEAGE (SM)	TYPE OF TERRAIN					
		CRATERS		RIDGES		VALLEYS	
		SM	%	SM	%	SM	%
ARISTARCHUS	25.8	12.3	47	11.6	45	1.9	6
PICARD	2.5	0.6	24	1.0	40	0.9	36
SCHILLER	CONTOURS NOT IDENTIFIED ON MAP	-	-	-	-	-	-
HADLEY	15.8	10.4	66	5.1	32	0.3	2
COPERNICUS	16.6	16.6	100	-	-	-	-
TOTAL	60.7	39.9	66	17.7	29	3.1	5

The principal mission requirements for Orientale and Frigoris were established by utilizing the LMP-1, -2, and -3 series lunar charts and identifying worthy geophysical experiment site based on examination of the maps and Lunar Orbiter photographs. As indicated on the site experiment plans (Tables 5.1-3 and 5.1-4), Orientale and Frigoris have several times the number of sites and traverses as the other sites. The site mathematical model was used to project the mission parameters for these larger sites and the pertinent results are shown in Table 5.1-13. Essentially, the new sites contain about four times as many sites, are twice as large in area, and require about three times as long to explore. A single central site at Orientale is preferred to separate sites at the primary and secondary regions as the additional expense of a second LSB does not save enough driving time to justify it. The reverse may be true at Frigoris. The reason for these choices is that the sum of the driving times from the primary LSB site to the primary experiment sites and from the secondary LSB site to the secondary experiment sites is approximately equal to driving time to both sets of experiment sites from a third, central LSB site for Orientale, but not so for Frigoris. With Frigoris, the sum of primary site and secondary site driving times is 562 days less than using a single site to do all sorties. In this case, an economic tradeoff is required to determine if the cost of installing an additional LSB at one of the sites is favorable compared to the cost of the increased mission duration utilizing a single LSB.

5.1.7 Functional Requirements

Functional flow diagrams were prepared for the typical remote exploration mission, Figure 5.1-12, and for a traverse segment of the typical mission, Figure 5.1-13, or a discrete experiment site segment of a typical mission, Figure 5.1-14. These diagrams were used to insure that all essential tasks had been identified, that time estimates were complete so that timelines could be prepared, and to estimate manpower requirements and determine the crew size. From these requirements, a crew size of four has been selected in order to provide two, 2-man teams.

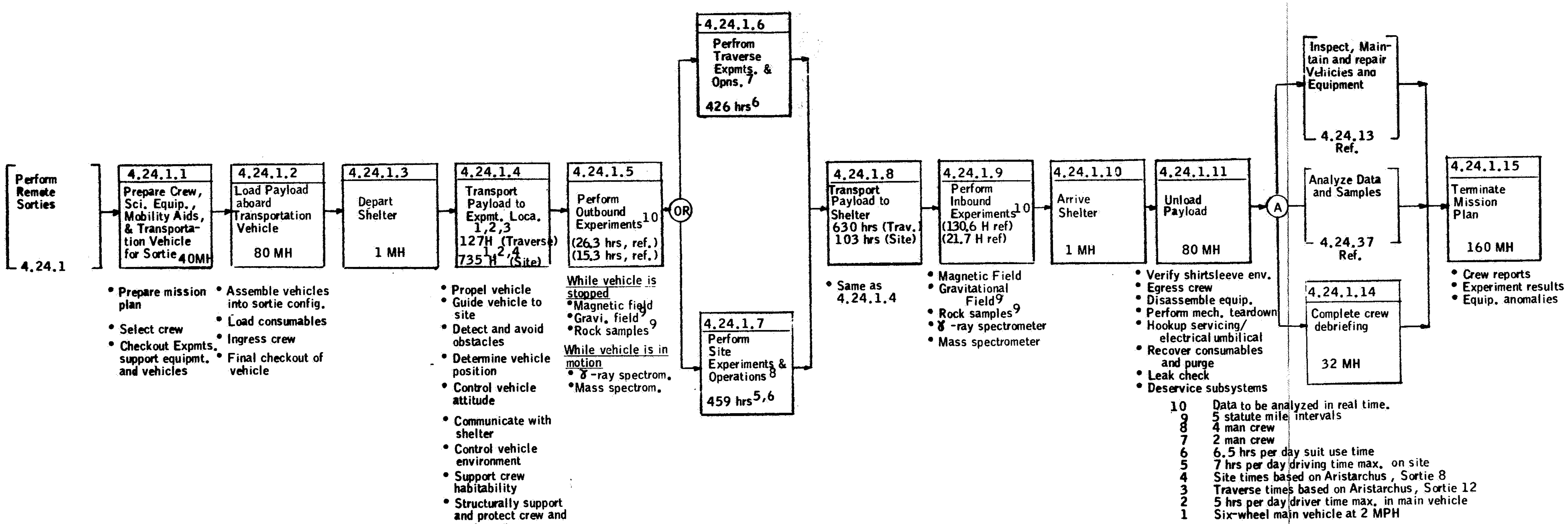
5.1.8 Timelines

Mission timelines were prepared for all the surface sorties except those on Orientale and Frigoris and are given in Appendix E. These plots were used to determine mission durations based on the data defined in Section 5.1.5. Total LSB remote sortie exploration mission durations vary from a low of 619 days at Picard to a high of 1150 days at Hadley or a range from about 1-1/2 to 3 years to accomplish all of the remote exploration. An inspection of the timelines shows that the constant mission duration criterion was not always well satisfied. Utilization of the vehicles and crew could be optimized through improved mission planning using the timeline data to reroute and combine the shorter missions. For the two larger sites, Orientale and Frigoris, the missions, as shown in Table 5.1-13, are considerably longer. They range from 4.9 years for the primary sites at Frigoris to 8.9 years for all the sites at Orientale.

Table 5.1-13. Mission Requirements for Orientale and Frigoris

MISSION PARAMETERS	5 LSB SITES		ORIENTALE			FRIGORIS		
	Average	Maximum	Primary	Secondary	Both	Primary	Secondary	Both
DRIVING TIME (DAYS)	221	263	402	783	1221	631	166	1359
SCIENCE TIME (DAYS)	330	470	649	592	1241	726	248	974
EXPERIMENTS	115	134	253	268	521	252	110	362
EXPERIMENT SITES	17.4	27	34	31	65	38	13	51
SORTIES	12.6	20	25	22	47	27	11	37
TRAVERSES	3.2	5	3	7	10	8	1	9
MAX. RADIUS FROM SHELTER (SM)	106.5	230	262	493	500	231	197	582
MISSION DURATION* (DAYS)	836	1150	1441	1761	3242	1798	585	2991
MISSION DURATION* (YEARS)	2.3	3.2	3.9	4.8	8.9	4.9	1.6	8.2

*DRIVING + SCIENCE + FIELD M&R + OVERHAULS



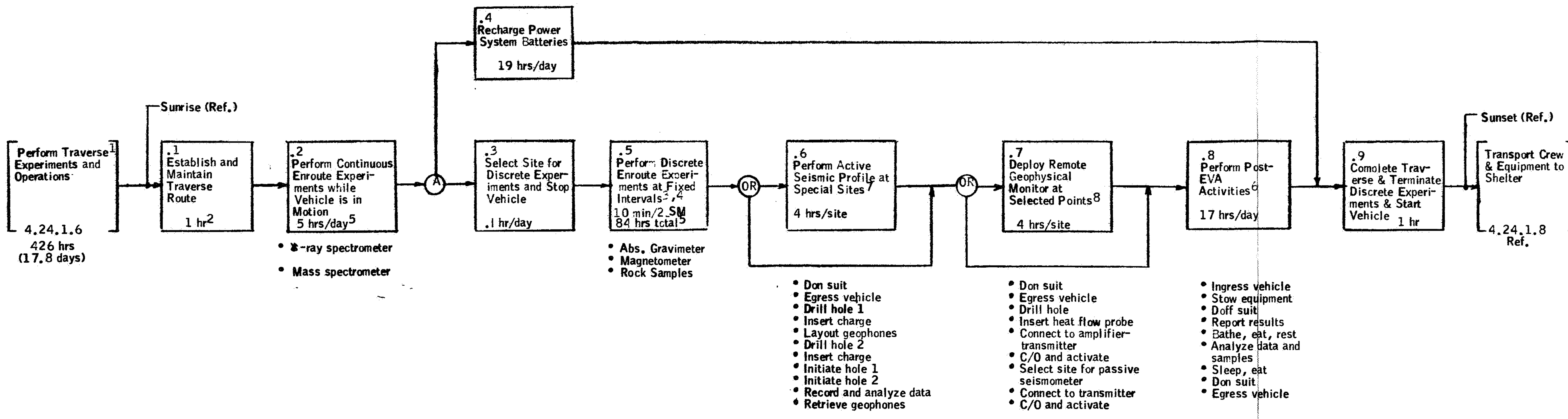
10 Data to be analyzed in real time.
9 5 statute mile intervals
8 4 man crew
7 2 man crew
6 6.5 hrs per day suit use time
5 7 hrs per day driving time max. on site
4 Site times based on Aristarchus, Sortie 8
3 Traverse times based on Aristarchus, Sortie 12
2 5 hrs per day driver time max. in main vehicle
1 Six-wheel main vehicle at 2 MPH

NOTES

Figure 5.1-12.

FUNCTIONAL FLOW DIAGRAM	NO. 4.24.1
PERFORM REMOTE SORTIES	
T. J. DOLAN 1 OCTOBER 1970	REV. A

SD 71-477

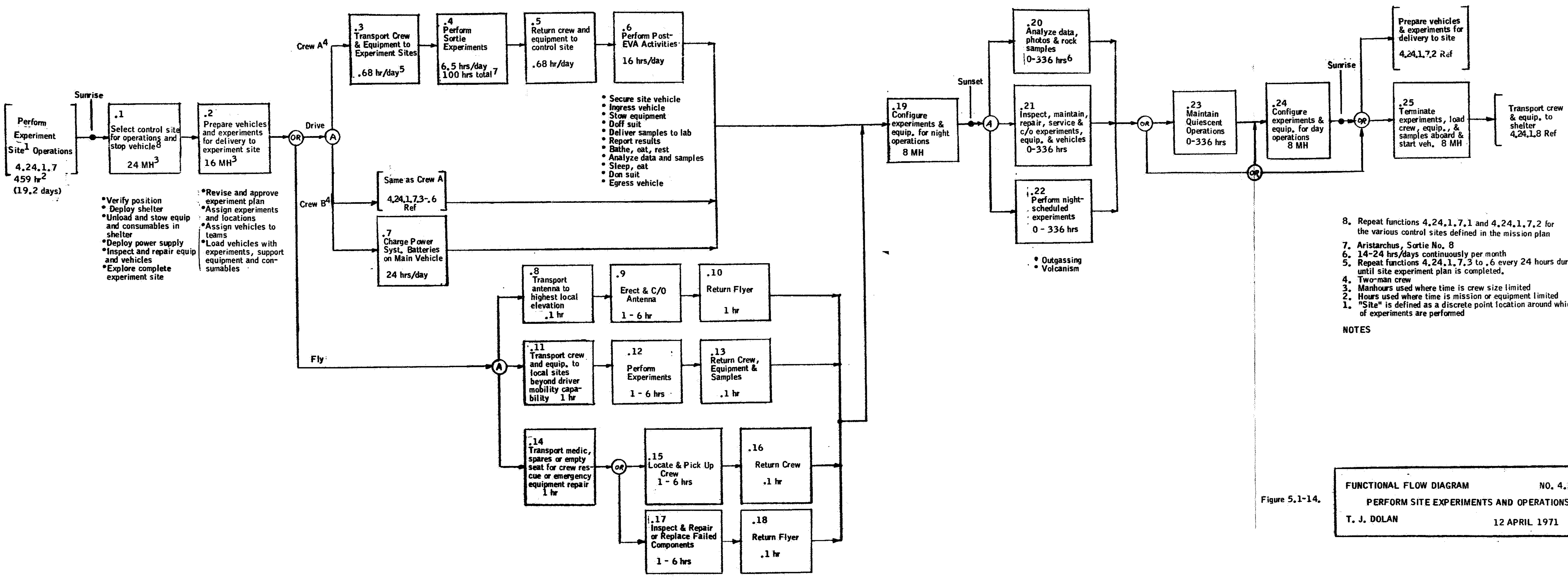


NOTES

1. "Traverse" is defined as a parth of specific length and direction along which a series of repetitive experiments are performed.
2. Hours used where time is mission or equipment limited
3. 2 statute miles
4. Data to be analyzed in real time and rerun if necessary
5. Aristarchus, Sortie No. 12; 5 driving hrs per day every day (including lunar night)
6. Repeat functions 4.24.1.6.2 to 4.24.1.6.8 at 24 hr intervals througnout traverse
7. For Aristarchus No. 12, profiles are required
8. For Aristarchus No. 12, 1 RGM is deployed at 3 sites

Figure 5.1-13.

FUNCTIONAL FLOW DIAGRAM	NO. 4.24.1.6
PERFORM TRAVERSE EXPERIMENTS AND OPERATIONS	
T. J. DOLAN	1 OCTOBER 1970 REV. A



NOTES

1. "Site" is defined as a discrete point location around which a series of experiments are performed
2. Hours used where time is mission or equipment limited
3. Manhours used where time is crew size limited
4. Two-man crew
5. Repeat functions 4.24.1.7.3 to .6 every 24 hours during daylight until site experiment plan is completed.
6. 14-24 hrs/days continuously per month
7. Aristarchus, Sortie No. 8
8. Repeat functions 4.24.1.7.1 and 4.24.1.7.2 for the various control sites defined in the mission plan

Figure 5.1-14.

FUNCTIONAL FLOW DIAGRAM	NO. 4.24.1.7
PERFORM SITE EXPERIMENTS AND OPERATIONS	
T. J. DOLAN	12 APRIL 1971 REV. A

5.1.9 Mission Requirements

The remote exploration mission requirements include the functional requirements--the major tasks to be accomplished by man or machine, and the performance requirements--the quantitative specifications which size the crew, equipment, and the time required to complete the mission objectives.

Requirements Analysis Sheets (RAS) were prepared for each of the remote exploration functions given in Section 5.1.7. The RAS's expand each function to another level of detail and define the performance requirements for men or machines necessary to accomplish the task. The RAS's are presented in Appendix C. The requirements contained therein are to a level of detail slightly beyond the immediate needs of the study, thereby assuring a continuity of requirements at the required level.

The mission requirements were computed from the histograms and probability distributions as described earlier in Section 5.1.6. These requirements are summarized in Table 5.1-14, which gives the values for an individual remote sortie and for the sum of all sorties, i.e., the complete LSB site. Also listed are two columns of values--a nominal and a maximum. The nominal is used for computational purposes within the typical mission concept while the maximum value is the design point previously described and is to be used for equipment design purposes.

Table 5.1-14. Nominal Remote Sortie Performance Requirements

	Parameters * A	Parameters * B
For Each LSB Site		
Map travel distance	3440 statute miles	3963 statute miles
Consumables	2000 pounds	3000 pounds
Adjusted travel distance	4210 statute miles	4850 statute miles
Science time (6.5 work hours/day)	330 days	470 days
Duration (driving, maint. and repair, overhaul)	836 days	1150 days
Distance on rough terrain	2300 statute miles	2650 statute miles
Distance on smooth terrain	1910 statute miles	2200 statute miles
Distance on 0-10° slopes	4082 statute miles	4701 statute miles
Distance on 11-30° slopes	116 statute miles	135 statute miles
Distance on 31° + slopes	11.6 statute miles	13.5 statute miles
Number of sorties	12.6	20
Number of traverses	3.2	5
Number of experiment sites	17.4	27
Number of experiments	115	134
Travel on experiment sites	462 statute miles	549 statute miles
Return payload (rocks)	2716 pounds	3285 pounds
Return payload (cores)	3755 pounds	5410 pounds
Payload weight	3608 pounds	3608 pounds
Payload power	1-3000 watts	1-3000 watts
Payload volume	9055 cubic feet	9055 cubic feet
Drill holes (10 feet deep)	110	150
Drill holes (100 feet deep)	16	24
Flyer missions	10	10
For Each Remote Stortie		
Payload weight	1140 pounds	1468 pounds
Payload power	1-3000 watts	1-3000 watts
Payload volume	100 cubic feet	123 cubic feet
Map travel distance	274 statute miles	700 statute miles
Adjusted travel distance	335 statute miles	855 statute miles
Sortie science time (6.5 work hours/day)	26.2 days	40 days
Sortie duration	48.6 days	90 days
Radial distance from shelter	106.5 statute miles	230 statute miles
Distance on rough terrain	183 statute miles	467 statute miles
Distance on smooth terrain	152 statute miles	388 statute miles
Distance on 0-10° slopes	325 statute miles	828 statute miles
Distance on 11-30° slopes	9.4 statute miles	24 statute miles
Distance on 31° + slopes	.94 statute miles	2.4 statute miles
Travel on experiment sites	26.6 statute miles	100 statute miles
Science time on experiment sites	19.1 days	37.3 days
Sample return (cores and rocks)	517 pounds	705 pounds
Data rate (bps)	$.7 - 10^4$	$.7 - 10^4$
Consumables	159 pounds	238 pounds
Drill holes (10 feet deep)	8.7	12
Drill holes (100 feet deep)	1.3	2
Flyer range (statute miles)	3	5
Flyer flights/sortie (4 sorties/LSB)	2	2
Crew size	4	4

*A Nominal parameters (averaged over five LSB sites)
B Design point parameters (95 percent values or maximum)

5.2 OBSERVATORY MISSION ANALYSIS

The objective of observatory mission analysis is to define the requirements necessary to operate the observatory in an effective mode. These requirements including siting, pointing, observatory layout, consumables and manpower. In this section, the observatory equipment listed in Section 3.1.3 and the mission described in Section 4.2 are combined and functionally analyzed.

5.2.1 Functional Requirements

Functional analysis of the observatory tasks is shown in Figures 5.2-1 to 5.2-7. Estimated task durations are shown on each of the functions.

The two low frequency radio telescopes, .3-1 MHz and 1-15 MHz, require extensive mobility support to complete their deployment. While self-erecting poles are planned to raise the individual antennas the required height above the ground plane, the physical dimensions of the telescopes, one requiring two elements, each 1.5 miles long and 5.6 miles apart and the other one-tenth this size, make this a formidable task. Coupled with it are the antenna alignment requirements that all elements must be in a common plane which is parallel to the surface, parallel to each other and perpendicular to the element centerline. This will require optical sightings with a transit either inside or outside of the mobility vehicle. The other radio telescopes only require assembly of the instrument and placement on the surface.

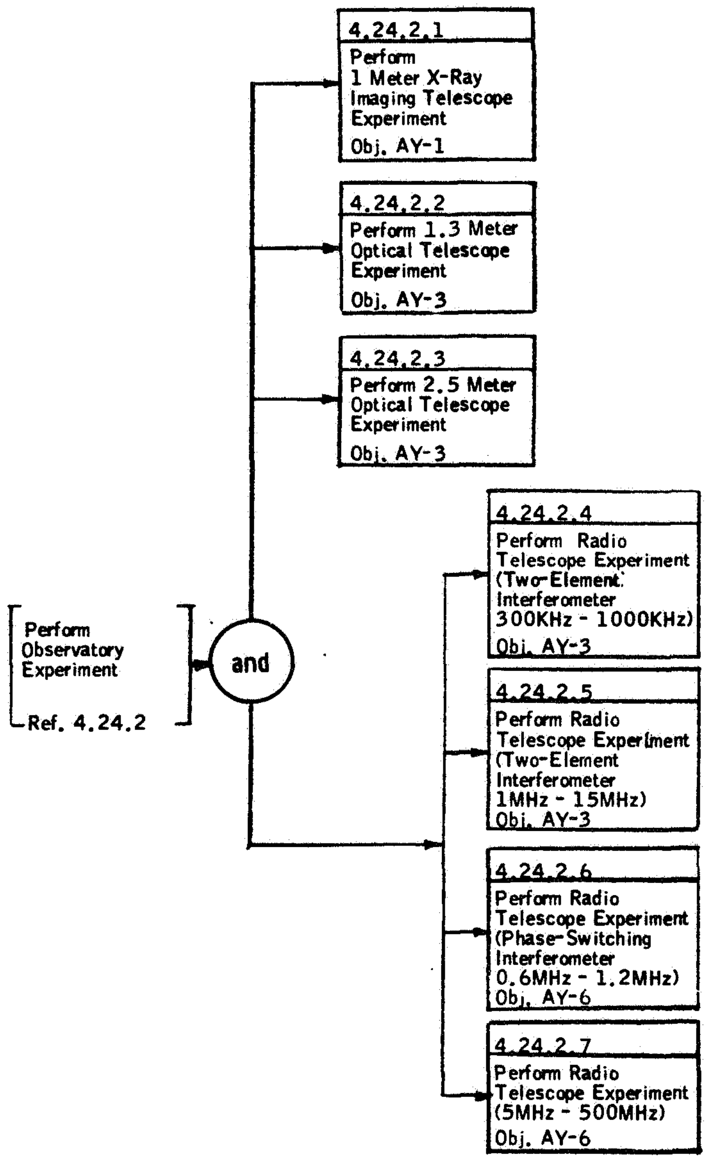
The X-ray and 50-inch (1.3-meter) optical telescopes are delivered as individual units to their respective sites and there assembled. Because of their weight, a crane and mobility vehicle will be required to transport them and to orient them in the proper direction at the site. Footings in the lunar soil will be required to provide and maintain pointing stability.

The large optical telescope will be delivered disassembled, including the 200-inch segmented mirror, and will require considerable site preparation, mirror assembly, installation, and alignment. Deployment of the modules and dome will again require cranes and mobility vehicles to assist in the erection and foaming of the main tube and covering the telescope with lunar soil.

From the functional analysis, manpower and duration estimates were made for all major tasks.

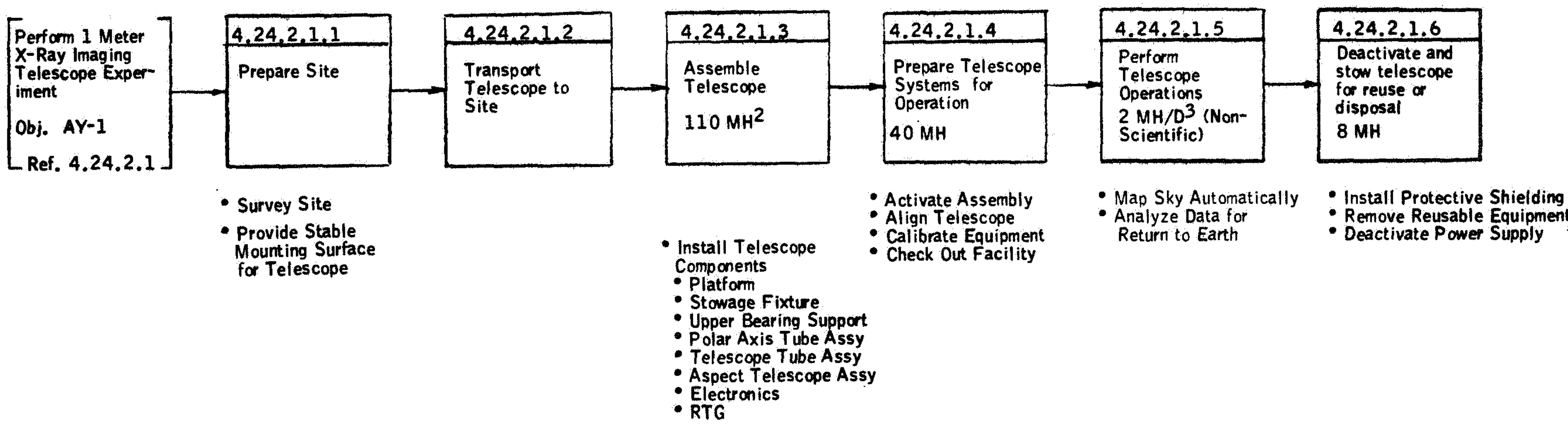
5.2.2 Mission Requirements

RAS's were prepared for all the functions given in Section 5.2.1. These are given in Appendix C. Table 5.2-1 summarizes the requirements by telescope class. The more important ones are those related to telescope orientation, pointing, and site characteristics which were taken from Reference (   ). These requirements will be referenced later in the discussion of the observatory site selection and layout.



FUNCTIONAL FLOW DIAGRAM NO. 4.24.2
PERFORM OBSERVATORY EXPERIMENT
C. C. TURNER Revision A 1 October 1970

Figure 5.2-1.

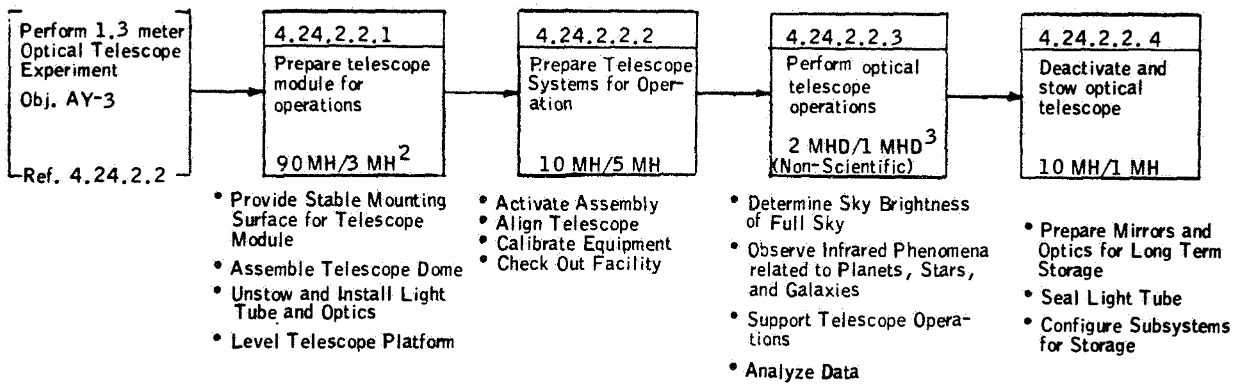


3 MHD = Man Hours/Day (Space Suit)
2 MH = Man Hours (Space Suit)
1 Ref. MIMOSA Final Report, Vol. II, Part 2, Data Sheet 3231

NOTES

Figure 5.2-2.

FUNCTIONAL FLOW DIAGRAM	NO. 4.24.2.1
X-RAY IMAGING TELESCOPE	
C. C. TURNER Revision A	1 October 1970

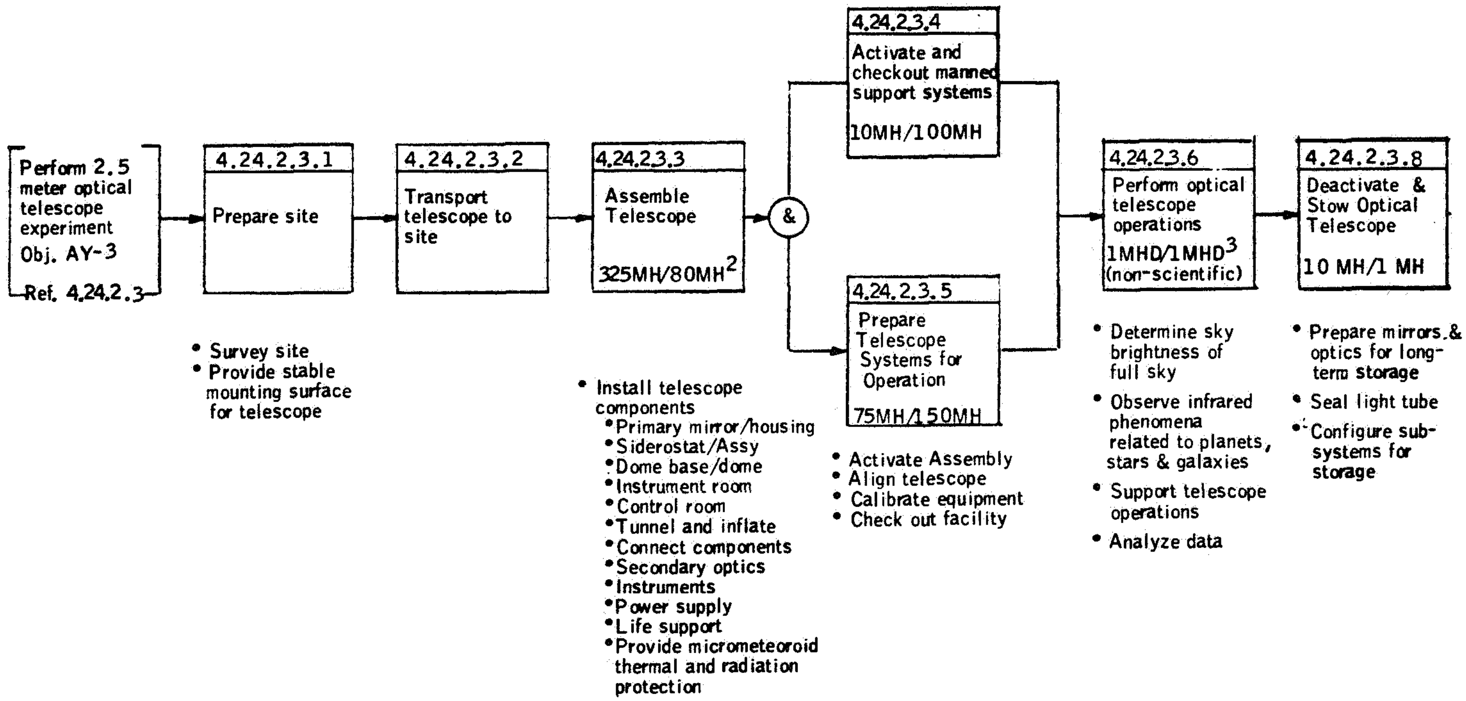


3 MHD/ MHD = Man Hours/Day (Spacesuit)/Man Hours/Day (Shirtsleeve)
2 MH/ MH = Man Hours (Spacesuit/Man Hours (Shirtsleeve)
1 Ref. MIMOSA Final Report, Vol. II, Part 2, Data Sheet 3242

NOTES

FUNCTIONAL FLOW DIAGRAM	NO. 4.24.2.2
50-INCH OPTICAL TELESCOPE	
C. C. TURNER Revision A	1 October 1970

Figure 5.2-3.

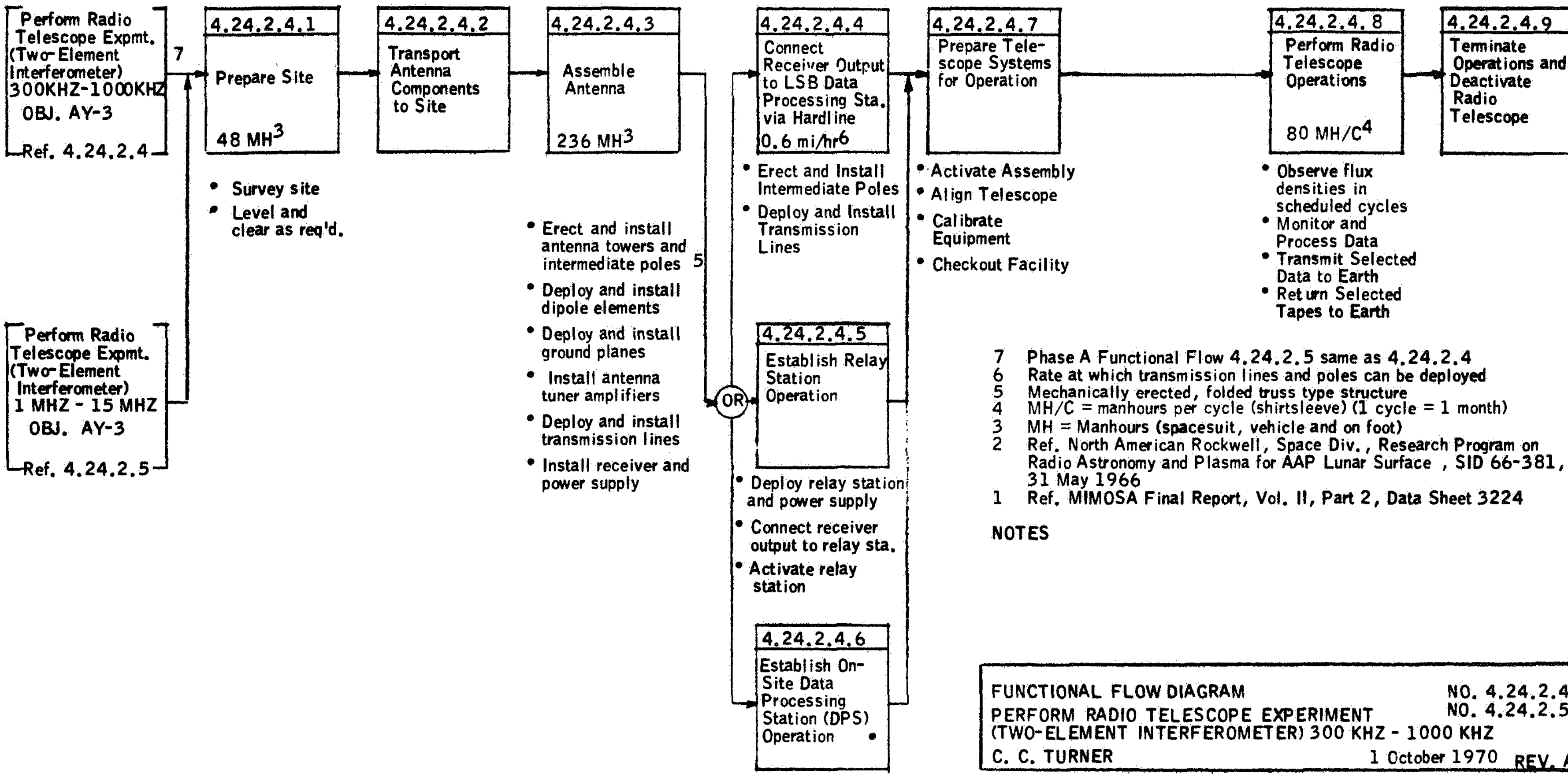


4 Deleted Function No. 4.24.2.3.7
3 MHD/ MHD = Man Hours/Day (Spacesuit/Man Hours/Day (Shirtsleeve)
2 MH/ MH = Man Hours (Spacesuite)/Man Hours (Shirtsleeve)
1 Ref. MIMOSA Final Report, Vol. II, Part 2, Data Sheet 3243

NOTES

Figure 5.2-4.

FUNCTIONAL FLOW DIAGRAM		NO. 4.24.2.3
100-INCH OPTICAL TELESCOPE		
C. C. TURNER	Revision A	1 October 1970



7 Phase A Functional Flow 4.24.2.5 same as 4.24.2.4
6 Rate at which transmission lines and poles can be deployed
5 Mechanically erected, folded truss type structure
4 MH/C = manhours per cycle (shirtsleeve) (1 cycle = 1 month)
3 MH = Manhours (spacesuit, vehicle and on foot)
2 Ref. North American Rockwell, Space Div., Research Program on Radio Astronomy and Plasma for AAP Lunar Surface , SID 66-381, 31 May 1966
1 Ref. MIMOSA Final Report, Vol. II, Part 2, Data Sheet 3224

NOTES

FUNCTIONAL FLOW DIAGRAM	NO. 4.24.2.4
PERFORM RADIO TELESCOPE EXPERIMENT	NO. 4.24.2.5
(TWO-ELEMENT INTERFEROMETER) 300 KHZ - 1000 KHZ	
C. C. TURNER	1 October 1970 REV. A

Figure 5.2-5.

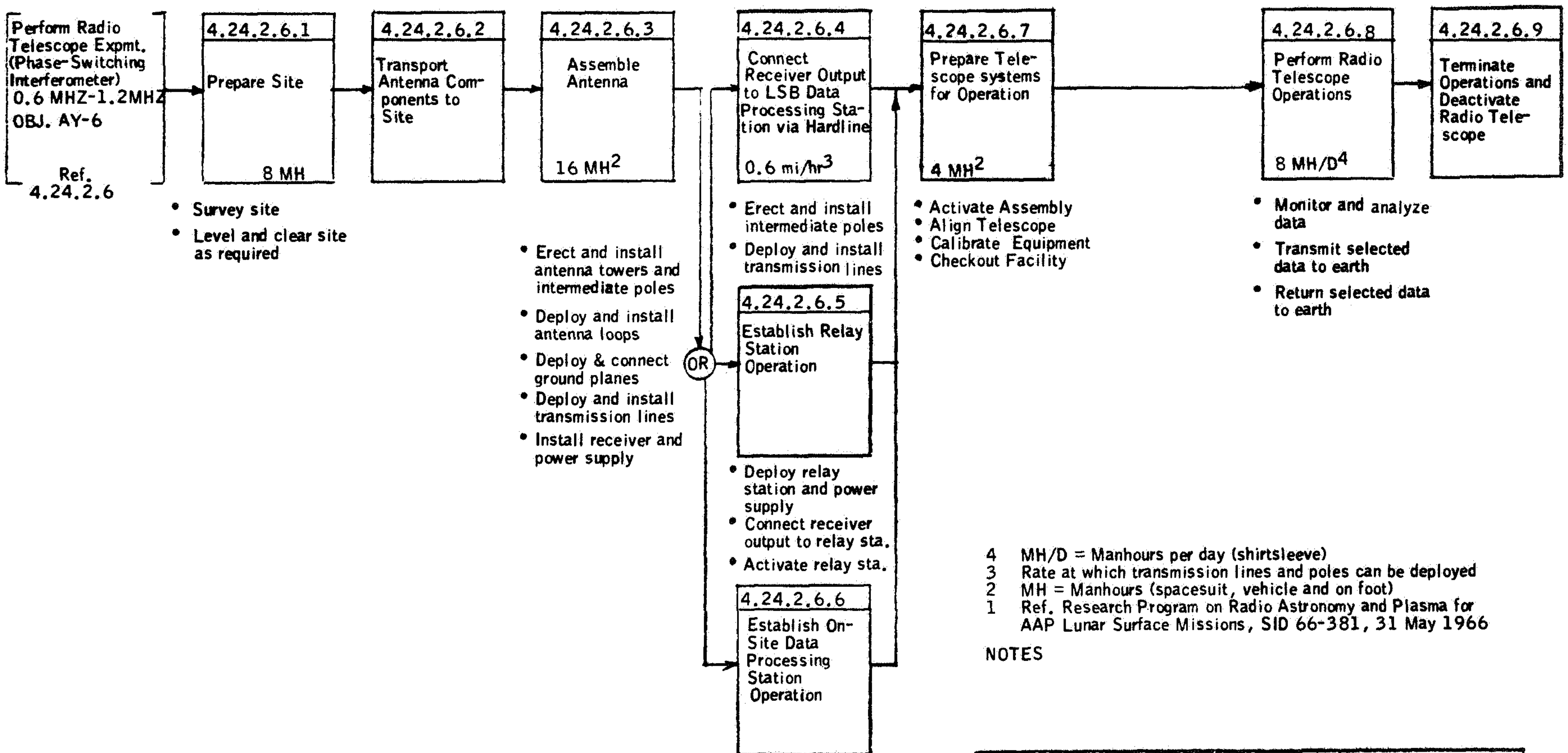


Figure 5.2-6

NOTES

4 MH/D = Manhours per day (shirtsleeve)
3 Rate at which transmission lines and poles can be deployed
2 MH = Manhours (spacesuit, vehicle and on foot)
1 Ref. Research Program on Radio Astronomy and Plasma for AAP Lunar Surface Missions, SID 66-381, 31 May 1966

FUNCTIONAL FLOW DIAGRAM NO. 4.24.2.6
PERFORM RADIO TELESCOPE EXPERIMENT
(PHASE-SWITCHING INTERFEROMETER) 0.6 MHZ - 1.2 MHZ
C. C. TURNER 1 OCTOBER 1970 REV. A

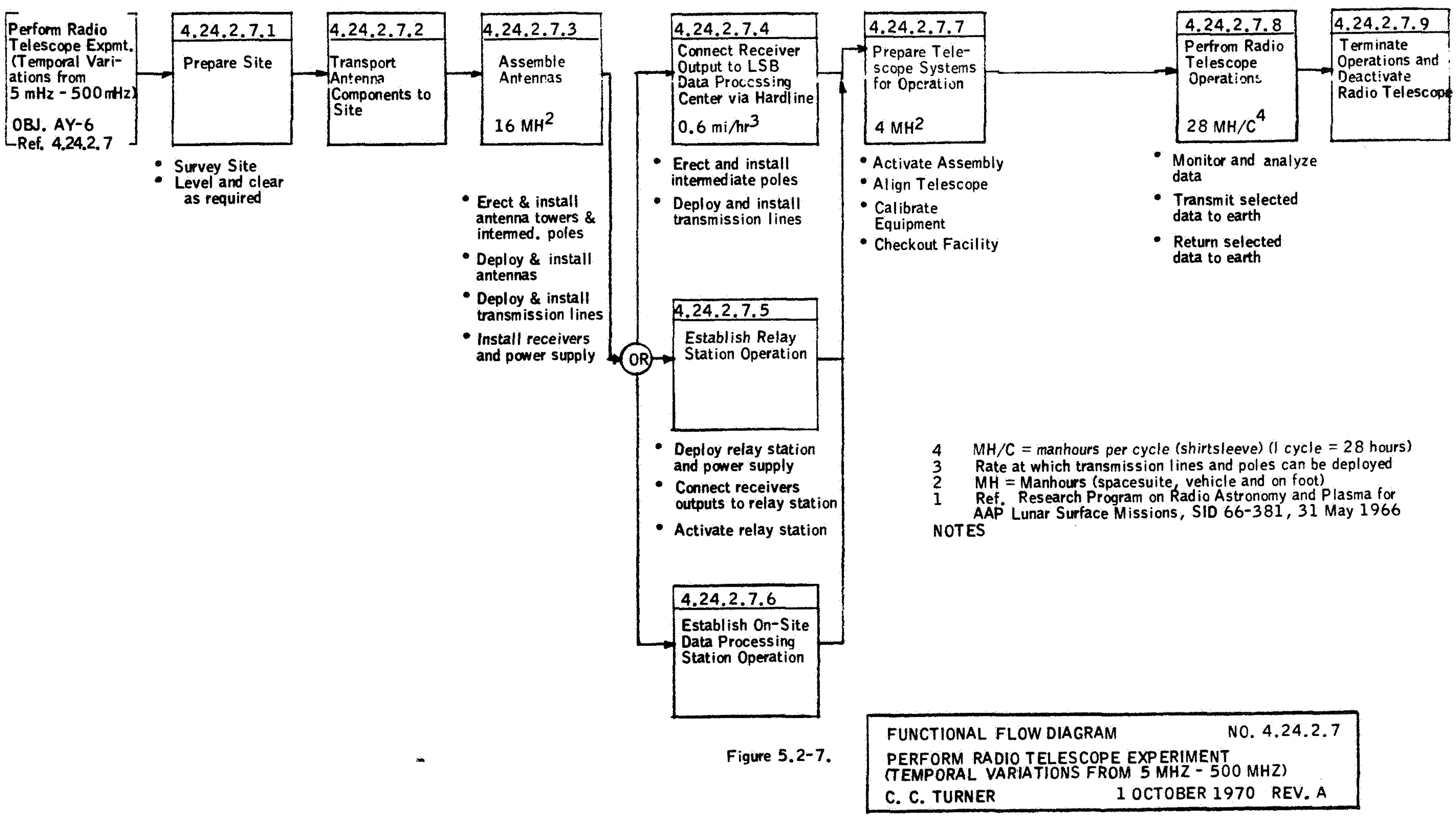

Perform Radio Telescope Expmt. (Temporal Variations from 5 mHz - 500 mHz)
OBJ. AY-6
Ref. 4.24.2.7
4.24.2.7.1
Prepare Site
• Survey Site
• Level and clear as required
4.24.2.7.2
Transport Antenna Components to Site
4.24.2.7.3
Assemble Antennas
16 MH2
• Erect & install antenna towers & intermed. poles
• Deploy & install antennas
• Deploy & install transmission lines
• Install receivers and power supply
OR
4.24.2.7.4
Connect Receiver Output to LSB Data Processing Center via Hardline
0.6 mi/hr3
• Erect and install intermediate poles
• Deploy and install transmission lines
4.24.2.7.5
Establish Relay Station Operation
• Deploy relay station and power supply
• Connect receivers outputs to relay station
• Activate relay station
4.24.2.7.6
Establish On-Site Data Processing Station Operation
4.24.2.7.7
Prepare Telescope Systems for Operation
4 MH2
• Activate Assembly
• Align Telescope
• Calibrate Equipment
• Checkout Facility
4.24.2.7.8
Perfrom Radio Telescope Operations
28 MH/C4
• Monitor and analyze data
• Transmit selected data to earth
• Return selected data to earth
4.24.2.7.9
Terminate Operations and Deactivate Radio Telescope
4 MH/C = manhours per cycle (shirtsleeve) (I cycle = 28 hours)
3 Rate at which transmission lines and poles can be deployed
2 MH = Manhours (spacesuite, vehicle and on foot)
1 Ref. Research Program on Radio Astronomy and Plasma for AAP Lunar Surface Missions, SID 66-381, 31 May 1966
NOTES
FUNCTIONAL FLOW DIAGRAM NO. 4.24.2.7
PERFORM RADIO TELESCOPE EXPERIMENT (TEMPORAL VARIATIONS FROM 5 MHZ - 500 MHZ)
C. C. TURNER 1 OCTOBER 1970 REV. A

Figure 5.2-7.

Table 5.2-1. Nominal Observatory Performance Requirements

Parameters	X-Ray Telescope	Radio Telescopes	Optical Telescopes
Number of telescopes	1	4	2
Frequency	$2 \times 10^{18} - 6 \times 10^{20}$ Hz (1-200 kev)	$3 \times 10^{5} - 5 \times 10^{8}$ Hz	$3 \times 10^{12} - 3 \times 10^{16}$ Hz (1-1000 microns and 900-10,000 A)
Duration	>5 years	>5 years	5 years
Consumables	1 pound/day (photo plates)	1000 pounds (tapes)	1600 pounds/year each (film)
Power (watts)	20	25	4000
Weight (pounds)	3564	12,423	44,055
Detectors (lb)	400	480	310
Crew support			
Assy and calibration	200 MH	550 MH	780 MH
Operation	2 MH/day	0*	5 MH/day
Volume (ft^3)	3106	1919	801
Data Rate (bps)	10^4	300 with 10^5 peaks	3.24×10^6 optical
Preferred location			
Longitude	0 - 360°	0-360°, .3-1.2 MHz 100°E-100°W, 5-500 MHz	90 - 100°
Latitude	0°	0°	-5 to ±3° or 90°
Surface geometry	100 km crater 1 km walls smooth floor	30 x 60 km smooth area	Smooth, flat bedrock surface; smooth, low horizon
Site stability	1 cm/km maximum displacement over 50 km for 7 days	None	.5μ/sec maximum for 14 days 5 cps minimum
Site lighting for optimum operation	Day and night	Day and night	Night only
Telescope pointing	±90° horizontal and vertical	±60° E-W ±80° N-S	±90° horizontal, 45 - 90° vertical
Directional alignment	Polar axis tube assembly parallel to lunar axis	E-W parallel interferometer antennas	E-W primary telescope axis, polar axis parallel to lunar axis (1.3 m)
Crew size (men/mo)	.59	1.07	2.14

*Data transmission and analysis support required at shelter

5.3 DRILLING MISSION ANALYSIS

The drilling equipment listed in Section 3.1.2 and the drilling missions described in Section 4.3 are combined in this section and functionally analyzed.

5.3.1 Functional Requirements

The major functions involved in drilling are given in Figures 5.3-1 through 5.3-4. Also shown on the individual functions are the time estimates in man-hours where tasks are crew-controlled and in hours when the machine determines the time required.

Figure 5.3-1 gives the scope of lunar drilling and lists the subobjectives supported by these tasks. Figure 5.3-2 analyzes the small rotary percussive, manual drill capable of 10-foot holes and 1.25-inch cores. Figure 5.3-3 gives the tasks associated with drilling a 100-foot hole. The drill is assumed to be mounted on a separate mobile trailer and towed to the drilling site. A separate trailer is suggested which is free of mission essential equipment to minimize possible equipment failures which might otherwise occur due to the dynamic loads of drilling and core breaking. Total time required to drill a 100-foot hole, including all tasks from site selection to stowage of equipment is 10 days. This includes a factor of 2.5 on the drilling times calculated from bit penetration rate and assumes a 5.5-hour EVA work day for the 2-man crew. Figure 5.3-4 shows the operations for a 1000-foot hole. It is preceded by three 100-foot holes and they in turn by fifteen 10-foot holes in order to determine the best location for the deep hole. The preliminary drilling takes 25 days and the deep hole takes 181 days if the drilling is performed under EVA conditions, or 100 days if IVA. The IVA drilling time factor is taken as 2.0 times the calculated bit penetration rate and the work hours per day are increased from 5.5 to 9. Actual time spent drilling averages out at 3.5 hours per day for EVA and 5 hours per day for IVA.

5.3.2 Mission Requirements

RAS's were provided for all the functions shown on the three functional flow diagrams. They are also given in Appendix C. Table 5.3-1 summarizes the requirements for the drills. Two deep holes were assumed sufficient for each LSB site. Based on a drilling pattern of three 100-foot test holes for each deep one, and five 10-foot holes for each 100-foot hole and adding in the remote sortie drilling requirements gives a total of 110 shallow holes and 22 intermediate holes for each LSB site. IVA drilling reduces the time required considerably due to the ease of working without suits and also simplifies the design of above-hole equipment such as drive motors and gearboxes which need not withstand the lunar environment. Drilling consumables for bit cooling and flushing chips were not required based on data from tests run by Westinghouse on their 100-foot drill working in Dresser basalt.

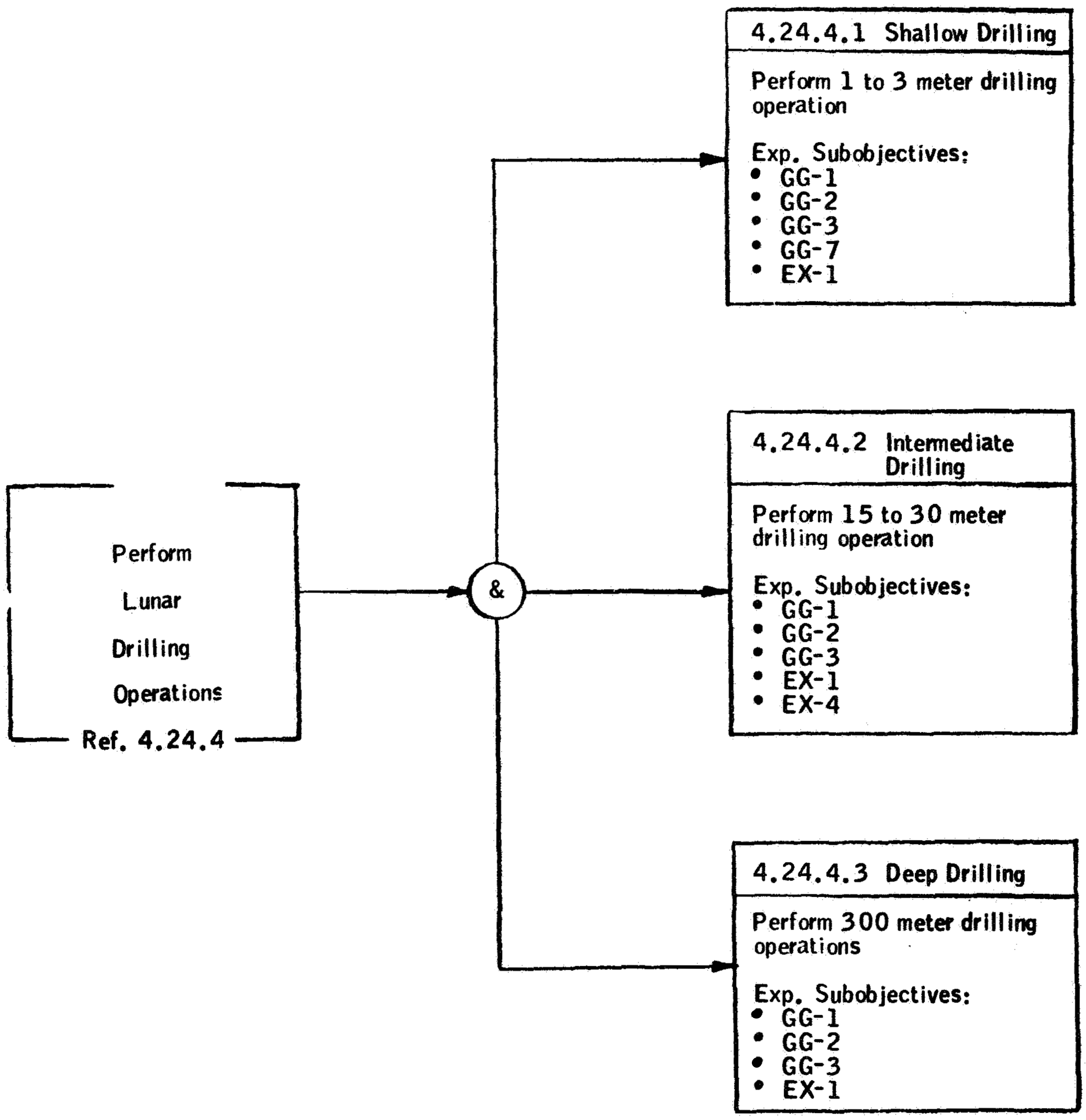
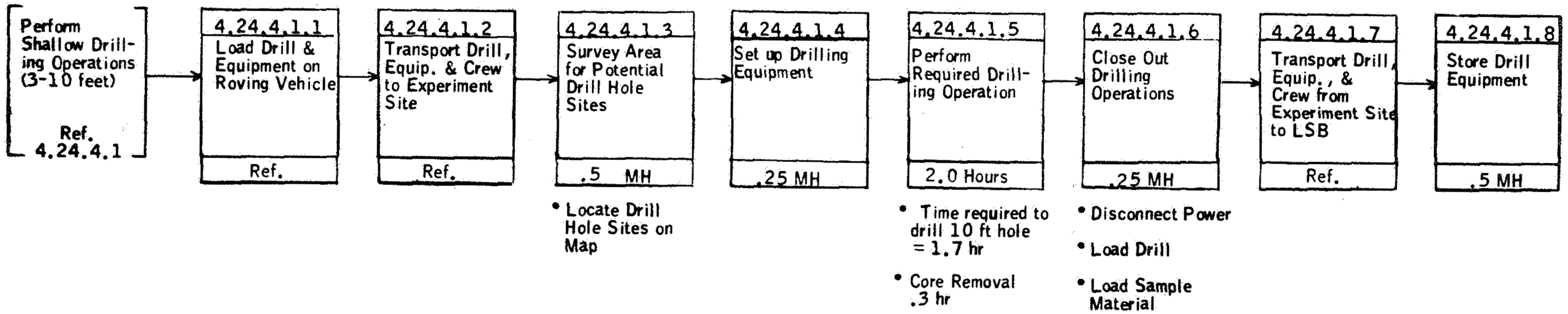


Figure 5.3-1.

FUNCTIONAL FLOW DIAGRAM NO. 4.24.4
PERFORM LUNAR DRILLING OPERATIONS
W. R. GARDNER 16 September 1970



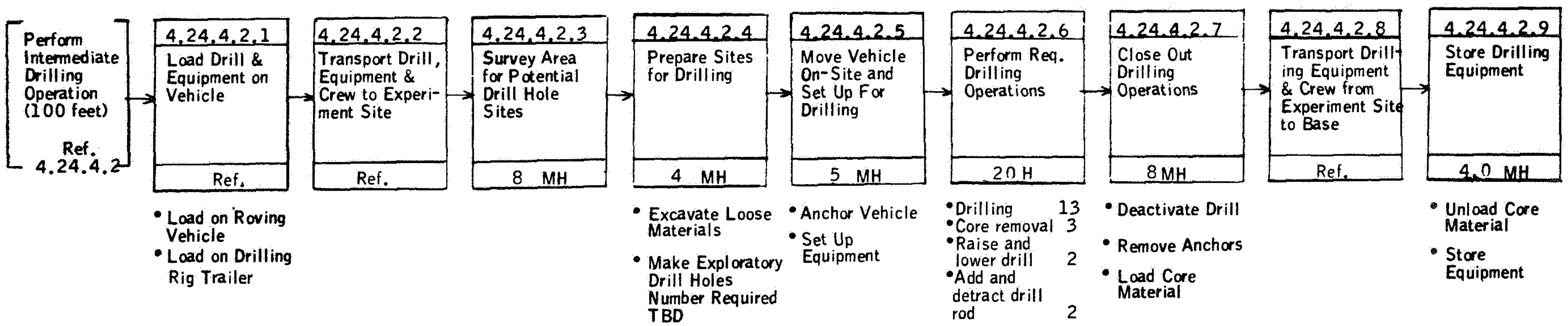
NOTES

1 Ref. MIMOSA Final Report, Vol. II, Part 2

Figure 5.3-2.

FUNCTIONAL FLOW DIAGRAM	NO. 4.24.4.1
PERFORM SHALLOW DRILLING OPERATIONS (3 - 10 feet)	
W. R. GARDNER	12 APRIL 1971 REV. A

SD 71-477



NOTES

2 Ref. ALSS Final Report, BSR 1112
1 Ref. MIMOSA Final Report, Vol. II, Part 2

Figure 5.3-3.

FUNCTIONAL FLOW DIAGRAM	NO. 4.24.4.2
PERFORM INTERMEDIATE DRILLING OPERATION (100 feet)	
W. R. GARDNER	12 APRIL 1971 REV. A

SD 71-477

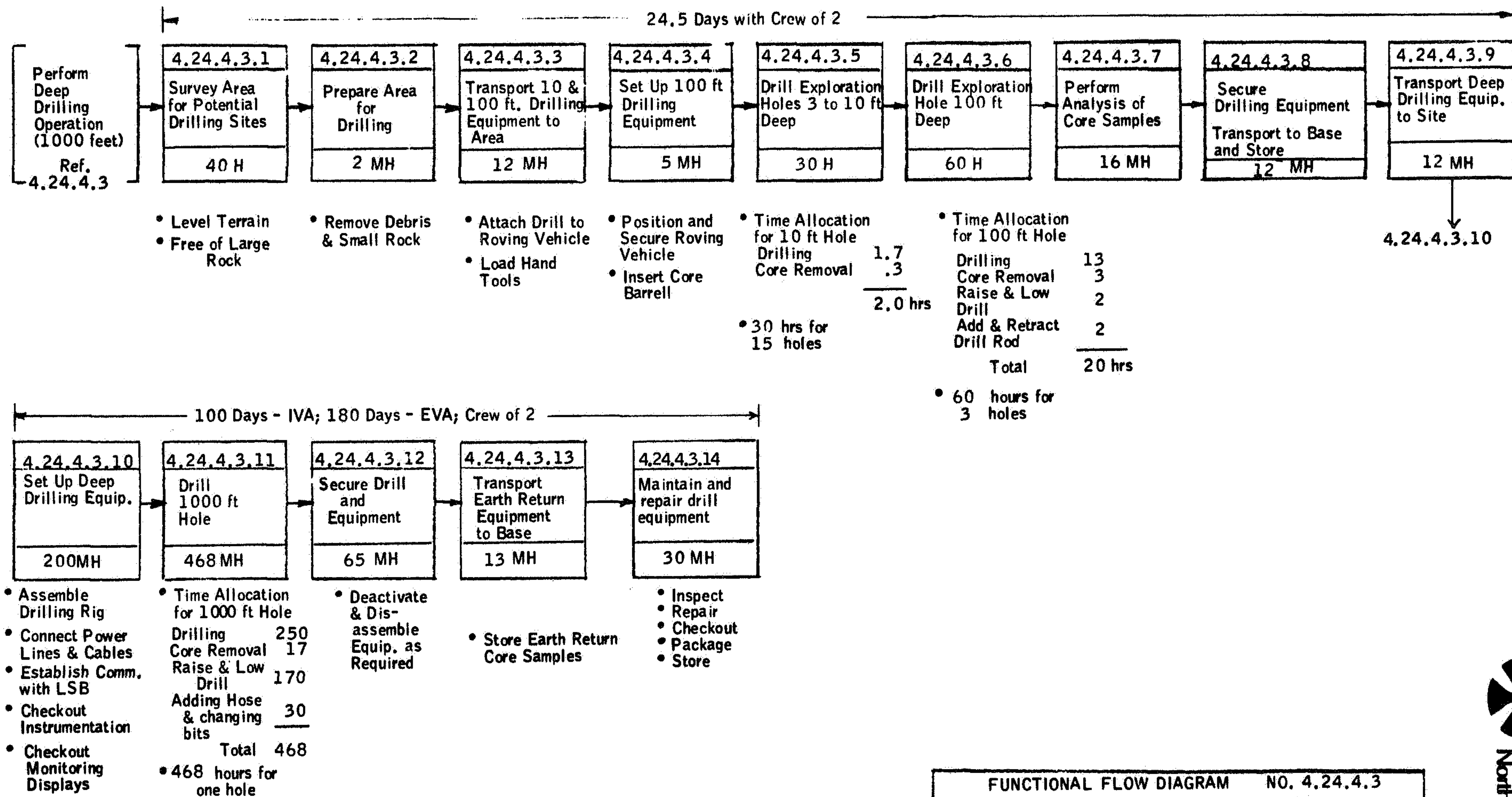


Figure 5.3-4.

FUNCTIONAL FLOW DIAGRAM NO. 4.24.4.3
PERFORM DEEP DRILLING OPERATIONS (1000 FEET)
W. R. GARDNER 12 APRIL 1971 REV. A

Table 5.3-1. Nominal Drilling Operations Performance Requirements

Parameters	Shallow Drilling	Intermediate Drilling	Deep Drilling
Hole depth (feet)	5 - 20	100	1000
Drill design	Rotary percussive	Diamond rotary	Diamond rotary
Operating mode	Manual	semi-automatic	semi-automatic
Penetration rate (feet/hour)	20	4	4
Number of holes per LSB site	110	22	2
Crew support	1	2	2
Consumables	0	0	0
Bit life (feet)	unknown	125	125
Drill weight (lb)	25*	300*	4200*
Power (kw)	.3 - 1.35	5.0	3.5 - 14.0
Volume (ft^3)	1.5 - 13	8 - 35	360
Core weight (lb)	7 - 28	138	1385
Drill diameter (inches)	2	2	2
Core diameter (inches)	1.25	1.25	1.25
Core barrel length (feet)	5	5	10
Data rate (bps)	0	0	0
Nominal duration per hole	1.5 hours EVA	10 days, EVA	72 days, EVA 50 days, IVA
Contingency factor	2.0	2.0	2.5, EVA; 2.0, IVA
Expected duration per hole	3 hours	20 days	180 days, EVA 100 days, IVA
Hole pattern	5 shallow/1 intermediate	3 intermediate/1 deep	2/LSB site
Crew size	1	2	2

Requires separate power supply -
*power supply not included

5.4 HABITABILITY REQUIREMENTS

Habitability is one of the more important considerations when designing facilities that support man for long-duration mission and provides the criteria for meeting the physiological and psychological needs of man in the system. The objective is to provide comfortable, efficient and safe working and living facilities in the lunar environment.

Habitability requirements include those elements necessary to support, maintain, and operationally assist the LSB crew in the performance of mission functions, and to achieve mission objectives. Habitability criteria are provided in the following sections for:

1. Mission Requirements
2. Crew Equipment
3. Subsystem Interfaces

5.4.1 Mission Requirements

The LSB shall provide the capability to support a nominal complement of 12 crewmen, with a maximum capability to support 18 crewmen for short periods of time during crew rotation, resupply, or for emergency operations.

Crewman Dimensions

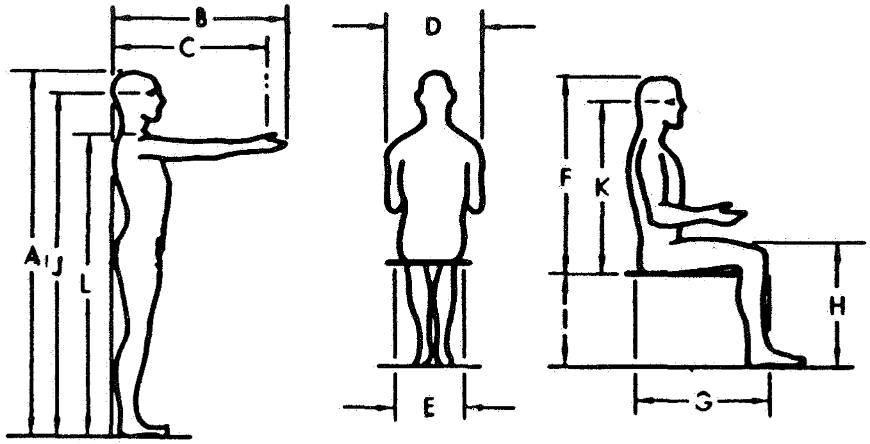
Pertinent crewman dimensions for a 5th and 95th percentile crewman are presented in Figure 5.4-1 to be used for developing LSB interior arrangements. Standing height, eye and shoulder heights (standing), and knee height (sitting) are increased 1.0 inch by the addition of shoes. The dimensions shown on Figure 5.4-2 are employed for design purposes where suited/pressurized transit or access is either required or anticipated.

Safety

Safety provisions for LSB design planning include, but are not necessarily limited to the following:

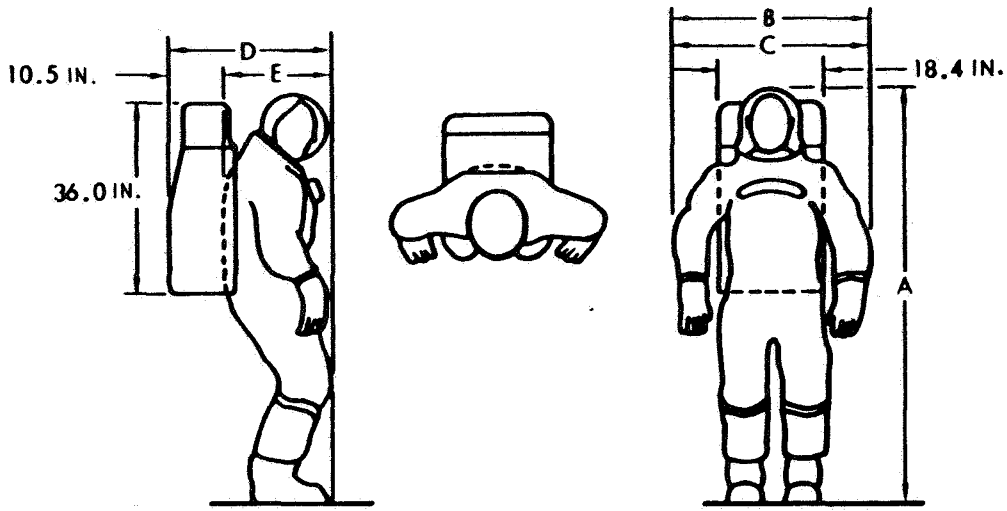
1. Provision for accommodation and survival of the full complement of LSB crewmen for a minimum of 30 days without access to any one pressurizable volume within the base.

2. Provisions for the protection and survival of the full complement of personnel at an emergency level during solar storm activity, consistent with the radiation allowables and with the specified radiation environment model and duration for solar storms.



DIMENSION	PERCENTILE (INCHES)	
	5th	95th
A - STANDING HEIGHT	65.8	73.8
B - MAXIMUM REACH	32.4	38.3
C - FUNCTIONAL REACH	29.0	34.2
D - SHOULDER BREADTH	17.3	20.7
E - HIP BREADTH (SITTING)	13.4	16.4
F - SITTING HEIGHT	34.7	38.8
G - BUTTOCK-KNEE LENGTH	22.0	25.5
H - KNEE HEIGHT (SITTING)	20.3	23.6
I - POPLITEAL HEIGHT	15.9	18.5
J - EYE HEIGHT (STANDING)	61.1	68.8
K - EYE HEIGHT (SITTING)	29.9	33.9
L - SHOULDER HEIGHT	53.1	60.8
WEIGHT (LBS)	140.1	210.7

Figure 5.4-1. Pertinent Crewman Dimensions



DIMENSION	PERCENTILE (INCHES)	
	5th	95th
A - HEIGHT	68.1	76.3
B - MAX BREADTH AT ELBOWS (ARMS RELAXED)	27.2	30.7
C - MAX BREADTH AT ELBOWS (ARMS AT SIDE)	26.0	27.3
D - MAX DEPTH WITH PORTABLE LIFE SUPPORT SYSTEM (PLSS) & BACKUP OXYGEN (OPS)	27.0	29.4
E - MAX DEPTH WITHOUT PLSS/OPS	15.5	17.9
WEIGHT (LBS), WITH PLSS/OPS	323.6	395.2
WEIGHT (LBS), WITHOUT PLSS/OPS	197.9	286.5

NOTES:

FOR DIMENSIONS D AND E, 2" HAVE BEEN ADDED TO MAXIMUM CHEST DEPTH OF SUITED/PRESSURIZED CREWMAN FOR PLSS CONTROL BOX, TO OBTAIN ENVELOPE DIMENSIONS.
MEASUREMENTS MADE ON A7L PGA, PRESSURIZED TO 3.75 PSIG.

Figure 5.4-2. Suited/Pressurized Crewman Envelope Dimensions

3. Provisions for emergency medical treatment of sick or injured crewmen. For those sick or injured crewmen that require medical treatment beyond the LSB on-board capability, further provisions must be made. This includes care and stabilization of the patient until medical aid can be brought in, or the patient can be returned to earth. The minimum period for which injured crewman must be stabilized awaiting medical aid is 30 days, or 83 hours during transit back to earth.

4. Provisions for the restraint of irrational personnel.

5. Provisions for suited operations inside the shelter, EVA, and entry into hazardous areas by at least a two-man crew. Provisions for the rescue of one man by the other in an emergency.

6. Provisions for containing (e.g., confining) emergencies such as fires, toxic contamination, depressurization, structural damage, etc.

7. Provisions for emergency treatment of injured personnel following an accident that renders unavailable the pressurizable volume containing the primary medical facilities.

8. Provision of pressure suits, backpacks and umbilicals, and related support equipment in readily available locations so that two suits may be reached and donned from any location in the LSB with any one pressurizable volume being inaccessible due to an accident.

5.4.2 Crew Equipment

The crew equipment items shall meet the performance requirements delineated in the following paragraphs.

Crew Personal Equipment

Crew apparel includes those garments customarily worn by the crew in a shirtsleeve mode of operation. They provide general comfort, warmth, and perspiration absorption. Estimated articles of clothing, crew linens, and personal effects required and the usage rates are shown in Tables 5.4-1, 5.4-2, and 5.4-3.

Emergency personal equipment consists of an emergency full-face oxygen mask, which provides for emergency breathing in the event of smoke or toxic gases. An integral oxygen bottle on each mask provides a minimum five-minute oxygen supply. One mask and bottle per crewman for the maximum LSB population expected will be provided. Personal radiation dosimeters are provided for each crewman. They are worn at all times (in pockets on crew garments) and are capable of measuring accumulated radiation dosage.

Table 5.4-1. Crew Apparel

Item	Unit Weight (lb)	Usage Rates (Days)	
		Nominal	Maximum
Shirt (short sleeve)	0.27	3	6
Trousers	0.77	6	12
Jacket (lightweight)	0.62	(As required)	
Undershirt	0.17	2	3
Undershorts	0.17	2	3
Socks (pair)	0.04	2	3
Shoes (pair)	0.55	(Not applicable)	

Table 5.4-2. Linens

Item	Unit Weight (lb)	Usage Rates (Days)	
		Nominal	Maximum
Sheets	0.37	6	10
Blanket	1.0	(Not applicable)	
Towels	0.75	4	6
Washcloths	0.08	3	6

Table 5.4-3. Personal Effects

Item	Per Man/Month Weight (lb)
Toilet articles (toothbrush, toothpaste, etc.)	0.12
Grooming equipment (shaving equipment, combs, hair and nail trimming, etc.)	0.34
Cleansers (soap, antispetics, deodorants, shampoo, etc.)	0.62
Personal equipment (items of crew's choice)	1.00

Pressure Garment Assemblies (PGA)

Based on the present state-of-the-art pressure suit development and the proposed lunar surface EVA work loading, it appears that more than one suit plus spares will be required to assure continuous surface exploration. Lunar dust, daily wear and tear, cleaning and drying, and the 30-day periodic seal replacement all add to the pressure suit requirements.

To assure the operability needed to support lunar surface exploration, a conservative estimate is felt to require a total of three pressure suit garment assemblies for each crewman per six-month tour of duty if he is to perform regularly scheduled lunar surface EVA's. The first suit is for immediate use, the second one for use while the first is being cleaned and repaired, and the third is a spare in case of complete failure or non-repairable damage. Enough spare seals will be required to change the seals in each garment every 30 days, plus a field repair kit for each suit for patching minor abrasions and surface tears.

Each PGA provides a mobile life support chamber for a crewman and a 100 percent oxygen environment at an operating pressure of 7.0 ± 0.2 psia. The PGA environment may be supplied by either of the following, depending upon the mode of operation.

1. EVA - a self-contained portable Life Support System (PLSS)

2. Inside the shelter - through an umbilical system from the shelter, connecting to a pressure control unit worn on the PGA. The capability to use the PLSS for inside operations is also required.

When an umbilical system is utilized, they supply oxygen and liquid cooling capability and provide for two-way voice communications, transmission of bioinstrumentation signals from the crewman, and transmission of electrical power and caution/warning signals to the crewman. Umbilicals must provide for transit from one pressure volume to another. For example, if one pressure volume becomes disabled (depressurized), the capability must exist to go from an operable volume to a disabled volume to make it safe and/or repair it as required. This transit could be made with the PLSS system but access by the crewman is somewhat more limited with the PLSS than with the umbilical system because of the interference from the large back-pack. Umbilical connections and storage must be provided for this equipment in each pressure volume. At the minimum, equipment for two crewmen must be supplied to satisfy the "buddy system" requirement.

In addition to the PLSS or umbilicals for life support, the following equipment is required for use with each PGA:

1. A liquid cooling garment worn as an undergarment to provide for general comfort, perspiration absorption, and thermal transfer between the crewman's body and the cooling media.

2. Fecal containment equipment to permit defecation during a suited mode.

3. Urine collection and transfer equipment to provide for the collection and intermediate storage of urine. Subsequent transfer of urine to the LSB waste management assembly is required.

4. Bioinstrumentation assembly to provide the capability for physiological monitoring of a crewman.

5. Personal communications equipment to provide dual earphones and dual microphones for crew voice communications capability.

6. Extravehicular gloves for EVA in lieu of the gloves normally provided for the PGA.

General Crew Equipment

Crew mobility aids in the form of handholds, guide rails, and other devices will assist the crew in moving safely from one area to another, for both internal or external aisles, passageways, stairs, ladders, etc., in either a shirtsleeve or suited/pressurized mode of operation. Handholds and guide rails are a minimum of 1.0-inch in diameter with a 2.0-inch clearance to adjoining structure or surface to permit use with a gloved hand (suited/pressurized operations).

Portable lights for emergency maintenance or inspection in the event of power failure will provide floodlight-type direct illumination of 100 foot-candles at a distance of ten feet and not less than 50 foot-candles at this same distance after three hours of continuous operation. Each portable light has a carrying handle and actuation device compatible for use with a gloved hand (suited/pressurized operations). A minimum of two are required per pressure volume.

Medical accessories (first aid) kits are required in each pressure volume. These kits provide for medical emergencies when the pressure volume in which the medical treatment area is located is unusable. These kits include such items as oral drugs, injectable drugs, dressings, bandages, and topical agents.

In addition to the personal radiation dosimeters worn by the crewmen, suitable devices at selected locations within the LSB are provided to measure ambient radiation levels as well as cumulative radiation dosage.

To maintain the LSB at an acceptable level of cleanliness, a variety of cleansers, deodorants, germicides, waxes, wipes, and brushes are required.

5.4.3 Subsystem Interfaces

Experiment Subsystem

The LSB crew involved in lunar surface experiment operations must have the skills necessary to activate, operate, maintain, record and analyze data, and deactivate the base experiments for each scientific discipline represented, including those field experiments associated with lunar surface vehicle and flyer operations.

Structures

The LSB shelter interior will be designed in accordance with good architectural and decorator practices in order to provide comfortable, efficient and attractive living and work spaces. The interior arrangement will insure crew comfort, efficiency, and physiological and psychological well-being. The LSB shelter is divided into basic functional areas including but not necessarily limited to the following:

- Individual staterooms
- Food preparation and serving areas
- Dining area
- Recreation area
- Personal hygiene areas
- Exercise area
- Medical treatment area
- Work areas
- Storage areas
- Aisles, passageways and airlocks

The total number of staterooms is divided between pressure volumes. In case of a malfunction and/or damage to any one pressure volume, the others can accommodate a full crew complement through dual occupancy of staterooms. Wall-to-wall living area guidelines for the shelter are given in Table 5.4-4.

All equipment installed within the shelter will permit access to the pressure hull for inspection and repair. The access provisions should permit a suited/pressurized crewman to gain access to the pressure hull (equivalent of a minimum 32 inches by 78 inches access-way). Additional access requirements are listed in Table 5.4-5.

Crew Accommodations

The 12 individual crew staterooms are designed for single occupancy during routine operations and dual occupancy during emergencies for periods of up to 30 days.

Crew furnishings dimensional requirements are listed in Table 5.4-6.

Table 5.4-4. LSB Living Area Guidelines

Area \ Crew Size	4		6		8		10		12	
	Per Man	Shelter Total	Per Man	Shelter Total	Per Man	Shelter Total	Per Man	Shelter Total	Per Man	Shelter Total
Staterooms										
General	50.0	150.0	50.0	250.0	50.0	350.0	50.0	450.0	50.0	550.0
Commander	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0
Galley										
Primary	9.0	36.0	8.0	48.0	7.0	56.0	6.6	66.0	5.5	66.0
Backup	2.0	8.0	1.7	10.2	1.5	12.0	1.5	15.0	1.5	18.0
Dining	11.0	44.0	7.3	44.0	5.5	44.0	8.0	80.0	8.0	96.0
Recreation	15.0	60.0	12.0	72.0	10.0	80.0	10.0	100.0	10.0	120.0
Exercise	8.0	32.0	5.4	32.0	7.5	60.0	6.0	60.0	5.0	60.0
Medical	36.0	144.0	24.0	144.0	18.0	144.0	14.4	144.0	12.0	144.0
Pers. Hygiene										
Primary	12.0	48.0	8.0	48.0	12.0	96.0	9.6	96.0	8.0	96.0
Backup	10.1	41.0	8.0	48.0	6.0	48.0	9.6	96.0	8.0	96.0
Total										
Ft^2/Man	153.1		124.4		117.5		120.7		108.0	
Ft^2/Crew		628.0		761.2		955.0		1172.0		1311.0

Table 5.4-5. Access Requirements (Hatchways/Doors)

Functional Area	Height (Inches)		Width (Inches)	
	Minimum	Preferred	Minimum	Preferred
General crew staterooms	78	82	28	30 - 32
Commanders staterooms	78	82	28	30 - 32
Primary galley	78	82	32	36 - 42
Backup galley	78	82	32	36 - 42
Dining area	78	82	32	-
Recreation area	78	82	32	-
Personal hygiene area	78	82	32	36
Crew exercise area	78	82	32	-
Medical treatment area	78	82	32	36 - 42
Crew work station	78	82	28	30 - 36

Table 5.4-6. Crew Furnishings Dimensional Criteria for LSB Shelter

Furnishings	Nominal Dimensions (Inches)		
	Width	Depth or Length	Height
Sleeping facility (bunk)			
Fixed	30	78	
Auxiliary	28	76	
Chair	18	18	18
Work or study desk	36	24	30
Work or study conference table	42	30	30
Work surface or counter			
Fixed	42	24	40
Auxiliary	36	18	40
Eating surface (table)	32	54	30
Examination table (medical)	26	78	36 to 40 (adjustable)

Galley Requirements

A galley provides for the nutritional needs of the 12-man LSB crew and is capable of serving a minimum of four crewmen simultaneously. The galley is capable of being occupied by up to two crewmen simultaneously during periods of food preparation.

The backup galley is capable of satisfying the nutritional needs of the 12-man LSB crew for a period of at least 30 days and is in a different pressure volume than the primary galley. The backup galley is capable of preparing and serving only dried (rehydratable), thermostabilized (canned), or other types of packaged food not requiring special preparation equipment or refrigeration or other preservation techniques.

Dining Area Requirements

One dining area accommodates up to four crewmen simultaneously during periods of routine operations. Staterooms, aisles, or other available space can be used as backup for the dining area.

Recreation Area Requirements

The recreation area will be utilized by the crew for relaxation and entertainment during off-duty hours and is located adjacent to the primary dining area. The recreation area can accommodate up to four crewmen simultaneously during periods of routine operations. The area can also be used in conjunction with the dining area to provide accommodations for up to 12 crewmen for purposes other than recreation, such as meetings.

Equipment provided for crew recreational purposes and off-duty crew relaxation includes the following:

1. Passive entertainment activities in the form of music (e.g., intercom, tape deck), television (either transmitted from moon, ground or video tape), and movies (projector and stowable motion picture screen).

2. Active entertainment consisting of communal games and limited craftwork (including possible use of indigenous lunar surface materials).

Equipment is required to accommodate crew physical conditioning. In view of the relatively high work loading of LSB crewmen performing lunar surface tasks, there is probably a minimal requirement for additional exercise. However, equipment and space allocation should be provided so a regularly scheduled exercise program can be instituted if subsequent research and/or experience dictates.

Personal Hygiene Requirements

The personal hygiene facilities are divided and located adjacent to the individual staterooms in separate pressure volumes. Equipment arrangement should maximize personal privacy and minimize interference between crewmen using adjacent equipment. Screens/doors are required in front of the toilets and shower dressing areas for personal privacy.

Medical Treatment Area Requirements

A medical treatment facility that will permit maximum use of the onboard medical skills, and also provide support for those additional skills that may be brought onboard should a serious accident or epidemic occur, is considered mandatory. This facility should be similar to the modified IMBLM's (Integrated Medical and Behavioral Laboratory Measurement System) as projected for the Earth Orbit Space Station after the aerospace medicine and bioscience experiments have been completed. Modification of the IMBLM's system for purely crew medical care and monitoring will reduce its size and complexity and also negate the need for an MD as all the medical measurements and treatment facilities needed for crew surveillance can be performed by Medex (See Section 4.8). The capabilities projected for LSB medical coverage are listed in Table 5.4-7, and approximate the capability found in a general practitioner's office in an outlying area.

To provide this level of medical capability, the medical area must have the following facilities:

Examination table
Body mass measurement
Sterilizer
Refrigerator/freezer
Field type X-ray
Sink, lavatory
Work surface
Set of medical diagnostic equipment

Airlock Requirements

A minimum of two LSB external airlocks for EVA crewmen are required, one each in opposite pressure volumes. Each external airlock will require a minimum height of 84 inches and a minimum diameter of 60 inches for a cylindrical airlock, or the equivalent for rectangular shapes. If the airlocks are used for dust control, additional internal space will be required for the washdown or vacuum equipment and controls for the system proposed to take care of this problem. Hatches and associated actuating mechanisms for access to and egress from each pressure volume must be operable by suited crewmen. The external airlocks used for incoming and outgoing LSB cargo must be sized for the largest equipment expected, and provide the crew accommodations necessary to effect the transit.

Table 5.4-7. Capabilities of the LSB Medical Facility

Group	Type	Tests
I	Clinical Evaluation	History Physical examination
II	Cardiovascular	Electrocardiogram Vectorcardiogram Cardiac output Arterial blood pressure Venous pressure Phonocardiogram Heart rate
III	Metabolism	Energy metabolism Balance studies Body mass Temperatures (core and skin)
IV	Clinical Laboratory	Complete blood count Urinalysis Plasma volume Electrolytes (blood and urine) Total protein Blood glucose Blood pH; pO_2; pCO_2 Reticulocyte count Red blood cell fragility Red blood cell mass and survival
V	Behavioral Effects	Vision test Audiometric test

Environmental Requirements

Acoustic Noise and Vibration. Acoustic noise levels must be low enough so that no adverse psychophysiological effects will be produced nor interfere with communication between crewmen at normal voice levels up to distances of 18 feet. Continuous noise levels shall not exceed 50 decibels in the speech interference level range (600 to 4800 Hz), 70 decibels at frequencies below this range, nor 60 decibels at frequencies above this range. The maximum acoustic noise levels for various frequencies in relation to LSB functional areas should be in accordance with the values specified by Figure 5.4-3.

Vibration emitting equipment should not be located in crew living areas and, where required in crew work areas, should be shock-mounted, insulated, or otherwise dampened so as not to adversely affect crew performance.

Radiation Protection. Radiation protection is required to limit LSB crew radiation dosage as specified in Table 5.4-8.

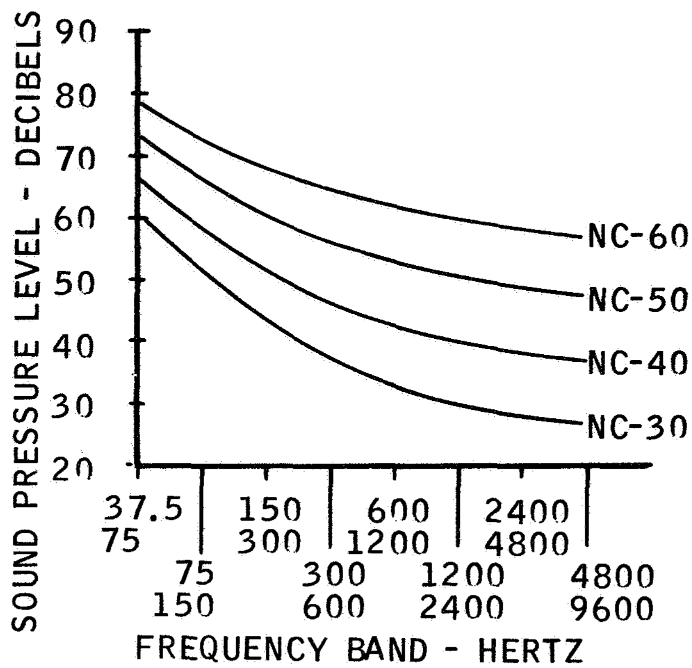
Table 5.4-8. Radiation Maximums (All doses in rems)

Organ/Depth	Period		
	Career	Year	30 Days
Skin (0.1 mm)	2400	240	150
Eye (3 mm)	1200	120	75
Marrow (5 cm)	400	40*	25

*This limit may be doubled if the crewman is not exposed to any further radiation for the succeeding 12 months following the one year counted for exposure (e.g., no more than 80 rem in a 24-month period).

The rate limit for radiation from all artificial sources should not exceed 0.15 rem/day. A dose of 25 rem within any 14-day period should be considered to constitute an emergency, requiring that the crewman be transferred from the area of high radiation to one of low radiation in the LSB or returned to earth.

Atmosphere. The cabin atmosphere will consist of an oxygen/nitrogen mixture at a normal operating pressure of 10 psia, but must be capable of operating at several selected pressures between 14.7 psia and 5 psia. The total atmospheric pressure so provided must maintain the partial pressure of oxygen in the alveolar spaces of the lungs between the limits of 100 mm Hg and 120 mm Hg at all times. The various oxygen/nitrogen mixtures necessary to provide a 3.08 psi partial pressure of oxygen, and an alveolar partial pressure of oxygen of 100 mm Hg for cabin atmospheres ranging from 14.7 to 5 psia are shown in Table 5.4-9. In the event of LSB pressure hull damage



NC CURVE	APPLICATION
NC-30	Sleep/rest areas
NC-40	Control areas where communications are critical: areas where some concentration and relaxed communication may be desirable (radio and television listening)
NC-50	Areas where good communication conditions are not essential (some distraction to external noise can be permitted); internal noise generation due to other activities may be present, general work/living areas
NC-60	Maintenance areas

Figure 5.4-3. Maximum Acceptable Acoustical Noise Levels

resulting in pressure decay, the duration of acceptable crew performance shall be considered to be that period of time until a partial pressure of oxygen of 1.9 psi is reached.

Table 5.4-9. Cabin Atmosphere Mixtures

Cabin Pressure (psia)	Oxygen (Percent)	Nitrogen (Percent)
14.7	20.9	79.1
13.4	23.0	77.0
12.3	25.0	75.0
11.0	28.0	72.0
10.0	30.9	69.1
7.0	44.0	56.0
5.0	61.6	38.4

Carbon dioxide partial pressures within the LSB should be maintained below 7.6 mm Hg in all habitable areas. The atmosphere constituents, including harmful airborne trace contaminants, will be identified, monitored, and controlled in each pressurized compartment.

The temperature will nominally be controlled between 65 F and 75 F in all habitable areas of the LSB. Selective, independent temperature controls, on an areas basis, are provided. The temperature of interior exposed surfaces with which a crewman may come in contact should not be less than 55 F for metallic surfaces or 40 F for nonmetallic surfaces, nor more than 105 F for both metallic and nonmetallic surfaces.

The water vapor partial pressure will be maintained between 8 to 12 mm Hg, and condensation on internal surfaces will be avoided. Air velocity will be maintained between 15 feet per minute and 100 feet per minute, with 40 feet per minute as the nominal ventilation flow rate. The capability will be provided to adjust the flow rate for crew comfort. Auxiliary ventilation for localized cooling and comfort will be provided, with both ventilation flow rate adjustment and selectable directional flow for certain areas. Provisions for odor control will be provided within each pressurized compartment of the LSB. Microbiologically and bacteriologically contaminated waste material will be disinfected as close as possible to its source prior to storage, processing or disposal, and the concentration of bacteria within the atmosphere and within each of the pressurized compartments containing crew quarters, process laboratories, or experimental facilities must be monitored and controlled by appropriate means.

Waste. Provisions are required for the collection, processing, and storage of both wet and dry waste materials (including fecal matter from the Dry Johns) that may be generated at the LSB. Waste materials will be treated, dried and compacted prior to storage and subsequent disposal. This process should meet the following criteria:

1. Wet wastes or trash that is susceptible to bacterialogical growth must be dried, deactivated and/or sterilized before compaction and storage.

2. Suitable waste collection containers must be provided throughout the base for short term storage (daily or every other day). These containers should be equipped with an additive for odor and bacteria control.

3. After deactivation, drying, and compaction, all wastes will be placed in a central storage area in preparation for final disposal.

4. Waste development rates on a man-day (24-hour) basis are shown in Table 5.4-10.

Table 5.4-10. Waste Products Generated

Source	Description	Basic Rate (lb/man-day)
Crew	Urine solids	0.13
	Fecal	0.38
Food management	Food waste	0.40
	Food packaging	1.18
	Utensils, soap, etc.	0.01
Crew related	Wipes	0.20
	Hair, nails, skin	0.05
	Toilet tissue	0.014
	Medical supplies	0.02
	Housecleaning supplies	0.02
	Soap, hygiene	0.033
	Dental	--
	Hair control	--
	Clothing, towels, etc.	0.58

Lighting. Lighting requirements as a function of area usage are shown in Table 5.4-11.

Crew Services

The crew services systems interfaces with the LSB crewman include the supply and processing of his metabolic intake and output requirements. The intake requirements include food, oxygen and water. The outputs include total thermal load, carbon dioxide, urine, feces, and the insensible water loss to the cagin atmosphere. The metabolic requirements are summarized in Table 5.4-12 for both shirtsleeve and EVA operations.

Table 5.4-11. LSB Lighting Requirements (Foot-Candles)

Area	Overhead (1)	Supplementary Local (2)	Emergency (1)	Low Level (1)
Crew staterooms	30	Desk 50 Bunk 50	5	0.5
Commanders staterooms	30	Desk 50 Bunk 50 Grooming 50	5	0.5
Primary galley	50	Work counter 50-70	5	0.5
Backup galley	10	Work counter 30	5	0.5
Primary dining	variable to 30 (3)	Eating surface 30-50	5	0.5
Recreation	variable to 30 (3)	30-50	5	0.5
Personal hygiene			5	0.5
Lavatories	30	50	5	0.5
Toilets	30		5	0.5
Showers	30		5	0.5
Exercise	30	-	5	0.5
Medical (5)	Selectable 50 and 150	Work counter 50-70	100 diffused 500 (4)	0.5
Work stations				
Maintenance/repair	30-50	Work counter 50-70	10	0.5
Experiment	30-50	Work counter 50-70	10	0.5
Control centers	variable 5-50		10	0.5
Airlocks	30		5	0.5
Aisles, passageways Tunnels-direct diffused	30			0.5

(1) Foot candles are measured 30 inches above deck.
(2) Unless specified, intensities are measured at the surface of use.
(3) Variable lighting to 30 foot-candles may be designed with 0.5 foot-candle low limit to provide night light.
(4) Auxiliary diffused illumination of 500 foot-candles will be provided, automatically actuated in event of power failure
(5) Diffused 500- to 1000-foot-candle lamp shall be located above the examination table and be directionally adjustable in medical and dental area.

Table 5.4-12. Metabolic Requirements Summary

I - IVA	
Intake Requirements	3200 kcal
Oxygen consumption	2.20 lb/man/day
Water - food and drink	6.63 lb/man/day
Food - total dry weight	1.70 lb/man/day
Output Requirements	
Total thermal load	13,000 Btu/man/day
Carbon dioxide	2.57 lb/man/day
Water loss (insensible)	2.46 lb/man/day
Urine	3.62 lb/man/day
Feces (wet)	0.21 lb/man/day
II - EVA	
Intake Requirements	4000 kcal
Oxygen consumption	2.70 lb/man/day
Water - food and drink	8.50 lb/man/day
Food - total dry weight	2.25 lb/man/day
Output Requirements	
Total thermal load	16,000 Btu/man/day
Carbon dioxide	3.71 lb/man/day
Water loss (insensible)	4.39 lb/man/day
Urine	3.19 lb/man/day
Feces (wet)	0.27 lb/man/day

In addition, the crew requires water for washing and cleaning to satisfy the following requirements:

1. Crew washwater - 4.0 pound/man/day
2. Crew shower water (based on three showers/man/week, minimum at 16.6 pounds of water/shower_ - 7.1 pounds/man/day
3. Dishwashing/housekeeping - 3.0 pounds/man/day
4. Laundry - not required

Hot water (155 F ±5 F) and cold water (50 F ±5 F) will be required in sufficient quantities for crew usage in both personal hygiene areas and food preparation areas. The capability will be required for mixing hot and cold water in a suitable ratio so as to provide water at a temperature comfortable for crew washing and showering.

Information Management

Audio and visual alarms are required in all habitable areas. The audio alarms will be both tone and voice with the voice alarm defining the crew action to be taken (e.g., preprogrammed crew actions). The visual alarms will be of the flashing light type and used primarily to alert the crew to the presence of a dangerous or potentially dangerous situation. Two-way intercommunications will be required between the primary or backup control stations and crewmen in pressure suits in the near vicinity of the base. Two-way RF communications are required between mobility vehicles and the shelter. Crewmen out on EVA from the vehicles will require RF communications with the shelter via the surface and flyer vehicles.

Additional communications requirements include:

1. The capability for private communications with the ground
2. The capability to receive selectable entertainment type audio and video communications (music and television)
3. The capability to broadcast (time-delayed) selectable earth radio and television programs

5.5 SHELTER EXPERIMENTS PROGRAM

The main purpose of the shelter is to provide a habitable environment and facilities for the crew. Many of the tasks to be performed inside the shelter were described in the previous section, some additional ones are: data analysis, housekeeping operations, shelter and experiment management, logistics planning, data transmission, preparation of equipment, data, and samples for return to earth, storage of cargo, and vehicle and equipment maintenance and repair. In addition, the shelter and environs can be used as a laboratory to perform non-site dependent experiments. This approach is particularly conducive to experiments which require numerous repetitions over a long duration.

A plan for such an experiments program is given in Table 5.5-1 which gives the experiments by identifying number, their minimum and maximum number of repetitions, the duration of a single repetition, and the IVA and EVA crew support times required (note that these are not necessarily equal to the experiment duration). These data were used to determine the shelter experiment weight, volume, and power requirements, to size the laboratory area, and to determine the science manpower required to support this plan.

The allocation of manpower to accomplish the experiments program is described in more detail in Section 1 of Part 2 and inAppendix F.

Table 5.5-1. Non-Site Dependent Experiment Plan

Discipline	Experiments	Lmtd to LSB Site?	Repetitions Min.	Max.	Duration of Experiment Operation	IVA (per man)	EVA in LSB Area
Bioscience	4001	no	75	250	40 hours	1/2 hr/sample	(per man - 2 men req'd per EVA)
	4003	yes	300	1200	150 hours	1/2 hr/sample	
	4006	yes	140	1400	duration of base	1/2 hr/test	
	4008	yes	3	10	" "	1/2 hr/test	
	4009	yes	6	36	" "	1/2 hr/test	
	4011	no	250	800	" "	1/2 hr	
Astronomy	4017	yes	1	10	1 year	10 hr	12 hr
	4021	yes	1	2	1 month	32 hr	20 hr
	4022	yes	4	32	4 months	4 hr/month	24 hr
	4023	yes	3	5	6 days	3 hr/day	12 hr
	4024	yes	30	90	30 days	1 hr/day	2 hr
	4025	yes	10	20	10 days	1 hr/day	3 hr
	4026	yes	1	2	1 year	0.5 hr/day	20 hr
Geology-Geochemistry	4032	no	1	300	As required	13 hr per EVA	6.5 hr per EVA
	4037	yes	50	1000		1 hr/sample	
	4038	no	10	50			0.5 hr/sample
	4048	yes	1	2	500	100	300
	4057	no	25	50	2 days		2 hr/traverse
	4059	no	1	10	4 hours		10 min. to 4 hr
	4060	yes	200	1500	duration of base	5-10 hr/day	
	4061	yes	200	1500	"	5-10 hr/day	
Geophysics	4045	no	2	6			15 hr (in conjunction with 4058)
	4046	no	25	50			15 hr (in conjunction with 4058)
	4047	no	no		continuous unmanned		1 hr
	4051	yes	30	90	cont. unman.		1 hr
	4058	no	25	100	50 days	2 hr	2 days
	4088	no	10	20	cont. unman.		
Geodesy/Cartography	4044	no	1/loc	2/loc			3 hr per location
Particles and Fields	4050	yes	60	100	2-3 months	2 hr/day	2 mo. - 3 mo. unmanned
Lunar Atmosphere	4053	no	50	200	2 months		2 months
	4055	yes	10	100			18 hr per release
	4064	yes	1	10	1 yr minimum		
	4066	yes	200	800	1 yr minimum		
	4071	yes	50	125	50 - 125 days		
	4074	yes	25	150	40 hours		360 hours
	4078	yes	15	50	50 hours		150 hours
	4079	yes	5	15	28 days/site		8 hr per site
	4081	yes	5	15	34 hours		
	4082	yes	5	15	13 hours		
	4084	yes	100	400	30 days	6 hr/day	
	4085	yes	100	300	5 hours		
	4086	yes	25	75	8 hours		
	4087	yes	5	50	4 hours		5 hours

1.0 SURFACE MISSION SYNTHESIS

The synthesis task is to provide an optimum conceptual solution for each of the missions defined in detail by the performance requirements of Part 1, Section 5. All of the concepts proposed herein will meet the mission requirements, and the objective is to find which is the most effective, i.e., which provides the best solution for the minimum cost. Possible technology development problems, such as the 200-inch segmented mirror, were not considered in the tradeoffs due to the long lead time available. It was assumed throughout that the concept which resulted in the minimum required weight delivered to the moon was also the minimum cost concept.

This section describes the various mission concepts proposed for the surface missions, the parametric data on performance, tradeoff comparisons, and the proposed approach. Additional details are found in Appendix G.

1.1 REMOTE EXPLORATION MISSION SYNTHESIS

Remote exploration mission synthesis has as its purpose the determination of the optimum transportation mode to deliver men and materials from either a surface base (LSB) or an Orbiting Lunar Station (OLS) to perform the remote exploration activities defined in the preceding parts of this volume.

1.1.1 Mission Concept Trades

For the remote exploration sorties on the lunar surface, three primary modes can be visualized:

1. Fly both crew and equipment to and from the site to minimize the enroute travel time

2. Fly the crew only and send the heavy equipment by unmanned surface vehicle to the site, in which case the crew would not leave the base until the equipment arrived at the experiment site

3. Utilize surface transportation both ways

In addition to the choice of the transfer mode, the scope of the sortie can be varied. Here, the alternatives are to either explore a single experiment site or explore a group of sites during the sortie. In general, it would be preferable to always explore more than one locale per sortie in order to get the most benefit from the investment in transportation time and consumables. However, this approach may not be possible if the sortie duration achievable with a particular mission concept is less than the time required to complete the exploration of one locale, transfer to the next, and complete exploration there.

Finally, the remote exploration sorties can be accomplished by crews based at an OLS, an LSB, or in a completely mobile base. Figure 1.1-1 summarizes the above discussion of mission concept options in a trade-tree format. The "Concept Description Number" on Figure 1.1-1 provides a correlation to Table 1.1-1 which presents the summary results of analyses of the concepts illustrated.

The parameters selected for the comparison in Table 1.1-1 include the initial mass of the mobility system concept to perform the sortie, i.e., either a manned tug or a surface vehicle. The mass of the OLS or LSB where involved is not included since they are shared with other lunar program missions. Also included in the comparison are the resupply mass per sortie, the sortie duration (resupply) cycle, and the total mass and time required to explore the selected model of an LSB site. The model assumes a typical site consisting of 17 locales, each requiring 16 days of exploration, and located at distances from a central LSB requiring an average of six days travel each way. Travel time between locales is assumed to average one day, and 14 days are allowed between sorties for debriefing, maintenance, and/or crew rotations. The weights are calculated at the delivery to lunar orbit, and include allowances for tug propellant for delivery and resupply to the surface, and for the tug missions where involved.

The conclusion reached from an examination of the data in Table 1.1-1 is that while use of the tug and flyer can reduce the program duration due to their lower travel times, the large mass of the propellant required increases the program mass delivered to lunar orbit and therefore results in a presumably higher program cost. Based on this premise and for the assumptions outline above, it appears that a central LSB concept utilizing surface mobility equipment for transportation to explore the immediate region is the optimum way to perform the remote exploration mission.

It should be noted that this conclusion only applies to those locales that are within a feasible driving range of the selected LSB site. As indicated in the earlier discussion of site selection for this study (Part 1, Section 5.1.1), not all lunar features of interest can be expected to be available at any one LSB site and some alternative concept will have to be adopted in order to achieve the scientific objectives associated with the missing features. Whether this alternate involves a second LSB, an OLS/tug, or some concept other than those described above, can only be determined after a future, more detailed site selection study is made and the missing elements identified.

1.1.2 Mobility Requirements

In order to implement the remote exploration mission concept selected in the previous section, mobility equipments will be required. Mobility support will also be required for other LSB functions. The following classes of mobility support have been identified (see also Figure 1.1-2):

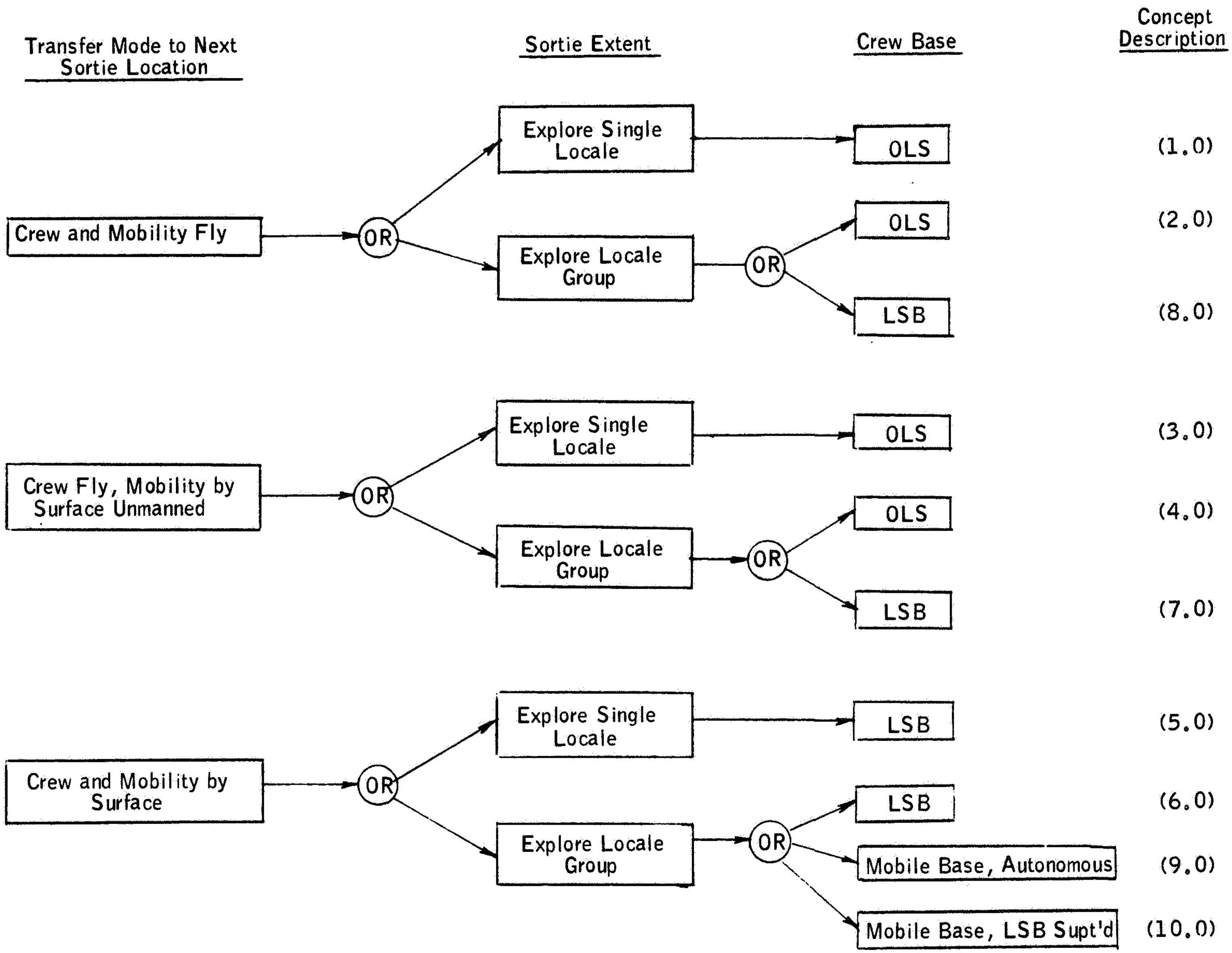


Figure 1.1-1. Remote Sortie Concepts

Table 1.1-1. Remote Sortie Concept Trade Data

Sortie Concept	Initial Mass (klb)	Consumables Per Cycle (klb)	Resupply Cycle (days)	Program* Mass (klb)	Min. Prog. Duration (days)	Special Considerations
OLS & TUG						
(1) Individual Locales	34.6	56.6	28	997	544	Use Tug shelter
(2) Grouped Locales	40.5	73.9	62	484	390	Mobile shelter req.
OLS, LSB & TUG						
(3) Individual Locales	71.4	41.7	60	694	374	• Personnel by Tug, supplies overland by LRV
(4) Grouped Locales	82.3	39	42	316	378	
LSB ONLY						LSB Dependent
(5) Surface to Ind. Locales	40.8	3.0	42	145	714	• for lab support
(6) Surface to Grouped Locales	46.9	6.7	77	110	462	• data reduction • vehicle maintenance • Tug for logistics
(7) Surface Resupply, Crew by LFV	48.7	8.9	67	157	402	
(8) LSB to Group by Tug	68.5	38	57	527	408	
MOBILE BASE CONCEPTS						
(9) Autonomous - Tug Resupply	113	48	70	400	450	Autonomous Prog.
(10) LSB Overland Resupply	92.5	9.1	58	203	360	LSB dependent

*Excludes crewmen

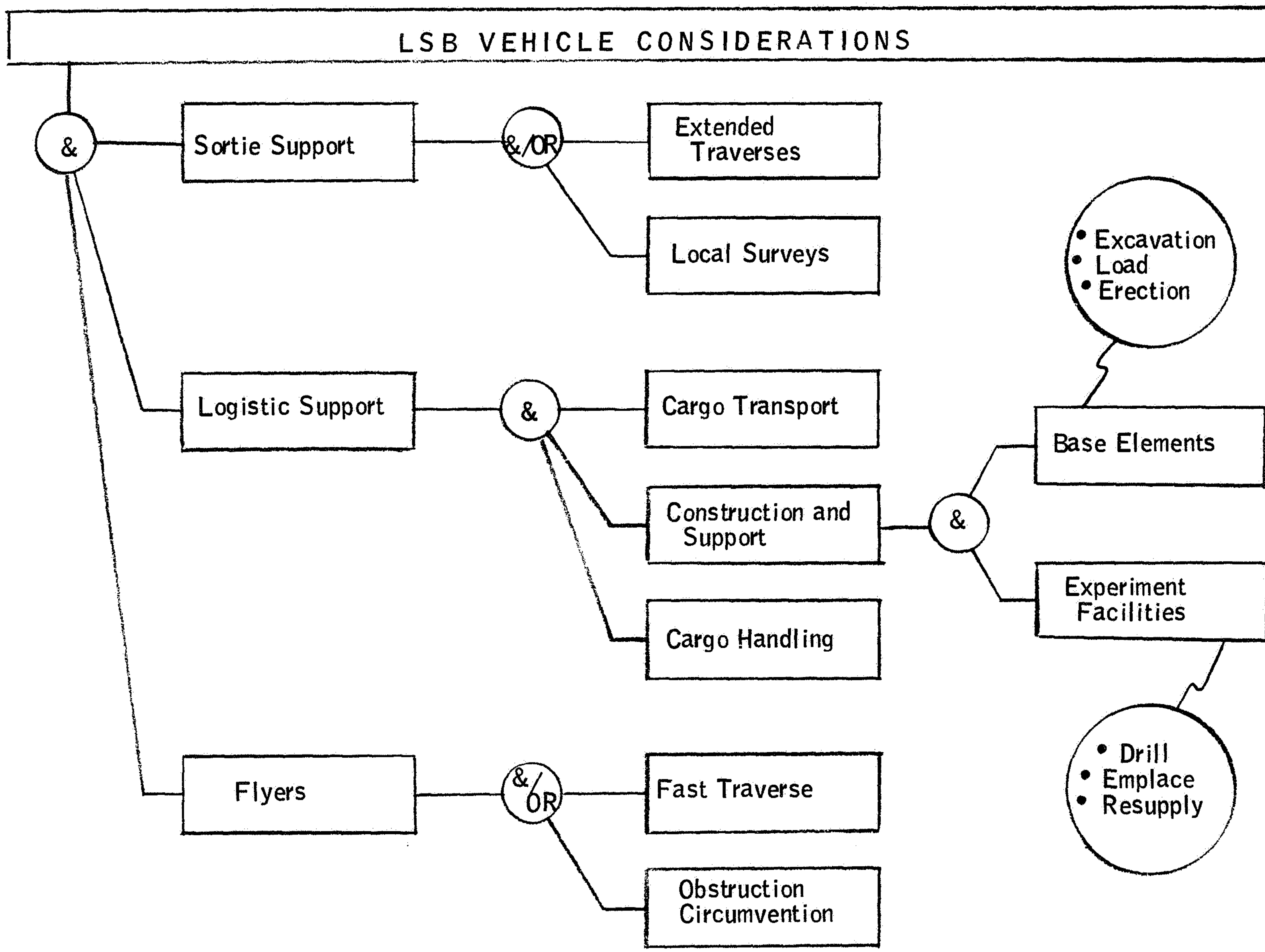


Figure 1.1-2. LSB Mobility Support Classes

1. Extended Sortie - a surface mission involving one or more vehicles in a multiday exploration trip away from the main base, wherein the crew is required to eat, sleep, and work on the trip.

2. Local Sortie - a surface mission within short radii from a mobile or fixed base such that return to the base is accomplished within a single 24-hour work budget.

3. Flying Support - flying vehicle may be useful either for fast traverses over longer ranges than a simple surface vehicle will permit, and/or for circumvention of or access to features of high relief in excessively rough terrain.

4. Logistic Support-Construction - involves a local activity wherein the base elements or scientific systems are assembled, transported, and/or maintained.

5. Logistic Support - Cargo Transport and Handling - involves the logistic vehicle loading and unloading, movement to the base storage facilities, and the loading into the facility. This requirement covers both transport and handling equipment.

6. Automated Unmanned Rover Sortie (not shown) - is similar to duration (1) above, but is completely automated and may be controlled from MSFN or the LSB if communications permit.

In the interests of obtaining maximum utility from a minimum number of vehicles, it would appear desirable to incorporate multiple functions into a single vehicle design. These functions could involve: mobility, living quarters, material handling, and construction assistance. The material handling and construction functions can be handled through attachments without serious compromise to the vehicle (Reference 13). However, the combination of mobility and living quarters, particularly for the longer missions, can impose some severe design requirements.

Numerous studies have concluded that the amount of free (living) volume per man has a definite effect on his performance. Figure 1.1-3 summarizes the results of these studies, and presents three levels of operation for the crew: no improvement where no functional degradation occurs; minimum degradation, wherein there is noticeable psychological effects with minimal functional degradation; and intolerance, where unacceptable performance is observed. These studies were conducted for continued confinement and it is reasonable to expect improvement when EVA time and a trained, highly motivated crew are considered. These constraints, however, provide a lower bound for long missions when even the best training may be overcome by this psychological influence. The average sortie is expected to take the crew away from home base for from 40 to 60 days. From Figure 1.1-3 it may be seen that the minimum free living volume for reasonable performance capability should be about 180 cubic feet per man and the average mission requires about 220 cubic feet. As indicated on the figure, the boundaries for previously considered vehicles do not provide adequate volume for the expected LSB extended sorties.

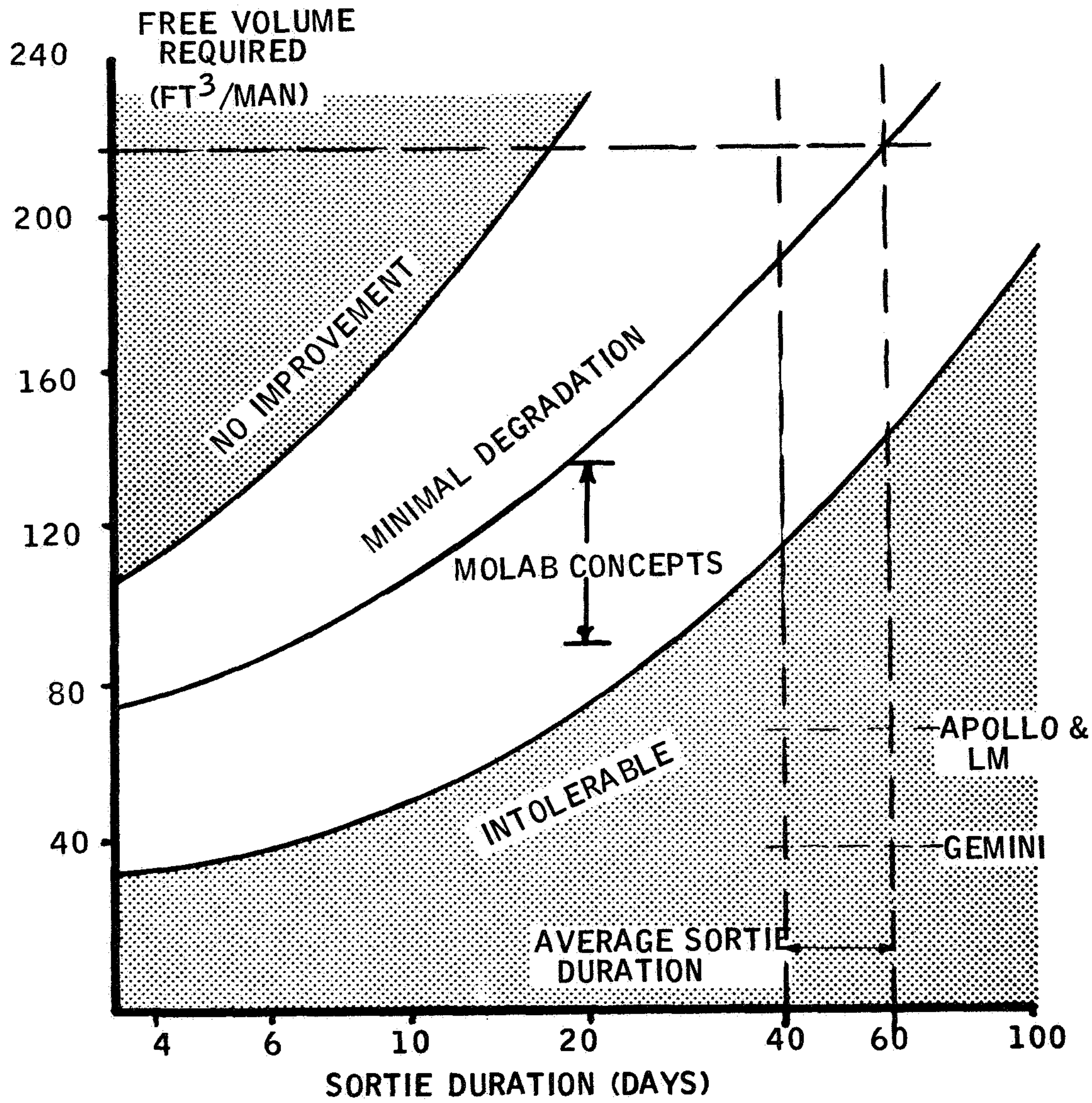


Figure 1.1-3. Sortie Cabin Volumetric Requirements Parametrics

All of the features and locales to be explored require some amount of local travel at the site and some are quite extensive. In addition, the activities at the main shelter will require multiple trips to outlying elements of the installation there. As indicated in Figure 1.1-4, the operating range and travel mode to the work site affect the EVA working hours and therefore the total time required to accomplish the task. These constraints make it highly desirable to provide the mobility equipment which is used for these local trips with some degree of living quarters to permit at least two full days work before being required to return to the shelter. Since all EVA will involve two-man crews in a "buddy system," the habitability provisions should provide for two men.

Also indicated on Figure 1.1-4 is the capability of the crewman on foot. As shown on the Apollo missions to date, a crewman can travel on foot using the loping "gait" possible in 1/6-g, almost as fast as a wheeled vehicle is predicted to be capable of over semi-rough terrain. The limiting factor, which constrained Apollo 14, is that the crew cannot transport equipment while traveling in this mode. The capability does provide a safety benefit however in the event the mobility equipment is disabled.

Figure 1.1-5 indicates the trends in the mobility cabin weights to provide increasing free living volume. The total mobility system payload weight including the cabin, scientific equipment, crew, and supporting consumables have a direct influence on the vehicle operation. The payload to total mass ratio will normally be approximately 0.8 and the mobility power is about one kilowatt per mile traveled for each 10,000 pounds of total mass.

Selection of a mobility concept for LSB applications must include consideration of all of the factors discussed above. The total living volume required for the sortie durations involved would lead to a vehicle which would be wasteful of power if used for the local travel activities and the construction and logistics task. A combination of at least the two following types of surface vehicles are required:

1. A prime mover with shirtsleeve habitability provisions for two men, capable of autonomous operations for up to 48 hours away from a shelter, and with interfaces for attachments to accomplish the construction and logistics tasks.

2. A mobile shelter which can be transported to an exploration site and provide adequate habitable volume for the four-man sortie crew for the sortie duration.

Additional vehicles may be required to transport other major equipment elements required on the particular sortie mission, e.g., the 100-foot drill and/or a lunar flyer. A typical concept is illustrated in Figure 1.1-6. This concept embodies all of the requirements and constraints identified above. The two prime movers provide redundancy, "back-out" steering, and two 2-man vehicles for local exploration when the remote locale is reached. These requirements in conjunction with the performance requirements in

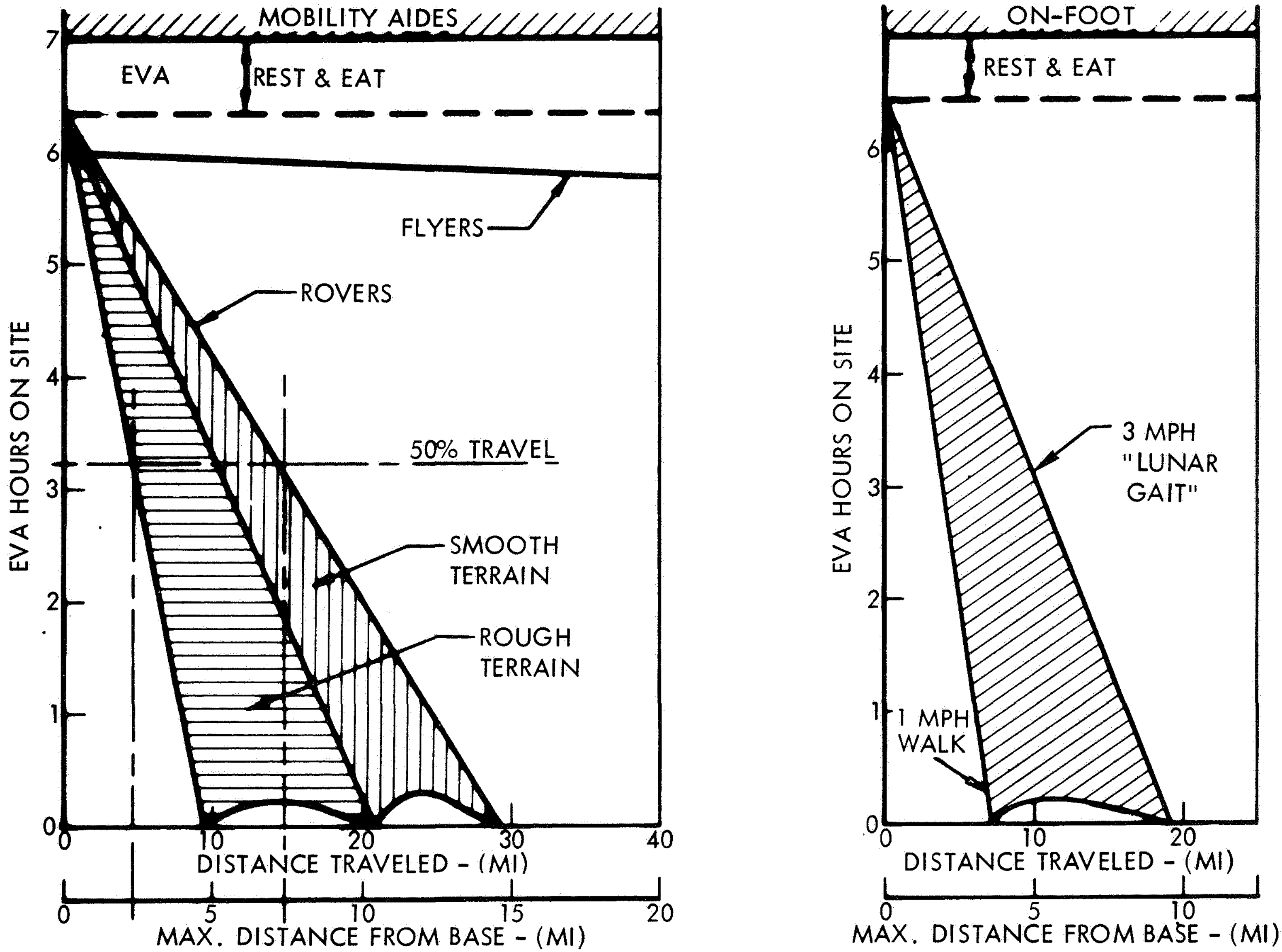


Figure 1.1-4. Travel Rate Influences on Work

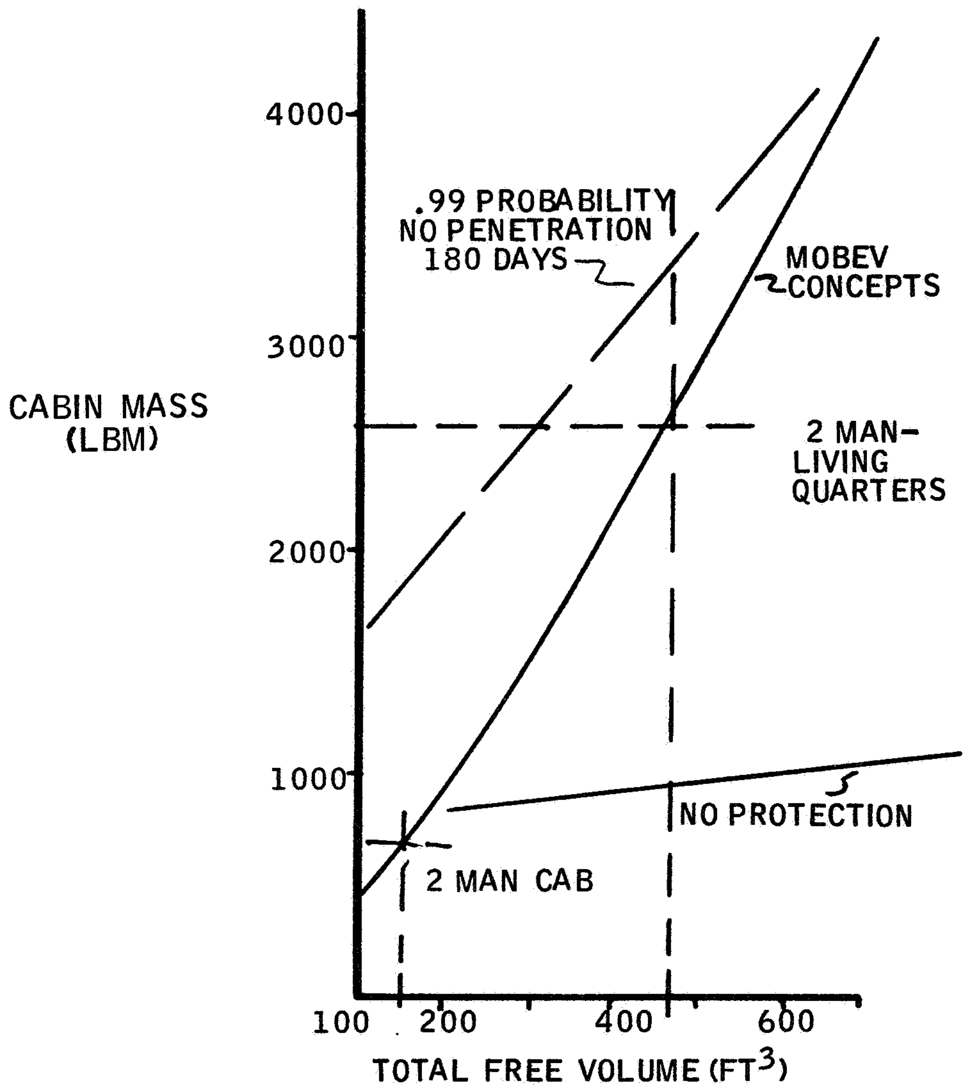


Figure 1.1-5. Cabin Mass Estimate

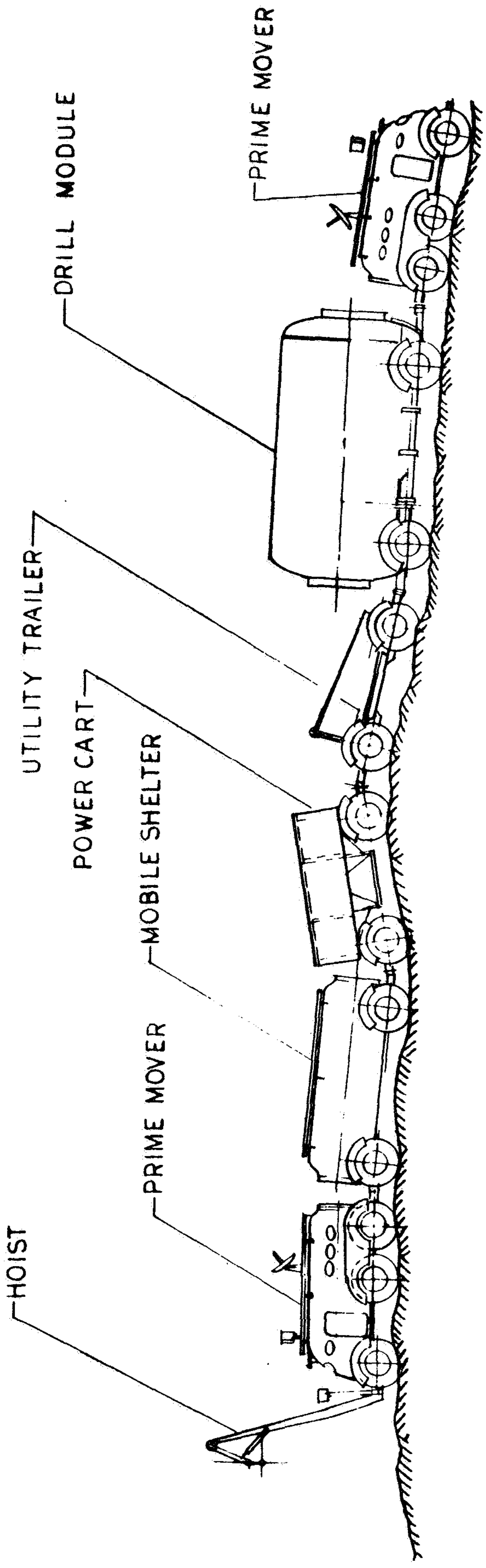


Figure 1.1-6. LSB Transportation Mode

Table 5.1-14, in Part 1 of this volume and the requirements arising from the lighting constraints discussed below, comprise the total mobility requirements for the remote exploration missions.

1.1.3 Lighting Constraints

Lighting conditions are of particular significance on the lunar surface because of the lack of a diffusion medium. Even bright sunlight does not provide adequate resolution at times and a high sun angle can produce "wash-out" due to low contrast. Inability to differentiate will reduce the average sortie speed.

In addition, the ability to drive during the lunar night would greatly increase the overall mission range and shorten mission duration. To date, however, investigations have provided only general guidelines for determining the impact on the mobility subsystems design and, in general, have inadequately treated lunar mobility operations during the lunar night. Four primary factors are affected by night operations: (1) ability to drive, (2) ability to navigate, (3) thermal control requirements, and (4) artificial lighting requirements, are discussed below. Their relation to the mobility system is summarized in Figure 1.1-7.

On the basis of this investigation into the feasibility of night operations, the following qualitative operating regimes have been derived:

1. Day driving - establishes a datum for qualitative comparison.

2. Night driving, full- to half-earth earthshine - driving possible with moderate reduction in traverse rate; landmarks are discernible with aids for reasonable accuracy in navigation; slight modification for heat paths from a thermal source necessary; moderate artificial illumination required for shadow, crevice, and obstacle supplementary lighting. Probable average speed reducing from day driving varies from 25 to 35 percent.

3. Night driving, half-earth to quarter-earth earthshine - driving ability still maintainable with existing light, but with more frequent starts and stops, hence slower rate; landmarks discernible for correlation with starfield mappings for navigation; same thermal control as above; additional and more frequent use of lighting than above. Probable average speed reduction varies from 35 to 75 percent.

4. Night driving, quarter-earth earthshine to no earthshine - driving ability considerably reduced due to very frequent stops for situation evaluation. Feature recognition may be impractical and navigation by starfield mappings alone

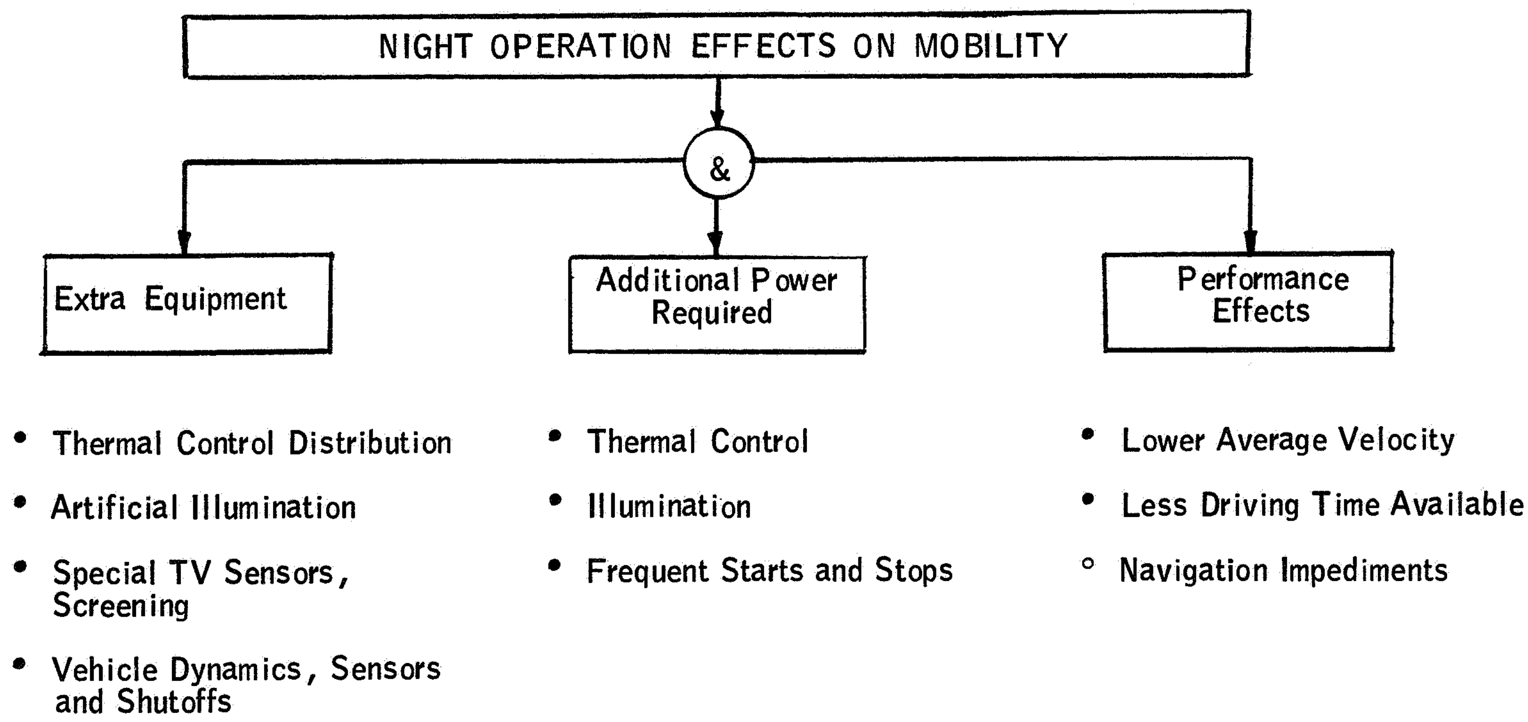


Figure 1.1-7. Night Operation Effects

is not considered accurate enough. Further, thermal control and additional lighting for driving and situation evaluation impose other penalties. Travel under these conditions is considered highly restricted.

Thus, driving may be possible in all the above regimes, but for night driving with less than a quarter-earth shining, the operation may become prohibitive in terms of power required, navigational accuracy, and traverse rate. A simplified speed profile was utilized in order to compute mission durations. The average daylight speed was taken as 3.5 miles per hour, and nighttime speed as 1.8 miles per hour.

Existing light intensifying cameras may permit the control of a vehicle in the lunar night via TV picture with only earth- or star-shine available. Artificial light for shadows and crevices may be necessary when applicable, but satisfactory operation is possible otherwise. A loss in resolution in the intensified TV picture may necessitate automatic shut-offs activated by vehicle dynamic sensors in the case of a hazardous situation.

The vehicle performance is affected by night operation primarily by increased power loads for auxiliary lights, power train thermal control, extra sensors, frequent starts and stops which require greater recharge time and also by more starts and stops for evaluation of hazardous situations.

Periodic landmark sightings to update a dead-reckoning navigation system are mandatory for an accurate position fix. Under reduced natural lighting conditions, artificial lighting or sophisticated sensing devices are required to establish a fix and each of these systems are high power consumers. Because of the importance of this problem, a brief study was made to select a feasible dead-reckoning system. The results are summarized in Appendix D. The selected subsystem weighs 64 pounds, requires 58 watts, and has an acceptably low position error.

The lack of solar radiation requires additional equipment to provide heat paths and possibly additional heat sources to provide thermal control. The internal thermal dissipation required depends upon the actual system. Typical penalties are shown in Table 1.1-2 for the dual-mode lunar roving vehicle (DLRV).

Lighting is required for shadow and crevice illumination and for obstacle identification. It has been estimated that about a 40-watt source would be sufficient to meet these demands (Reference). EVA or remote reconnaissance lighting requirements are a function of range and require illuminated area. Here, it is estimated that 500 watts would be required.

Table 1.1-2. DLRV Thermal Control Requirements - Lunar Night Operations

Thermally Controlled Component	Quiescent Mode			Driving Mode*	
	Minimum Storage Temperature (°F)	Cover-On Heater Requirements (watts)	Cover-Off Heater Requirements (watts)	Minimum Operating Temperature (°F)	Cover-On Heater Requirements (watts)
Battery	+40	7	45	+40	7
Power control unit	0	6	28	0	6
Nav. comm.	-65	4	19	0	6
Mobility controller	-65	5	32	-40	7
Crew station	-65	4	11	0	5
Drive mechanism	-300	6	6	-40	180

NOTE: These values are total internal thermal dissipation required to maintain the indicated minimum temperatures.

* Cover-off mode is not feasible at lunar night

1.2 OBSERVATORY MISSION SYNTHESIS

The objective of this mission synthesis was to determine the optimum physical relationship of the seven telescopes which comprise the observatory with the shelter. Diverse site requirements apply to each telescope but widely-separated facilities mean overlapping manpower, data processing and transmission equipment, shelters, and logistics flights. Also, the shelter is expected to be a source of noise, vibration, dust, and contaminating gases which would preclude a common structure.

1.2.1 Mission Concepts

The single site which would best satisfy all telescope pointing and environmental requirements is located on the far side and on the equator. Such an observatory could require its own separate shelter for its four astronomers and additional support personnel to maintain the shelter. The OLS, if operational, could be used as a communications and data relay system to reduce the cost of a separate lunar satellite communications system. Only periodic contact would be possible with the polar-orbiting OLS which is in a low-altitude orbit.

A colocated LSB would reduce the program costs by sharing common services and skills. However, no need has been established for extended geoscience exploration on the extreme far side as all the desirable features can be found on the near side and on the limb.

A third alternate is similar to the first except that no OLS is presumed available; therefore, a special communications satellite system is required.

The same three concepts can occur on the near side and also on the limb, but always on the equator in accord with the performance requirements. These options are shown schematically in Figure 1.2-1.

1.2.2 Optimum Mission Selection

The primary observatory variables are site location and degree of isolation from LSB noise and vibration. A highly automated facility requiring minimal crew support is assumed at a centralized observatory with all telescopes located at a single site. Program duration is not a factor in the trades as all the astronomy experiment requirements are open-ended. The observatory mass to be assembled is constant for all concepts.

Therefore, the selection criteria included the time to assemble the observatory and its communication equipment, the initial mass of facility and equipment, the program mass required for the first year, and the six-month resupply mass. The trade study results are shown in Table 1.2-1.

The selected concept was the one with the LSB colocated on the limb because it was the least cost for this location. Near-side concepts, although providing the absolute minimum cost, were deleted because of earthshine-induced limitations on the optical, IR and low-frequency radio telescopes' exposure

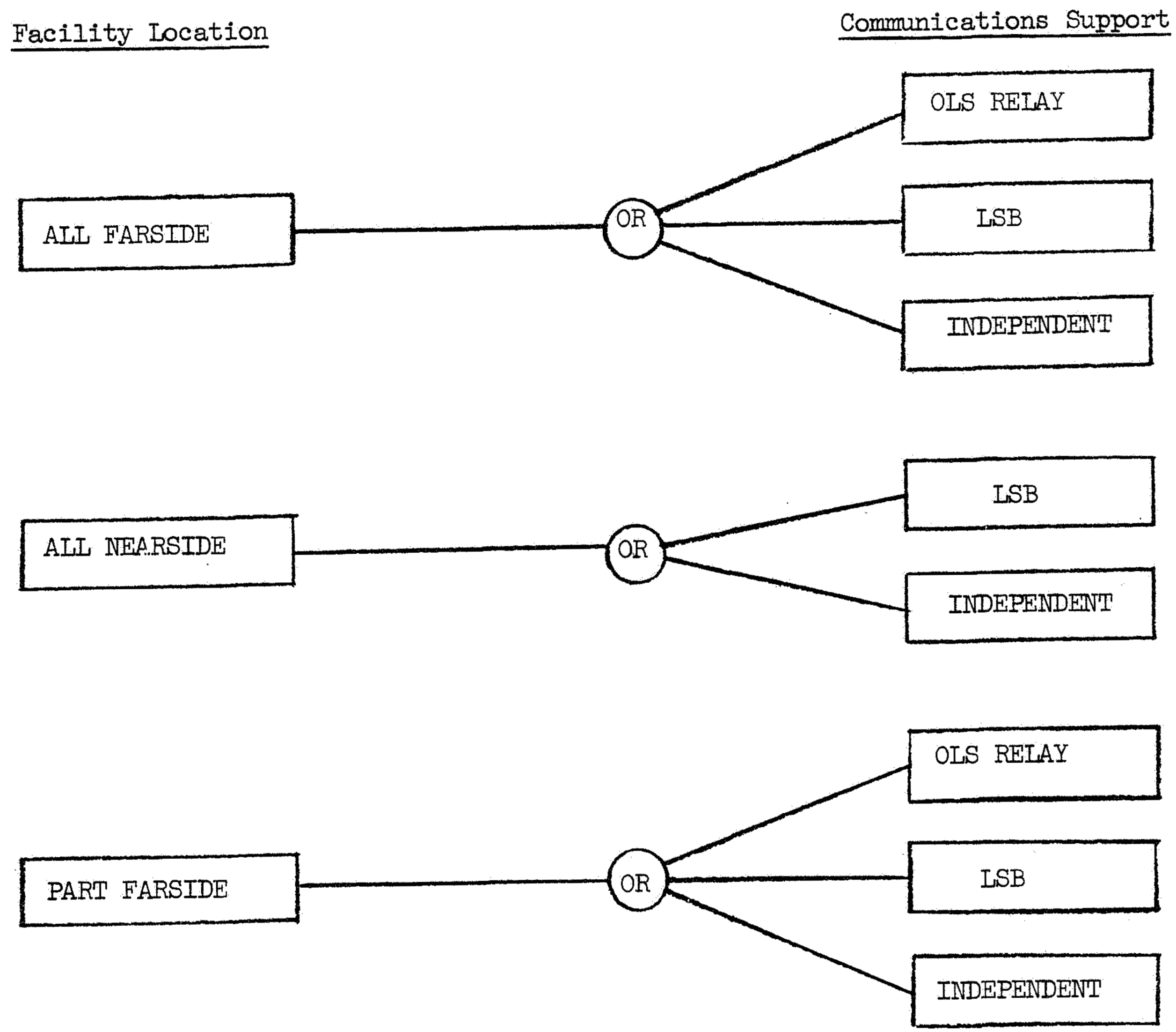


Figure 1.2-1. Observatory Sortie Options

Table 1.2-1. Observatory Concept Trade Data

Mission Concepts	Installation Time-Min. (days)	Installation Mass(2) (klb)	Program Mass(1)-1st Year (klb)	Resupply Mass(1)-180 Days (klb)	Operational Considerations
<u>All Facilities Farside</u>					
Communication via OLS relay	107	99.0	299	12.2	Periodic contact
Dependent on LSB for services	102	66.7	221	12.2	Comm. link charged to LSB
Independent	147	100.0	310	14.7	Deploy & maintain comm. link
<u>All Facilities Nearside</u>					
Dependent on LSB for services	102	66.7	221	12.2	
Independent	107	99.0	299	12.2	4-man base
<u>On Limb - Part Farside</u>					
Farside communication via OLS relay	107	123.0	370	21.3	2 three-man bases, overland resupply to remote site
LSB colocated on limb	141	99.0	299	14.7	Deploy & maintain comm. link; overland resupply to remote site
Independent	148	124.0	375	21.3	2 three-man bases, overland resupply

(1) In lunar orbit
(2) On surface for installation only, no operations

times and viewing areas. Far-side concepts were dropped because an acceptable geoscience exploration site was not found along the equator. The co-location was desirable as the trade data indicate considerable savings with a co-located LSB observatory due primarily to sharing the shelter, maintenance personnel, and communications equipment.

The desirability of this concept was enhanced because a rich geological site was available on the leading limb in Mare Orientale. The coincidence of these two sites permitted the mutual site requirements to be jointly satisfied with a slight compromise to the observatory. The RF shielding may not be as effective as the full far-side location and libration will reduce the optical viewing times somewhat. The communications problem will not require an OLS or satellites but some relay towers will be necessary for 100 percent communication with earth during maximum libration periods.

1.3 DEEP DRILLING MISSION SYNTHESIS

Synthesis of the deep drill mission requires evaluation of EVA versus IVA operations and of the alternate bases of operations for the drilling crew - orbit or surface. Also to be evaluated are the noise, dust, and vibration associated with drilling in proximity to the shelter or the observatory. The IVA drilling time, determined earlier, was 100 days compared to 180 days with EVA. The penalty paid for this time reduction, however, is the increased weight of the drilling module to be transported to each site.

1.3.1 Mission Concepts

The alternate deep drilling mission concepts are shown schematically in Figure 1.3-1. In Concept (1) the EVA drill and crew are delivered by tug from the OLS and the tug is used as a surface shelter for the crew. The drill is not attached to the tug but carries its own footings for stability. Since the tug surface duration is presently limited to considerably less than 180 days, several tug and crew rotations will be made during the drilling for resupply of the crew.

Concept (2) is similar to the above except a two-man shelter is also delivered with the drill and crew together with supplies which permit the crew to remain at the site without resupply for the 180 days. This reduces the number of tug flights.

Concept (3) is similar to Concept (2) except that a drilling shelter and tunnel/airlock are deployed to permit full IVA drilling operations with the attendant time reduction.

A similar set of concepts were developed substituting the LSB for the OLS and a surface vehicle for the tug. Concepts (4) and (5) have EVA drilling occurring immediately adjacent to the shelter and three to four miles distant, respectively. Concepts (6) and (7) have IVA drilling adjacent to the shelter and at a distant exploration site. This concept assumes 40 days are required to travel, complete preliminary drilling, and deploy the mobile shelter and the drilling shelter.

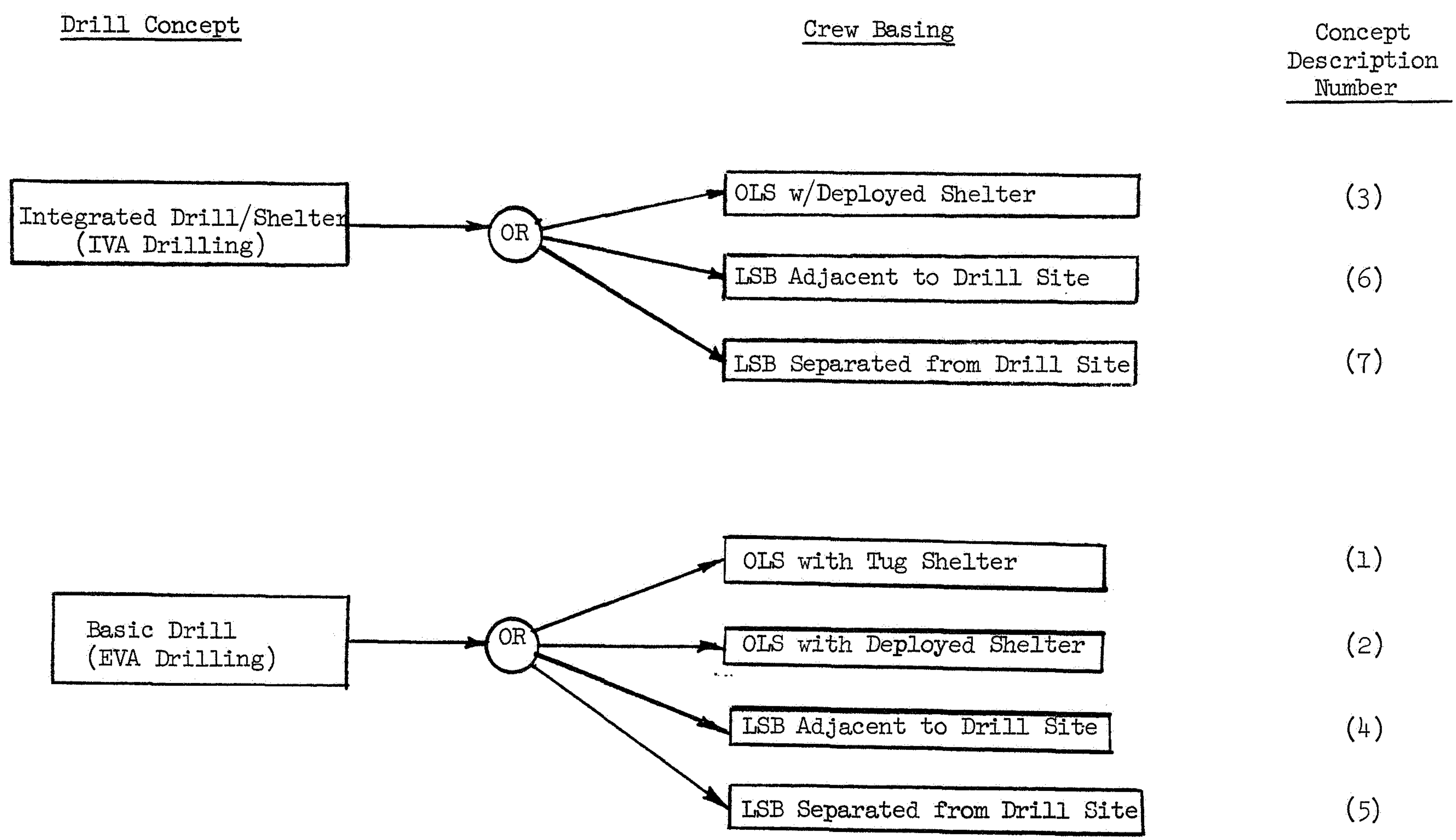


Figure 1.3-1. Deep Drilling Sortie Concept Options

1.3.2 Optimum Mission Selection

The same basic criteria are used for deep drilling mission selection as for remote exploration sorties. Sortie duration is based on drilling two 1000-foot holes, in agreement with the mission performance requirement. Each hole requires 180 days for EVA operations not including setup or disassembly and maintenance which require 25 and five days, respectively. For IVA drilling the drilling time drops to 100 days. These figures are based on a semiautomatic drill rate of four feet per hour, using core barrels 10 feet long and a drill weight of 4,200 pounds.

The results are shown in Table 1.3-1 which lists the concepts, the evaluation criteria, and some special considerations regarding assumptions on allocating weight penalties. Concept (6), the IVA drilling operation near the shelter, was selected for the LSB because it was the minimum cost and the shortest program. This concept was subsequently expanded to provide greater mobility for the drill by making the deep drill an integral part of a special drilling module, adapted from one of the logistics transportation modules, and adding a chassis and powered wheels. In this manner it can be driven with the surface vehicle to remote sites.

Table 1.3-1. Deep Drilling Concept Trade Data

Mission Concept (a)	Initial Mass (klb)	Consumables per Cycle (klb)	Optimum Resupply Cycle (days)	Program Mass (klb)	Min. Duration (days)	Special Considerations	
WITH OLS ONLY							
(1) Tug-Shelter/ EVA Drill	36.8	4.6	60	335	447	Tug constrained staytime	(c)
(2) Deployed Shelter/ EVA Drill	25.7	7.1	140	167	436		(c)
(3) Integrated Shelter/IVA Drill	19.9	7.1	140	115	280		(c)
LSB PROVIDES HOUSING							
(4) EVA Drill - local	14	6.7	140	134	427	(b)	(d)
(5) EVA Drill - 1 hr travel	18.5	7.9	160	152	469	(c)	(d)
(6) Integrated Drilling Shelter @ LSB	15	6.6	138	99.7	275	(b)	(d)
(7) Drilling Outpost	28.2	7.4	140	126	288	(c)	(d)

(a) Two holes/site
(b) LSB provides personnel housing and vehicular support
(c) Vehicles and power trailers charged to program
(d) Includes tug fuel

1.4 CREW CAPABILITIES

Man's metabolic processes and requirements impose certain limitations on his capabilities in the lunar environment. The effects of reduced gravity and the personal protective equipment which must be worn for all external surface operations require careful planning of his time and work output in order to achieve a continued and acceptable level of crew performance. It is the intent of this section to provide the metabolic criteria needed for defining crew requirements to be used in design of the shelter, spacesuit operation, base life support consumables, and work output and crew sizing.

1.4.1 Crew Metabolic Capabilities

The crew has definitive requirements, capabilities, and limitations. However, the assignment of absolute values is complicated due to differing metabolic rates in relation to variations in crewman size and weight. In addition, these variations in response to size are not constant due to the modifications of age, fitness, hormonal, and enzymatic individual differences. As an example, in a given population of men, one of small stature may be able to do more work and require more oxygen and replacement water than a much larger individual. Considerable effort has been made to relate metabolic costs to body surface area, weight, height, body type, and degree of "physical fitness." It has been established that the fitness of an individual, which is related to cardiovascular-pulmonary endurance and neuromuscular conditioning, modifies the ability of a person to accomplish work, with increased metabolic efficiency and decreased oxygen-food costs. Further, skill and coordination also improve the overall efficiency of individuals, thereby modifying the total energy expenditure for specific tasks.

Extrapolation of the present data from actual flight programs and development of additional knowledge applied through experimentation in future space efforts will enable the physiologist to delineate with greater certainty the metabolic requirements for long-duration missions. However, certain recommendations can be made utilizing the limited data available from past space flights, and data from earth-bound experimental programs.

It is reasonable to assume that members of the LSB crew should normally be able to maintain a work level at approximately one-third of their aerobic work capacity for more than eight hours. Utilizing the mean values of the Gemini astronauts, this value is approximately 380 kcal per hour (1,120 Btu per hour). This value represents the level of work which is operationally self-paced and results in optimum physiological efficiency. As evidenced during the Gemini flights, this value will probably be exceeded significantly for short periods of time, especially during EVA and emergency conditions.

Figure 1.4-1 illustrates that the maximum measurable work which man can sustain until exhausted is greatest for periods of less than one minute. Physical conditioning is of the greatest importance, as is evident from the difference in the two curves, where even the "healthy men" are subjects who are young, physically active, and accustomed to the work performed in the tests. Data on continuous energy expenditure for periods beyond one hour are very meager. However, it is generally agreed that healthy, well-conditioned

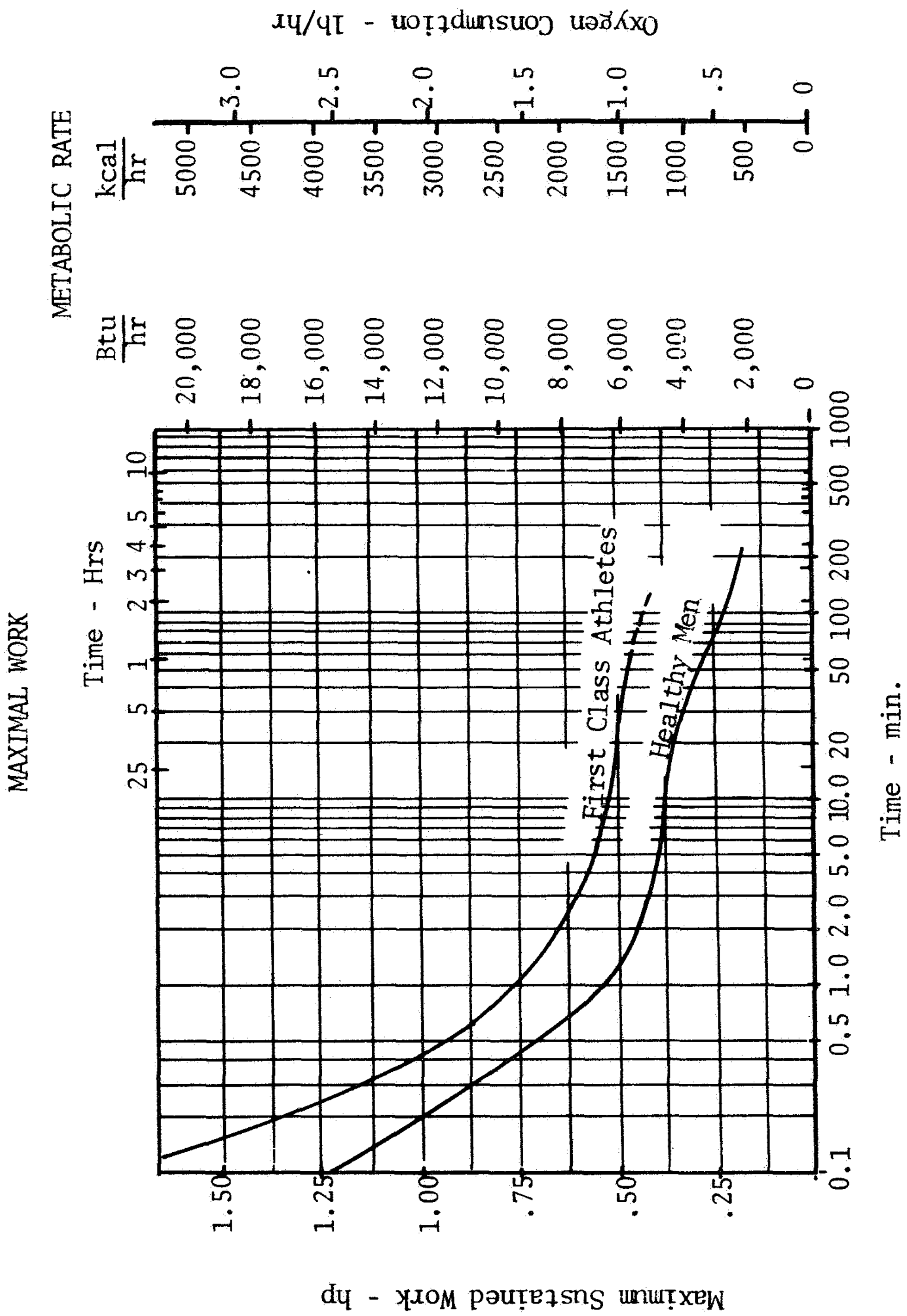


Figure 1.4-1. Maximum Sustained Work Capacity of Man
(Reference 15)

men such as the selected astronauts can sustain 1,800 Btu/hour output for approximately six hours. Also, such men can sustain a heavier activity output of 2,200 Btu/hour for approximately two hours prior to exhaustion. Efforts that exceed 2,000 Btu per hour result in the utilization of anaerobic metabolic pathways and are self-limiting. As an example, peaks of 5,000 Btu per hour can be accomplished for a period of one to two minutes but require as much as five to ten minutes of rest for recovery.

Experimental evidence indicates that significant subject-to-subject differences exist, even in men of the same approximate size. These differences give rise to variations as high as 60 percent, within a given population, when different men perform the same tasks. These differences vary as much as 30 percent when adjustments for body size are made, and as high as 10 to 15 percent when repeated measurements are made on the same individual. Therefore, the establishment of an absolute value would require that the measurements be performed on the man, under carefully controlled conditions, using the exact tasks to be employed in the activity of interest. While the ergonomic literature includes the range of 1,250 kcal (4,960 Btu per day) for a man at rest to 5,750 kcal (22,819 Btu per day) during heavy work, the cost of crew operations in lunar environment lie somewhere between these values.

Lunar surface operations are made up of basically the same types of tasks required to support similar space- and earth-based scientific programs. In the case of lunar surface systems there are two basic modes of operation, the shirt-sleeve or internal functions and the extravehicular functions that must be conducted external to the spacecraft or lunar shelter. There are certain physical limitations for both modes, but those associated with EVA operations are much more restrictive and cause a greater impact on the number of crewmen required to accomplish a task or group of tasks and will in all probability require more crew time and energy than their counterpart earth-based or shirt-sleeve tasks.

The Extravehicular Mobility Unit (EMU) consists of the complete pressure garment assembly (PGA) with integral thermal meteoroid garment, the portable life support system (PLSS), the liquid cooling garment, the EVA gloves, and the EVA visor assembly. Once the crewman has donned the EMU and checked out the life support systems he is ready to begin his EVA tasks. The various limitations imposed on the crewman while in the EMU and in the lunar environment are concerned with time, the forces he can exert, walking speeds, ascending and descending ladders, stairs or rough lunar terrain, body positioning, lifting and carrying limitations, and the limitations in the use of tools and equipment.

Simulation studies have provided remarkably similar results in predicting energy costs of locomotion in the lunar surface. These preliminary studies of locomotion using simulators have indicated that the metabolic costs in lunar gravity for a man in the two to four mph range of locomotion in a pressurized suit will probably be equal to or be as much as 50 percent less than that required by the same crewman in the unpressurized condition in 1 g. Also, these studies indicate the metabolic costs (shirt sleeves) for certain tasks may be slightly more while those for walking may be considerably less.

As reported for both Apollo 11 and 12 crews, their EVA metabolic rates were somewhat less than those predicted, based on the simulation studies. Both crews reported that it was difficult to walk "heel-toe, heel-toe," on the lunar surface because of the suit restrictions on mobility. Also, they reported a rate of about four feet per second which is a normal earth walking rate but was accomplished by a loping, stiff-legged, flat-footed movement to which they had no difficulty in adapting.

For purposes of this study all EVA operations were scheduled and time-lined based on Apollo results and also take advantage of the crewman's natural tendency of self-pacing his energy output at an approximate level of 1,100 Btu per hour ± 10 percent depending on the individual. Thus, there should be little possibility of endangering the crewman by exhaustion should an emergency arise.

Ascending stairs and ladders appears to be easier because of the reduced gravity since the astronaut can see where to put his feet. This also applies when going up inclined lunar terrain, but descending down over rough terrain or stairs will require considerable care in placing the feet since he is hindered by the lack of vision.

Human physical capabilities put a limitation on the size and weight of equipment/cargo that can be safely handled by one crewman. As a general rule for 1-g shirt-sleeve operations the more compact the item the more easily it can be handled. For bulky equipment, the center of gravity should not be more than 20 inches from the carrier's body, and the weight of bulky items (approximately 30 inches on a side) should not exceed 20 pounds if they are to be carried any distance. Package/item weight is considered heavy when it reaches 35 percent or more of the carrier's body weight. As an example, a 180-pound crewman should not handle more than 60 pounds in 1-g. For lunar surface 1/6 g operations, a good "not-to-exceed" limit would be 50 pounds (300 pounds earth weight). This maintains an acceptable weight limitation within the guidelines and provides a slight margin for the additional restriction on mobility of the crewman in the EMU.

Earlier studies utilizing 1/6 g simulator where test subjects carried loads of up to 500 earth-pounds in the shirt-sleeve condition walking, sprinting, and loping has provided much data. It was found in these tests that maximum loads could be handled much easier if they were strapped on as a backpack. The maximum load of 500 pounds earth weight used in these tests is very close to what the LSB crewman would be carrying if the weight of the EMU is added to the 300-pound earth weight (50-pound lunar weight) suggested for one-man-lunar-carrying tasks.

Probably the most important body positions for exploration aside from the upright position required for walking are stooping and kneeling. Stooping and kneeling in the present Apollo EMU are very difficult if not almost impossible. Tools were furnished for retrieving surface samples, and one of the suggestions of the Apollo 12 crew was to lengthen the handle of the trenching tool so subsequent crews could dig deeper trenches.

Another limitation imposed on the crewman in the EMU is his ability to pick up, manipulate, and operate various tools and controls because of the lack of flexibility in the arms and wrists of the suit. Obviously his tactile sense and finger dexterity are reduced because of the bulkiness of the extravehicular gloves. However, on the Apollo 11 and 12 EVA there was no difficulty in operating PLSS controls but use of the hammer in driving core tubes provided a minor problem, because of restricted arm mobility, and caused inaccuracies in striking the tube.

It is anticipated that the spacesuits available in the 1980 time period will provide enough additional mobility to overcome the problems of flexibility which impede the functions of kneeling, stooping, and the handling and operation of the tools and experiment equipment needed for lunar exploration.

Overall increased mobility of the suit will allow higher torque forces to be exerted by the crewman and also provide some reduction in the time required to accomplish a given task.

Current spacesuits utilizing combined gas and liquid cooling systems provide adequate thermal regulation for the crewman at the expected levels of energy expenditure for lunar operations. The great disadvantage of these suits is the restricted mobility which in turn holds down work accomplished.

A relatively new idea considers use of the crewman's skin as a gas tight bag which only needs additional support in the form of an elastic mesh porous restraint garment that will prevent the skin from yielding to the potential distortion of gas forming in the tissues. It is now known as the space activity suit (SAS) in which it appears the crewman would gain a considerable increase in mobility and lose some of the complex life support equipment (Reference).

A full space activity suit is a complete elastic leotard with integral gloves and socks. A partial pressure helmet and full breathing bladders are part of the assembly. The lower part of the back does not contain a bladder but is heavy elastic material to allow flexion and torsion of the spine. For use in the space environment, one adds to this garment a freely permeable outer garmet for protection against micrometeorites with a reflective outer coating to protect against extremes of thermal radiation. The complete assembly should allow much better mobility and much more natural movement than presently designed suits. The basic physiology of such a suit is established and the elastic materials available promise to be adequate for the task.

The advantages of the space activity suit approach are numerous. In addition to increased mobility and more natural movement, there is a lower metabolic cost than is exacted by full pressure suits. The simplicity of the approach is appealing, but obviously this problem is not a simple one. In addition to preserving the basic shape of the skin over the body, three vital physiological functions must be carefully maintained. These physiological systems are, in order of priority: the mechanics of respiration, the systemic and pulmonary circulation, and thermoregulation. However, it appears that the possibility of gaining so much in mobility and in the reduction of overall complexity of life support systems warrant further investigation and development for lunar surface and space EVA operations.

For purposes of estimating metabolic capabilities for the LSB crew, a brief summary of the present NASA astronaut population was compiled to derive an average or nominal astronaut size. This average was compared to the later population surveys to take into account, at least to a degree, the predicted size increase for personnel selected for lunar operations during the 1980 time period.

The 70th percentile dimensions of the 1967 Air Force survey were selected as the base for LSB metabolic capabilities. The values shown in Table 1.4-1 are computed on the basis of an assumed division of the work day between shirtsleeve and EVA and should provide an adequate base for deriving LSB metabolic cost data for consumables and for determining task scheduling of EVA operations.

Table 1.4-2 summarizes the metabolic costs for a typical shirtsleeve man-day of lunar surface operations and compares them with the data from Table 1.4-1, and the hourly emergency metabolic costs. The upper limit of programmed or emergency metabolic costs must be controlled within a maximum value by scheduling mandatory rest periods for relaxation and recuperation.

1.4.2 Energy Expenditure Rates

To assist in determining consumables, duration, and the number of crewmen required for a lunar surface exploratory mission, it is necessary to provide a list of the basic tasks and estimated crewman energy expenditure rates in Btu/hr for each. This preliminary compilation of tasks and functions and the estimated Btu/hr energy expenditure requirements are based on Apollo 11 and 12 data, and the accepted everyday activity levels as published in the literature. Table 1.4-3 presents the estimated energy expenditure rates for each of the major categories of LSB operations.

The task energy expenditure rates given in Table 1.4-3, except for the Apollo 11 and 12 operational data, have for the most part been estimated by factoring the earth-based task metabolic rates as follows:

1. Shirtsleeve tasks. Multiply the task Btu rate by 0.95. Thus a task requiring 1000 Btu would require 950 Btu for lunar operations.

2. EVA tasks. The tasks concerned with locomotion have been given the same rate as the 1-g shirtsleeve locomotion tasks. For those tasks requiring stooping, kneeling, and squatting such as placing equipment, picking up samples, trenching, and maintenance tasks that require a considerable body movement to accomplish, the earth-based task rates were multiplied by 1.2. Thus, a 1000 Btu maintenance task would require 1200 Btu for lunar operations.

Table 1.4-1. Estimated Metabolic Rates, Thermal Balance and Water Requirements for LSB Operations

70th Percentile Man 2.03 M^2 Body Surface	Unit/Rate per Man	Shelter Shirtsleeves Operations 18 hr/day	EVA Operations 6.5 hr/day	Total Requirements for 1 man/day	Remarks
Oxygen Consumption					* The values shown ±10% should be adequate for the variations in metabolic requirements of the astronaut population that will be available during the 1980 period based on the 1967 Airforce population survey
O_2 intake	lb	1.21	1.49	2.70	
CO_2 output	lb	1.42	1.75	3.17	
Heat output	Kcal	1805	2210	4015	
	Btu	7190	8810	16,000	
Heat Loss					
Sensible	Btu	5394	6606	12,000	
Latent	Btu	1796	2204	4000	
Water Loss					
Latent	lb	1.59	2.80	4.39	
Sweat	lb	.57	1.17	1.74	
Urine	lb	2.12	1.07	3.19	
Feces	lb	.13	.10	.23	
Total	lb	4.41	5.14	9.55	
Water Intake					
Oxidation	lb	.48	.57	1.05	
Food and Drink	lb	3.93	4.57	8.50	
Total		4.41	5.14	9.55	

Table 1.4-2. Summary Estimated Metabolic Rates

70th Percentile Man 2.03 M^2 Body Surface	Unit/Rate per Man	Routine LSB Shirtsleeve Operations - per Day	LSB Operations and 6.5 Hours EVA per Day	Emergency per Hour Quantity/Man	Emergency 8 hr Totals
Oxygen Consumption					
O_2 intake	lb	2.20	2.70	.33	2.64
CO_2 output	lb	2.57	3.17	.41	3.27
Heat output - Kcal	Kcal	3280	4000	507	4056
Btu	Btu	13,020	16,000	2012	16,096
Heat Loss					
Sensible	Btu	9750	12,000	1510	12,050
Latent	Btu	3270	4000	502	4016
Water Loss					
Latent (Insensible)	lb	2.46	4.39	.41	3.28
Sweat	lb	.94	1.74	.90	7.20
Urine	lb	3.62	3.19	.16	1.36
Feces	lb	.21	.23		
Total	lb	7.23	9.55	1.47	11.84
Water Intake					
Oxidation	lb	.60	1.05		
Food and Drink	lb	6.63	8.50		
Total	lb	7.23	9.55		

Table 1.4-3. LSB Estimated Task Energy Expenditure Rates

Task - Function	Rate - Btu/Hour	Remarks
Stationkeeping - Shirtsleeves		
Personal		
Sleep	280	
Personal Hygiene	500 - 600	
Eating	420 - 430	
Recreation	430 - 1380	Reading, table tennis
Food Mgmt. and Prep.	750 - 950	
Cleaning, Janitorial	800 - 1100	
Trash Disposal	700 - 800	
Admin. - Management	550 - 650	
Communications	↓	
Data Handling	↓	
Scheduling	↓	
Crew Medical Care	↓	
Safety	↓	
Cargo Handling	600 - 1100	
Maintenance		Includes both scheduled and unscheduled maintenance tasks for the LSB subsystems
Electrical Power Systems	600 - 900	
Env. Control Systems	600 - 1100	
CO_2 management	↓	
Atmospheric control	↓	
Active thermal control	↓	
Water management	↓	
Waste management	↓	
Information Maint. Syst.	600 - 900	
External comm. equip.	↓	
Internal comm. equip.	↓	
Base displays and controls	↓	
Caution and warning systems	↓	
Crew Systems	600 - 900	
PGA's	↓	
PLSS's	↓	
Miscel. equipment	↓	
Facilities	600 - 1000	
Galleys	↓	
Hygiene equipment	↓	
Lighting	↓	
Structures	600 - 1000	
Hatches	↓	
Airlocks	↓	
Misc. base equip.	↓	

Table 1.4-3. LSB Estimated Task Energy Expenditure Rates (Cont'd)

Task - Function	Rate Btu/Hour	Remarks
Stationkeeping - EVA		
Maintenance & Servicing		
Rover	800 - 1600	
Flyer	800 - 1600	
Propellant Facility	800 - 1600	
Cargo Handling Equip.	800 - 1600	
Base Antenna Servicing		
Operations		
Space Tug Landing Fac.	700 - 900	
Cargo Handling	680 - 1600	
Cargo Transfer to LSB	680 - 1000	
Experiment Ops. - Shirtsleeves		
Equipment Assembly	680 - 1210	
Equipment Checkout	680 - 900	
Equipment Operation	680 - 800	
Data Processing	610 - 750	
Laboratory Support		
Handling & Packaging	610 - 850	
Film Processing	610 - 800	
Experiment EVA and/or Mobility Operations		
Task Preparation		
Assembling/Loading Equip.	800 - 1075	
Personal Time		
Resting/Eating	480 - 550	
Walking		
@ 1 MPH	875 - 975	
@ 3 MPH	975 - 1150	
@ 1 MPH w/100 lb	1050 - 1275	Carrying 100 lb pack
@ 1 MPH + Operating a Cart	875 - 975	Powered cart
Driving		
Open Rover		
Checkout	680 - 820	
Operation	640 - 770	
Shutdown	680 - 820	
Cabin Rover		
Checkout	680 - 820	
"Airlock"	530 - 640	Going through the airlock
Operation	560 - 750	
Shutdown	680 - 820	
Flying		
Checkout	680 - 820	
Site Preparation	800 - 1000	Takeoff site only
Operation	710 - 820	
Shutdown	680 - 820	

Table 1.4-3. LSB Estimated Task Energy Expenditure Rates (Cont'd)

Task - Function	Rate Btu/Hour	Remarks
Construction, Cargo Handling, Geological Exploration		
Manual		
Digging	1100 - 1300	Self-paced
Lifting	800 - 1075	"
Shoving	800 - 1100	"
Heavy Equip. Assembly	1000 - 1470	Non-continuous
Other: Heavy	1785 - 2000	Rest period equivalent of work period
Medium	1190-1785	Intermittent rest periods
Light	595-1190	Continuous, 3 to 4 hours
Equipment Operation - Remote Control		
Standing	530 - 640	
Sitting	480 - 580	
Hand-Held Power Equipment		
Core Drill	1000 - 1200	Torque and percussive forces
Other Scientific Exploration		
Package Deployment	1050 - 1275	
Adjustment-Calibration	700 - 800	
Recording Data (Writing)	575 - 660	

1.4.3 LSB Work Budget

A basic work budget has been prepared in Table 1.4-4, showing the maximum energy available in BTU's for a typical day where EVA must be performed. The metabolic budget for crewmen engaged in lunar surface operations has been estimated to range from 14,000 Btu to 17,500 Btu per day for the 90th percentile crewman. Using a nominal value of 16,000 Btu per day as a basis and subtracting the metabolic needs for personal time, the maximum available is 9560 Btu for eight hours of EVA operations. Since PLSS operation must begin before or at the time of entering the airlock, the time needed for these operations is shown in the 8-hour EVA timeline and must be subtracted from the total, leaving 8810 Btu for 6-1/2 hours of work time and 30 minutes for rest/eat breaks. Most of the tasks associated with LSB operations will fall below the maximum hourly metabolic rates given here. Those tasks requiring a higher output than that desired must be so scheduled and/or paced that the crewman will not exceed his metabolic energy reserves.

Table 1.4-4. LSB Work Budget

	Time	Cum. Time	Metabolic Rate	Metabolic Budget 90th Percentile - 16,000 Btu
Sleep	8:00	8:00	280 Btu/hr	13,760 Btu
Eat	1:45	9:45	450	12,970
Personal hygiene	1:00	10:45	630	12,340
Don suit	0:20	11:05	810	12,070
EVA	8:00	19:05	(9560 Btu/8 hr)	
Doff suit + maint.	0:30	19:35	810	2,110
Debrief	1:10	20:45	610	1,400
Uncommitted (recreation, etc.)	3:15	24:00	430	0
		EVA Time Remaining		EVA Metabolic Budget
EVA				
Seal suit	-	8:00	-	9560 Btu
Check out suit	0:20	7:40	810 Btu/hr	9290
Pumpdown (10 min. concurrent)	0:20	7:30	450	9210
Outside airlock activities	7:00*	0:30	(8810 Btu/7 hr)	400
Ingress/clean suit	0:30	0:00	810	0
Vent suit	-	-	-	-

*Breakdown: 6:30 work, 0:30 break/eat

1.4.4 Work Shift Limitations

A work shift of ten hours per day, six days per week, with a potential two to four hours work on the seventh day for required functions has been assumed for all normal LSB operations. For EVA surface operations, seven hours (which includes a 30-minute rest period) is considered the maximum that should be scheduled when consideration is given the equipment now available and that which may be available during the 1980 time period. Considerable time is required in both pre- and post-EVA for equipment care and checkout to assure safe EVA operation in the lunar environment. Although the Apollo 12 astronauts felt they could easily have accomplished eight hours of EVA if their equipment were not a limitation, the scheduling of more than seven hours of EVA work does not appear practical at this time. However, assuming that the Apollo 12 mission could have supported eight hours of continuous EVA, it is rather doubtful that the enthusiasm of man's second landing on the moon would carry over to a long-term surface exploration mission.

The newer EVA suits that will be available for LSB operations will no doubt be more comfortable, provide better mobility, be easier to don and doff and to maintain. However, operational safety will still require meticulous care in preparation and checkout prior to use plus cleaning and servicing after use, all of which are time consuming.

1.5 MANPOWER REQUIREMENTS

1.5.1 Shelter Operations

In order to define the crew activities required for operation of the shelter, all base functional requirements were separated into four crew operation categories: (1) shelter operations, (2) administration and management, (3) maintenance, and (4) housekeeping and sanitation. The crew activities defined encompassed all base functions and crew requirements associated with their performance but excluded those required by conduct of scientific experiments.

Table 1.5-1 summarizes the equivalent manpower requirements under all categories for operation of the LSB. The total for routine and periodic shelter operations is 30 equivalent man-hours per day. Routine base operations are those that occur normally every day and require 12.3 equivalent man-hours. Periodic base operations are those operations that occur at regular intervals other than daily and must be performed periodically or at varying frequencies. Periodic operations require 17.7 equivalent man-hours daily, and consist mostly of maintenance activities.

Flight Operations

Lunar base flight operation consists essentially of lunar ground activity in support of the resupply operations. In support of logistics resupply, lunar surface activity is required in the way of cargo unloading and cargo transfer to base. It is estimated that about 10 man-hours are required for this operation.

Table 1.5-1. Routine and Periodic LSB Operations

Crew Operations	Equivalent Man-Hours per Day	
	Routine (daily)	Periodic
Flight operations	0.3	-
Administration and management	5.0	0.8
Maintenance	0	16.2
Housekeeping and sanitation	7.0	0.7
Subtotal	12.3	17.7
Total	30.0	

LSB Administration and Management

Base management includes all task functions associated with station control. The estimated time required to perform this category on a routine daily basis is 5 hours. This time is distributed between stationkeeping, scheduling, and data management functions. Crew medical care and emergency procedures, a function performed on a periodic basis, require about 12 man-hours per month, or the equivalent of 0.8 man-hours per day making the total time required for administration and management about 8 hours per day.

Station command encompasses the command decision tasks -- based on overall mission plans and operations scheduling functions -- to assure that all base activities are accomplished successfully and in an integrated and coordinated fashion. In addition, the base command must maintain control on safety standards, establish communication guidelines and policies, be responsible for crew utilization and crew records and files.

Data management essentially consists of two categories: (1) management of data operation concerned with monitoring, processing and routing of data signals received from LSB operating subsystems, and (2) management of scientific data processing involving data storage, processing, and evaluation of experiments.

Crew medical care is estimated to require one man-hour per month per man or 12 man-hours total per month for a 12-man crew. In addition to administering first aid for minor injuries, diagnosing and treating crewmen for possible illness, plus routine physical examinations are included as part of medical care.

LSB Maintenance

This functional category encompasses all crew activity associated with the maintenance of lunar base subsystems, with the objectives of preventing and repairing equipment malfunctions and failures. However, estimates of crew activity time required to maintain operation of the base subsystems are provided based on the maintenance philosophy developed in Part 3 of Volume III.

Table 1.5-2 contains the maintenance time summary on an averaged monthly basis in terms of scheduled and unscheduled maintenance man-hours. Scheduled maintenance is defined as any planned maintenance activity deemed necessary to enhance the functional success of the equipment. Unscheduled maintenance is usually caused by a subsystem or component failure or by the evidence of degraded system performance. All activity involving in failure isolation, part replacement, and adjustment prior to the time that all equipment is operating and back on line come under this heading. About 60 percent of the 497.3 man-hours per month total is required by the crew and mobility subsystems.

Table 1.5-2. Maintenance Time Summary

Subsystem	Man-Hours per Month (Averaged)	
	Scheduled	Unscheduled
Crew	150.0	19.0
Structures	5.0	4.0
Facilities	24.0	9.0
ECLSS	61.5	11.1
Mobility	160.0	-
Electrical	5.0	2.5
Information	42.0	4.2
Subtotal	447.5	49.8
Total	497.3 (16.2 MH/Day)	

Housekeeping and Sanitation

Included in this category are the daily routine activities associated with food service management and food preparation, after meals cleaning of galley and dining area, disposal of collected trash and the maintenance of personal hygiene equipment. Activity required on a periodic basis includes general cleaning of base modules or staterooms and passageways, and arrangement of food cargo at each resupply cycle.

The task of menu planning may be supervised by the person in charge of crew medical care. A crewman with skilled training in food preparation would be responsible for actual meal preparation. General cleaning is a menial task that could be accomplished by some scheme of duty roster rotation. Cleanup of crew staterooms would be the responsibility of the occupants. Any food cargo remaining in a permanent storage replaceable unit must be moved to a temporary storage unit or placed in the new resupply permanent storage unit at each resupply cycle. Moving or rearrangement of supplies, other than food, in the same container unit may be required. The total daily work load estimated for these tasks, based on a timeline of each, is 7.7 man-hours per day.

1.5.2 LSB Manpower Development

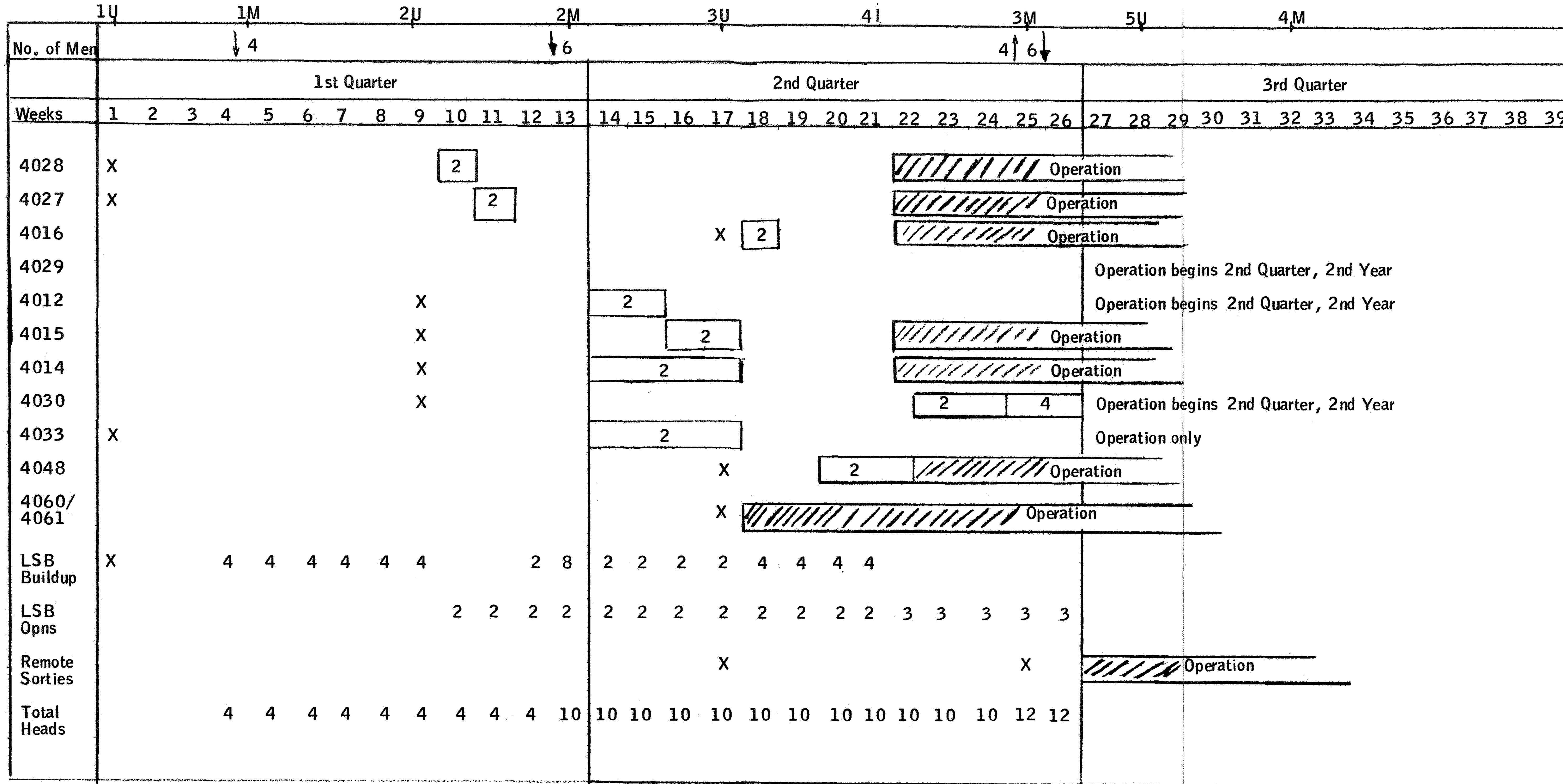
The method utilized to outline the basic skill requirements and to develop the manpower loading for LSB operations is based on the proposed lunar surface experiment program. LSB stationkeeping operations were estimated from the data developed for the EOSS, and amended for LSB requirements. LSB base operations data were treated in the previous section and detailed estimates of experiment manpower are compiled by discipline and experiment in Appendix F of this report.

From the experiment and base operations data, two other charts have been constructed. The first, Table 1.5-3 shows the crew requirements for base buildup over the first six months of base operation. This has been shown on a weekly basis with the total available crew shown across the bottom of the chart. The X's indicate availability of hardware needed for buildup. Start of operation for each of the various experiments is indicated. Detailed manpower requirements are summarized in Table 1.5-4.

The manpower spread shown in Table 1.5-4 for the various experiments has been derived on a basis of hours per month per quarter. The hours are then reduced to equivalent men per the crew workshift data for EVA and shirt-sleeve operations. Because of the changing monthly requirements in hours for the drilling experiments (4033 and 4048), they are indicated at the level of two equivalent men.

Table 1.5-4 also combines the manpower requirements of the shelter with those of a second shelter, presumably at another LSB site, to illustrate the phasing. Note that in either case, the lunar population does not exceed 12 men.

Table 1.5-3. Base Buildup Manpower



2-1-39, 2-1-40

Table 1.5-4. Lunar Surface Base Manpower Requirements* (Hours/Month by Quarter)

*Phase-in of second LSB shown in 5th and 6th year columns

	First Year								Second Year (Pattern repeated to end of 4th year)								Fifth Year								Sixth Year					
	1st Quarter		2nd Quarter		3rd Quarter		4th Quarter		1st Quarter		2nd Quarter		3rd Quarter		4th Quarter		1st Quarter		2nd Quarter		3rd Quarter		4th Quarter		1st Quarter		2nd Quarter		3rd Quarter	
	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA
. EXPERIMENT/FUNCTION																														
4028 Radio telescope				37		37		37		37		37		37		37		37		37		37		37		37		37		37
4027 Radio telescope				84		84		84		84		84		84		84		84		84		84		84		84		84		84
4016 1.3-meter telescope			94	122	94	122	94	122		122	77	76	77	76	77	76	77	76	77	76	77	76	77	76	77	76	77	76	77	76
4029 IR astronomy											17	46	17	46	17	46	17	46	17	46	17	46	17	46	17	46	17	46	17	46
40-2 X-ray astronomy											60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
4015 Radio telescope				84		84		84		84		84		84		84		84		84		84		84		84		84		84
4014 Radio telescope				84		84		84		84		84		84		84		84		84		84		84		84		84		84
4030 2.5-meter telescope											60	211	60	211	60	211	60	211	60	211	60	211	60	211	60	211	60	211	60	211
4033 Subsurface drilling			304	16			304	16											304	16			304	16						
4048 Deep drilling			201	914	77	1220	201	914	77	1220									201	414	77	1220	201	914	77	120				
4060																														
4061 Lab operation				104		135		135		135		175		135		175				135		135		135		135		135		135
4001-11 4050-88 Shelter site experiments					40	75	40	75	40	75	40	75	40	75	40	75			141	262	141	262	141	262	141	262				
Base No. 1 science hours			94	515	134	621	134	621	194	681	254	932	254	892	254	932	214	682	214	682	214	682	214	682	214	682	214	682	214	682
Base No. 2 science hours																			141	397	141	397	141	397	141	397		135		135
II. MANPOWER - EQUIVALENT MEN																														
Base No. 1 Science																														
Shelter experiments			.56	1.91	.80	2.30	.80	2.30	.80	2.30	1.50	3.45	1.50	3.30	1.50	3.45	1.27	2.53	1.27	2.53	1.27	2.53	1.27	2.53	1.27	2.53	1.27	2.53	1.27	2.53
Observatory				2.47		3.10		3.10		3.10		4.95		4.80		4.95		3.80		3.80		3.80		3.80		3.80		3.80		3.80
Deep drilling				2.00		2.00		2.00		2.00																				
Base No. 2 Science																														
Shelter experiments																				2.30		2.30		2.30		2.30		.50		.50
Drilling																				2.00		2.00		2.00		2.00				
Remote sorties				3.00		4.00		4.00		4.00		4.00		4.00		4.00												4.00		4.00
Base No. 1 buildup and operations				2.53		2.90		2.90		2.90		3.05		3.20		3.05		2.20		2.20		2.20		2.20		2.20		2.20		2.20
Base No. 2 buildup and operations																		6.00		1.70		1.70		1.70		1.70		1.70		1.50
Base No. 1 Total				10.0		12.0		12.0		12.0		12.0		12.0		12.0		6.0		6.0		6.0		6.0		6.0		6.0		6.0
Base No. 2 Total																		6.0		6.0		6.0		6.0		6.0		6.0		6.0
Total lunar population				10.0		12.0		12.0		12.0		12.0		12.0		12.0		12.0		12.0		12.0		12.0		12.0		12.0		12.0

FOLD-OUT #1

FOLD-OUT #2

2-1-41,

*Phase-in of second LSB shown in 5th and 6th year columns

ar				Sixth Year							
Quarter		4th Quarter		1st Quarter		2nd Quarter		3rd Quarter		4th Quarter	
	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA
	37		37		37		37		37		37
	84		84		84		84		84		84
7	76	77	76	77	76	77	76	77	76	77	76
7	46	17	46	17	46	17	46	17	46	17	46
0	60	60	60	60	60	60	60	60	60	60	60
	84		84		84		84		84		84
	84		84		84		84		84		84
0	211	60	211	60	211	60	211	60	211	60	211
		304	16								
7	1220	201	914	77	120						
	135		135		135		135		135		135
.	262	141	262	141	262						
4	682	214	682	214	682	214	682	214	682	214	682
1	397	141	397	141	397		135		135		135
7	2.53	1.27	2.53	1.27	2.53	1.27	2.53	1.27	2.53	1.27	2.53
	3.80		3.80		3.80		3.80		3.80		3.80
	2.30		2.30		2.30		.50		.50		.50
	2.00		2.00		2.00						
							4.00		4.00		4.00
	2.20		2.20		2.20		2.20		2.20		2.20
	1.70		1.70		1.70		1.70		1.50		1.50
	6.0		6.0		6.0		6.0		6.0		6.0
	6.0		6.0		6.0		6.0		6.0		6.0
	12.0		12.0		12.0		12.0		12.0		12.0

FOLD-OUT #2

2.0 LOGISTICS MISSION SYNTHESIS

2.1 MISSION CONCEPTS

2.1.1 Translunar Geometry Constraints

The selection in Part 1 of this Volume of a reusable logistics system with transfer nodes in earth and lunar orbit introduces certain constraints on the logistics cycle. These constraints were examined briefly during this study utilizing digital programs and data developed previously in studies of the various translunar shuttle concepts.

Mission Model

The mission model in the digital program utilizes JPL ephemeris tapes to obtain the state vectors of the sun, earth, and moon, and the orientation of the lunar equator as a function of date. Energy requirements for the earth departure and earth arrival maneuvers and hyperbolic excess velocity vectors (magnitude and direction) for the lunar arrival and lunar departure maneuvers are interpolated from built-in tables of these variables as a function of earth-moon distance, transfer time and inclination of the transfer plane to the moon's orbit plane.

Earth Departure. The earth departure maneuver is assumed to be coplanar from a 258-nautical mile circular orbit, which is inclined 31.606 degrees to the earth equator plane. This altitude-inclination combination satisfies two conditions: (1) earth-moon transfer geometry which repeats every two sidereal months (54.6 days), and (2) rendezvous compatibility with the launch site (Kennedy Space Center assumed) once each day. Velocity losses for the earth departure maneuver are computed as an empirical function of the initial thrust/weight ratio and the impulsive delta-V.

Earth-moon transfer in the mission model occurs in a plane which is coincident with the circular earth orbit plane at the translunar injection (TLI) epoch and which contains the earth-moon direction vector at the lunar arrival epoch. Translunar flight times are constrained to the range from 56 to 128 hours. The combined effects of earth orbit nodal regression (-6.6 degrees/day), the continually changing earth-moon direction, and the coplanar earth departure constraint result in discrete departure opportunities for a specified translunar flight time. These opportunities are unequally spaced, but occur on the average every 9.1 days. A "departure window" can then be created for each opportunity by varying the translunar flight time.

Lunar Vicinity. Either single impulse or three impulse maneuvers are utilized for lunar orbit insertion (LOI). Transearth injection (TEI) maneuvers for the included data are all based on three-impulse maneuvers. The first maneuver of the three impulse technique (e.g., for LOI) consists of a coplanar, non-periapsis insertion into an elliptical orbit having a 24-hour period and a periapsis altitude equal to the final circular orbit altitude of 60 nautical miles. The second maneuver accomplishes a pure plane change at apolune of the elliptical orbit. The third maneuver consists of a combined plane change and circularization at perilune of the elliptical orbit. Velocity losses of 100 fps each were assumed for the LOI and TEI maneuvers. The final circular lunar orbit plane inclination to the lunar equator was chosen to be 90 degrees. Other inclinations may be more desirable for particular mission modes or surface locations and would have to be considered in a more extensive study. For example, an orbit might be selected to provide coplanar ascent and descent to the LSB site within some preselected time interval less than the 14-day interval which is inherent in a polar orbit.

The orientation at LOI of the polar lunar orbit ascending node on the lunar equator may be constrained; i.e., when the translunar shuttle must rendezvous with an Orbiting Lunar Station (OLS) or overfly some particular surface site within some time constraint, or the ascending node may be unconstrained; i.e., when there is no requirement to rendezvous with the OLS and it is acceptable to achieve the site overfly by waiting in orbit. A coplanar, single impulse LOI maneuver is utilized in the unconstrained case and a three-impulse maneuver for the constrained. Each of these cases is examined in the following. The transearth flight time is optimized between limits of 56 and 128 hours on the basis of maximum outbound payload.

Earth Return. Moon-earth transfer is assumed to occur in a plane which contains the earth-moon direction vector at the TEI epoch and which is coincident with the circular earth orbit plane at the earth orbit insertion (EOI) epoch. The combined effect of the moon's counter-clockwise motion about the earth and the earth orbit plane's clockwise regression results in multiple solutions satisfying the earth return geometry constraint. These solutions correspond to sequentially longer staytimes in lunar orbit. The staytime increment between successive solutions varies considerable due to the three-dimensional geometry involved. Velocity losses of 100 fps are assumed at EOI.

Earth-Moon Logistics with Constrained Orbit Nodes

Initial Delivery Departure Window. The initial delivery to lunar orbit was selected to occur at the earliest opportunity for a maximum outbound payload in the calendar year 1985. The departure window occurs during January 8, 1985. A specific earth orbit node variation with time is required to achieve this departure window. The time dependent nature of the earth orbit nodal orientation requires the use of a "reference epoch" for defining nodal values. January 0.0, 1985 was arbitrarily selected for this purpose, and the departure window data correspond to an earth orbit which has a reference nodal value (Ω Ref) of 60 degrees at the "reference epoch".

The plane change at LOI is assumed zero throughout this departure window since this is the initial delivery and there is no requirement to rendezvous with a pre-established lunar orbit plane. Three-impulse LOI maneuvers are utilized, however, simply for consistency with subsequent resupply missions for which three-impulse maneuvers will be required. Impulsive delta-V values for the four major maneuvers and the optimized transearth flight times are shown in Figure 2.1-1. The delta-V values for TLI and for LOI are independent of staytime in lunar orbit. Translunar and transearth flight times, required staytimes in lunar orbit, and total mission duration are shown in Figure 2.1-2. The selenographic longitude of the ascending node at the time of insertion into the initial 60-nautical mile orbit varies over fairly narrow limits during the earth departure window as shown in Figure 2.1-3. Also shown is the selenographic longitude of the subsolar point at the LOI epoch which can be used to derive the initial lighting conditions.

Subsequent data will all be related to the initial departure window solution shown in Fugure 2.1-1.

Resupply Mission. OLS (or OLS/LSB) resupply missions involve a rendezvous with the OLS in the then existing OLS polar orbit plane. This, in general, requires a plane change both at LOI and at TEI. Every two sidereal months, however, the plane change at LOI is near zero because the earth orbit altitude and inclination were initially selected to yield a regression rate for which the earth-moon geometry repeats (approximately) at two-sidereal month intervals. Selecting an initial point approximately in the center of the departure window of Figure 2.1-1 (92-hour translunar flight time, JD = 2, 446, 073.92), the resupply mission opportunities were generated for the subsequent eight sidereal month interval. The mission delta-V magnitudes and related angle δ , which is a measure of the plane change requirements for the LOI and TEI maneuvers, are shown in Figure 2.1-4. The favorable departure opportunities exhibit low values for δ and for the delta-V magnitude at both LOI and TEI. Examination of Figure 2.1-4 indicates that there are intermediate departure opportunities for which the related LOI and TEI plane change angles are small and the delta-V magnitudes only slightly higher than those associated with the best departure opportunities. The optimized transearth flight times for these intermediate opportunities, Figure 2.1-5, are all about 86 hours, as compared to 116-118-hour return flight times for the best opportunities.

The selenographic longitudes of the orbit ascending node on the lunar equator and of the moon-sun direction at LOI are shown in Figure 2.1-6. Favorable departure opportunities all correspond to orbit orientations which are approximately normal to the earth-moon line at LOI. The sun direction, which initially is closely aligned with the ascending node direction, drifts counter-clockwise with respect to the lunar orbit due to the apparent daily motion of the sun.

Earth-Moon Logistics Without Constrained Orbit Nodes

The cislunar shuttle performance capability for the intermediate opportunities of Figure 2.1-4 is increased if the initial ascending orbit node is not constrained. This occurs because the cislunar shuttle can execute a coplanar LOI maneuver at every mission opportunity. A single impulse LOI maneuver is utilized for this mode because of the zero plane change requirement. Mission delta-V characteristics are shown in Figure 2.1-7. Variations in the LOI delta-V are due to earth-moon distance and inclination effects only. Plane changes are still generally required at TEI, however, and account for the large variations in TEI delta-V magnitudes. Associated transearth flight times and mission durations are shown in Figure 2.1-8.

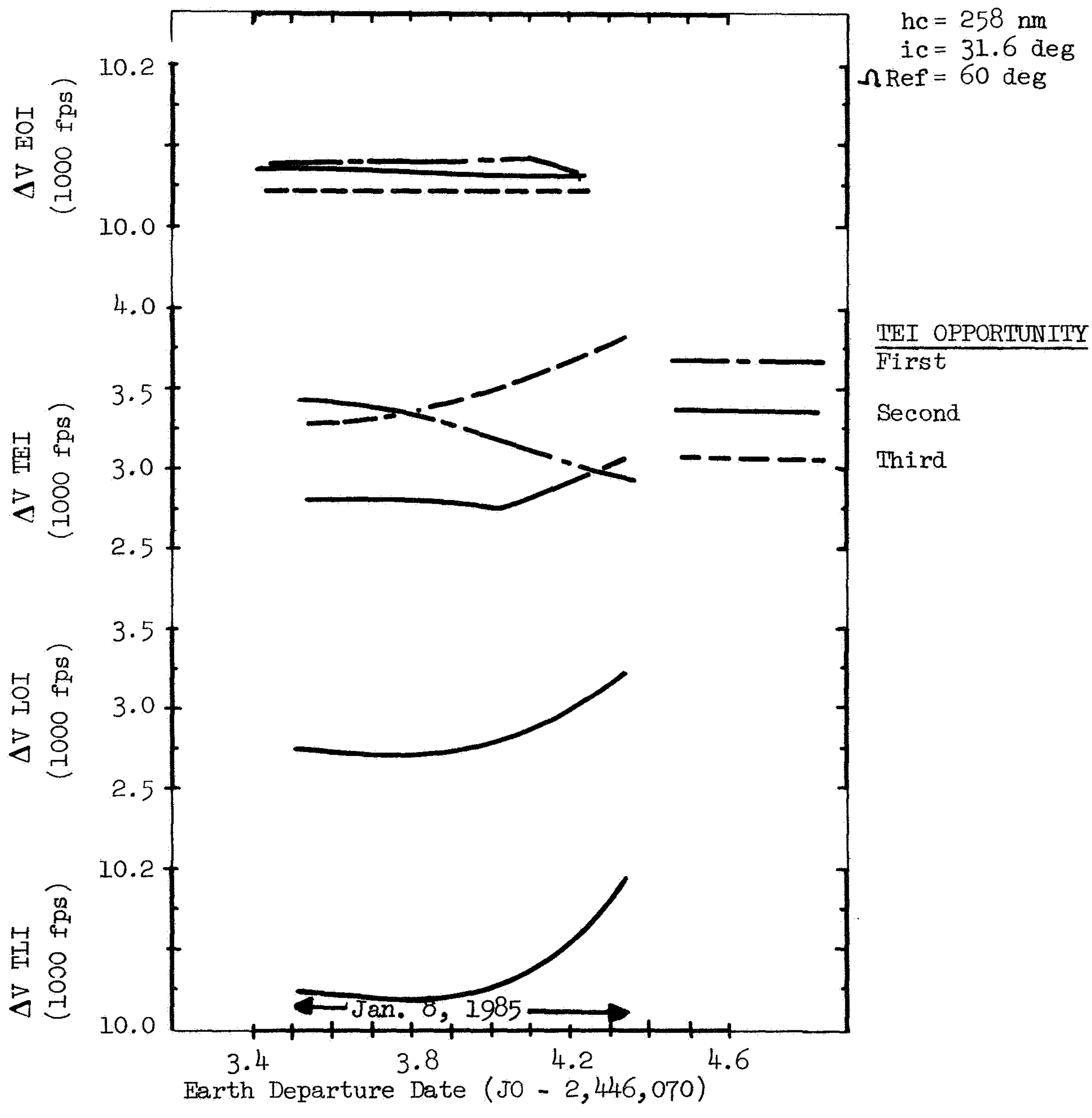


Figure 2.1-1 - Initial Delivery Mission Impulsive Delta-V's

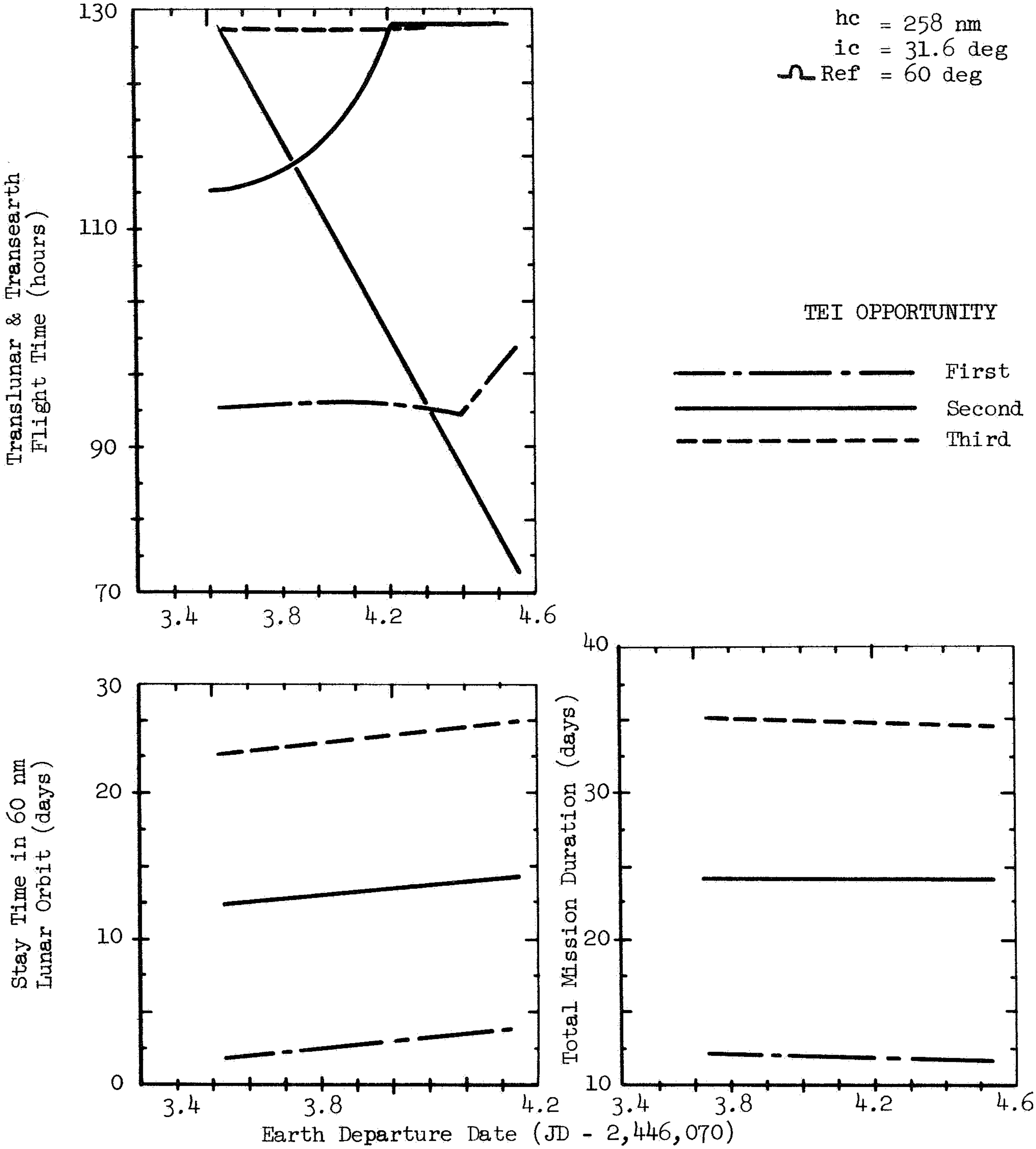


Figure 2.1-2 - Initial Delivery Mission Durations

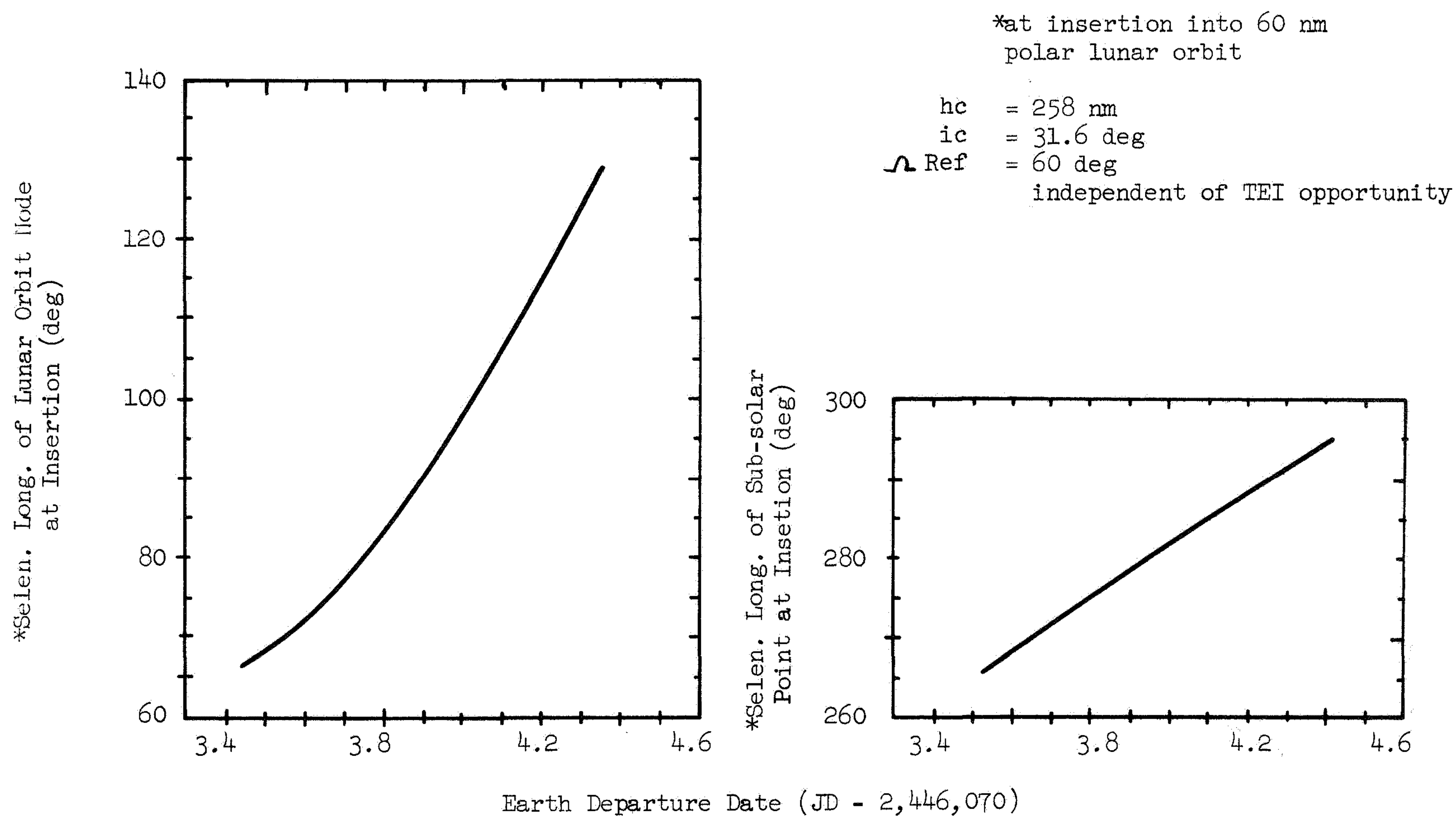


Figure 2.1-3 - Initial Delivery Mission Orbit

hc = 258 NM
ic = 31.6 DEG

Ω Ref = 60 DEG
Δ TLI = 92 HRS

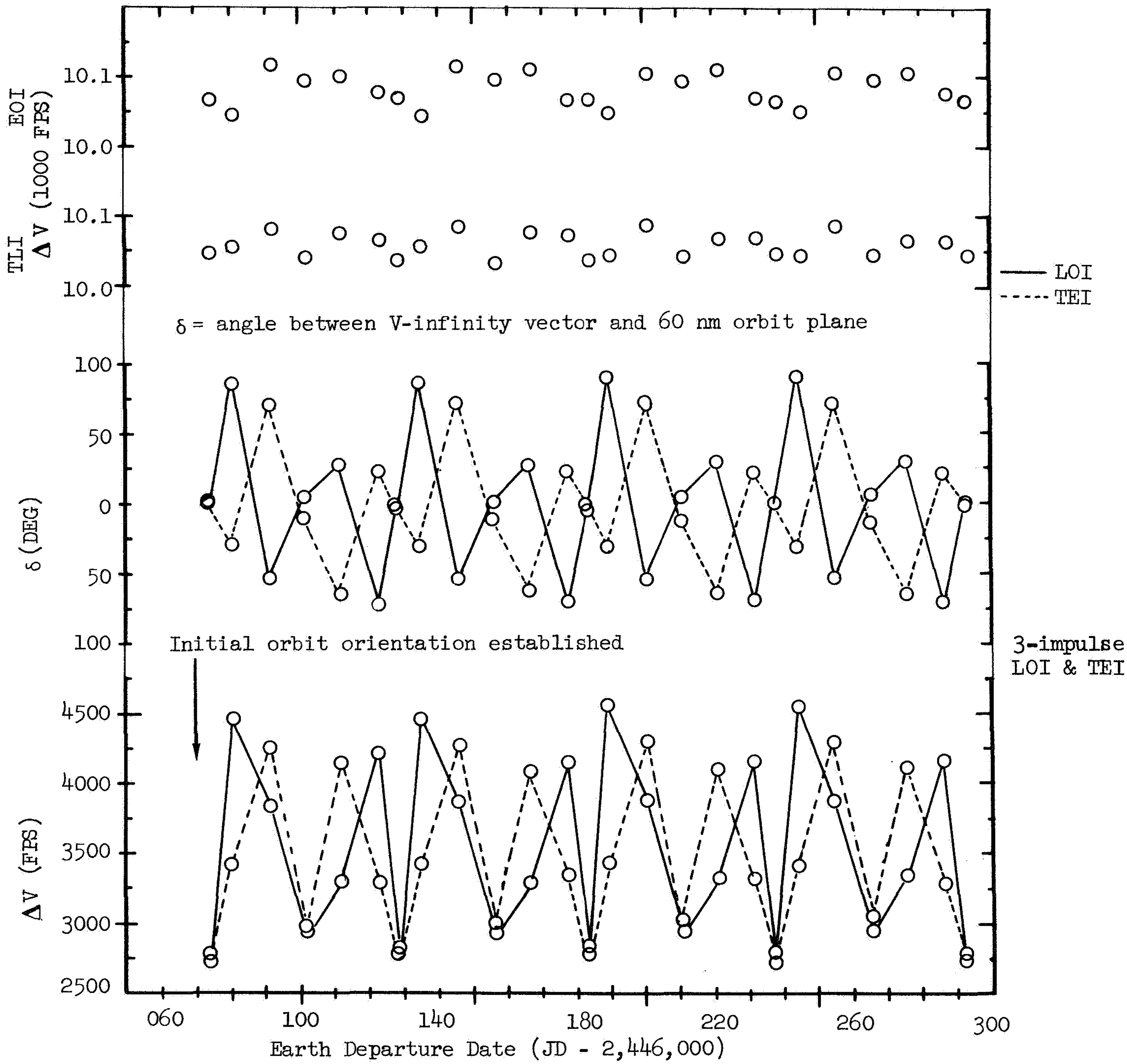


Figure 2.1-4 - Lunar Resupply Mission
Delta V's - with Constrained Orbit Nodes

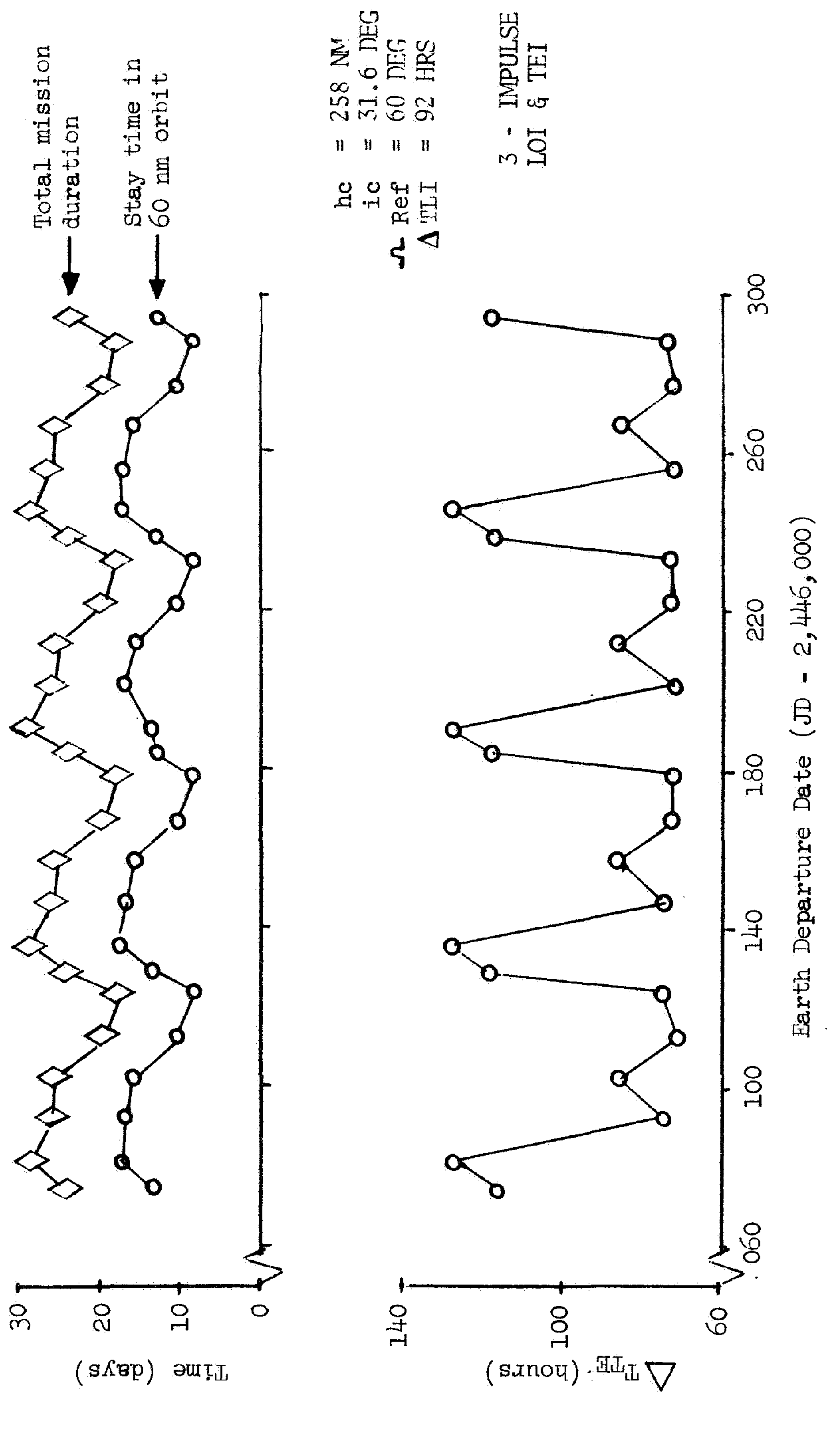


Figure 2.1-5. Lunar Resupply Mission Durations With Constrained Orbit Nodes

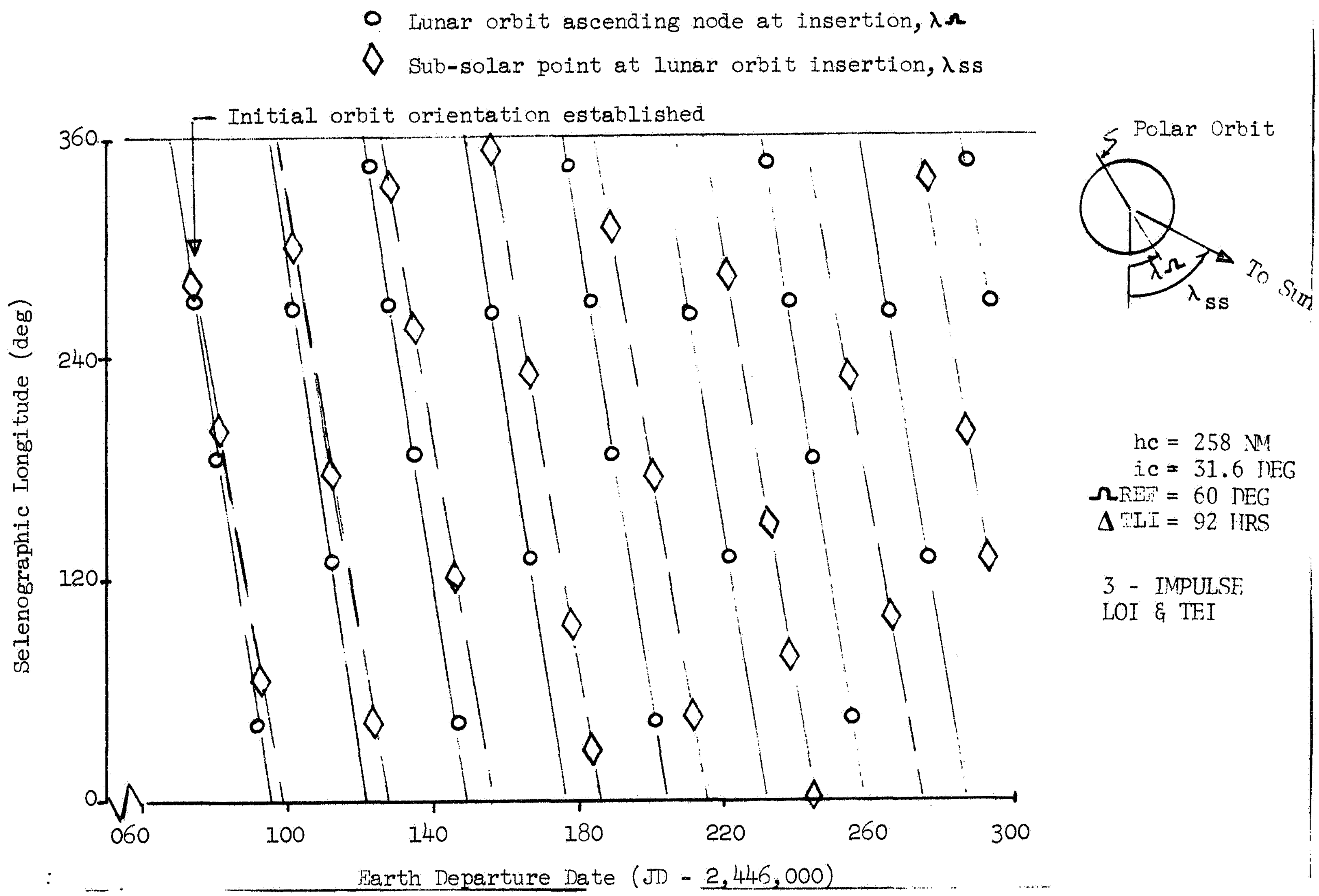


Figure 2.1-6. Lunar Resupply Mission Orbit Orientations With Constrained Orbit Nodes

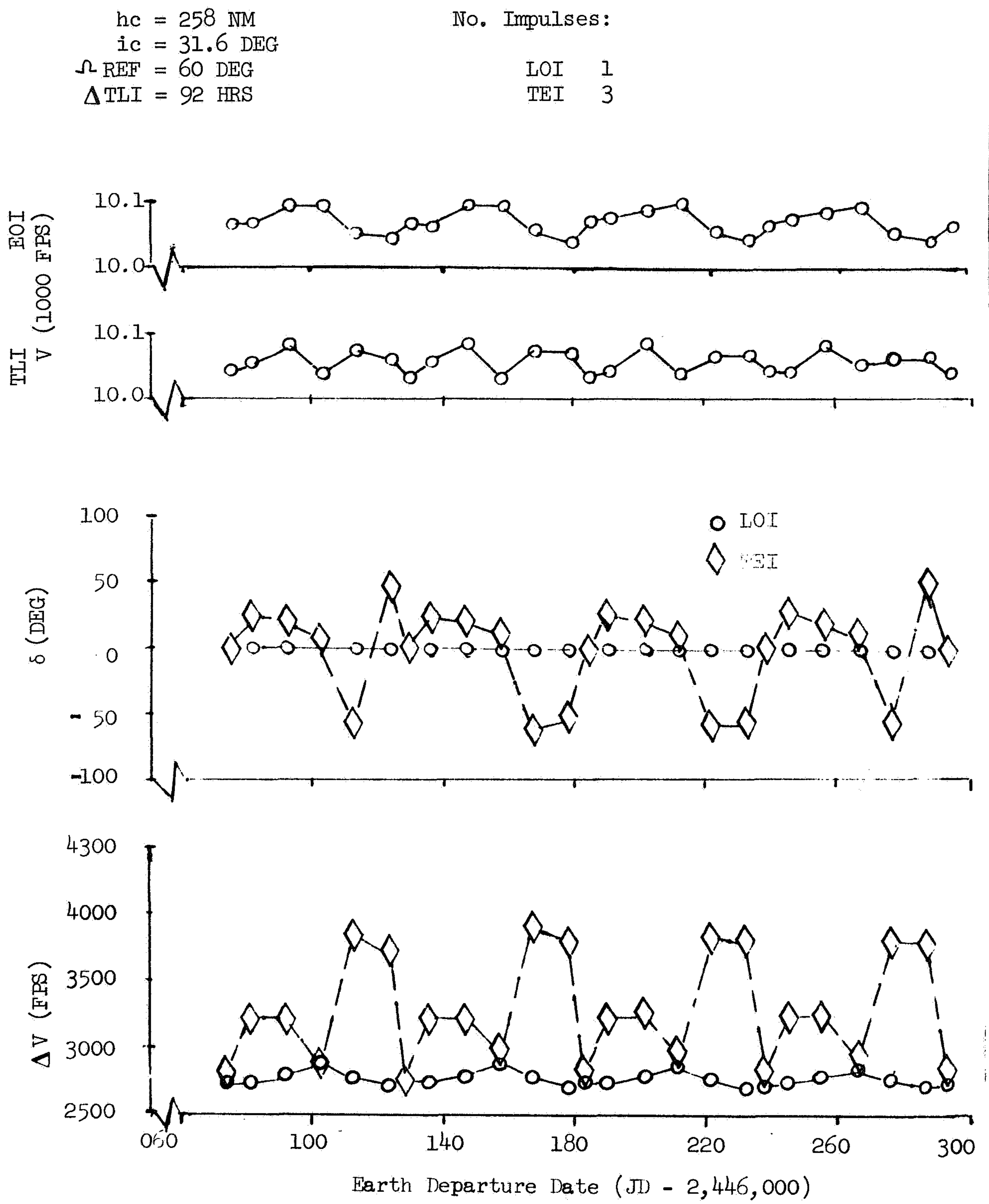


Figure 2.1-7. Lunar Resupply Mission Delta V's
Without Constrained Orbit Nodes

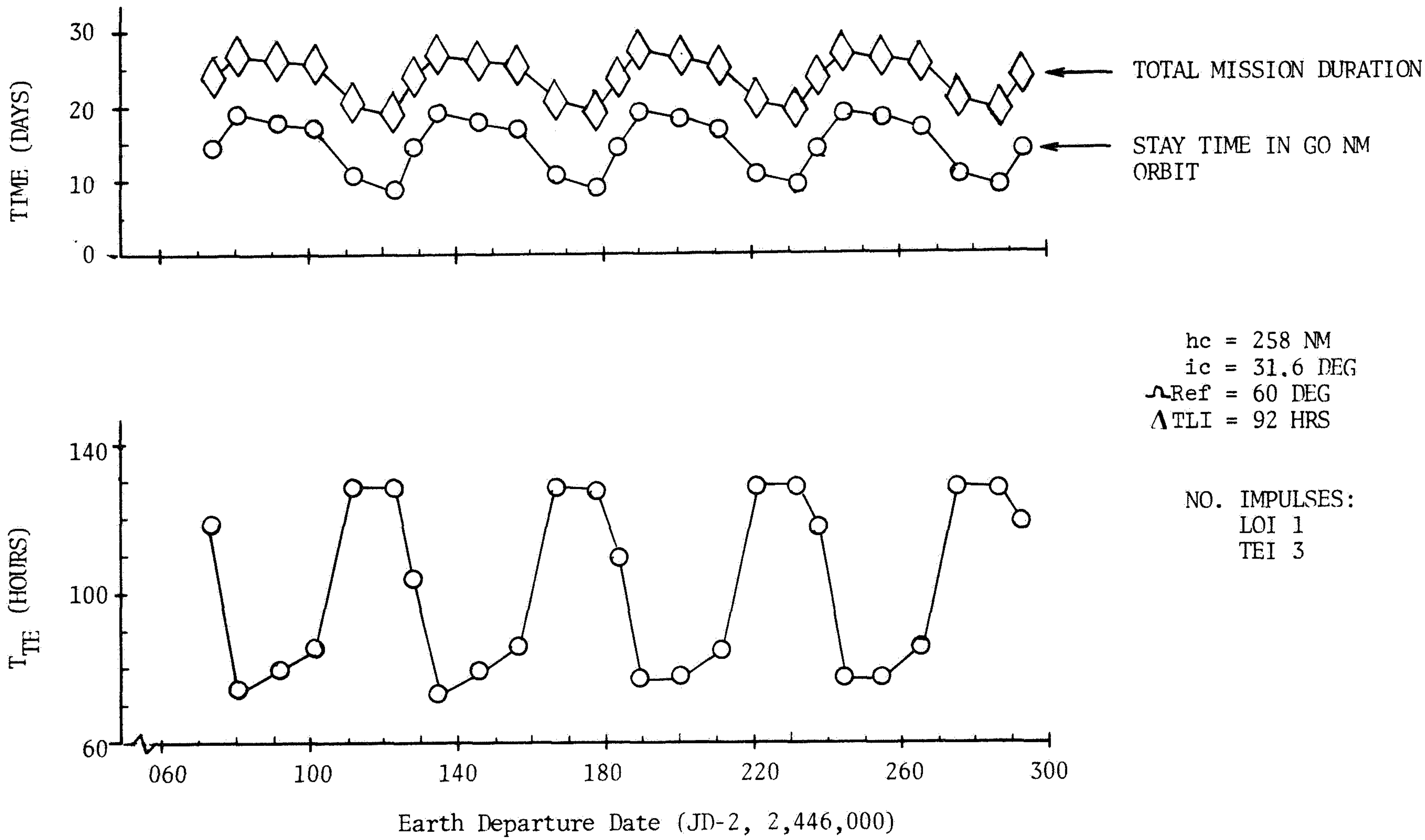


Figure 2.1-8. Lunar Resupply Mission Durations - without Constrained Orbit Nodes

The selenographic longitude of the lunar orbit ascending node on the lunar equator, Figure 2.1-9, is always between 100 and 120 degrees. The sun direction in selenographic coordinates changes about 12 degrees in longitude per day.

A polar lunar orbit was assumed for the unconstrained orbit node mode because a near coplanar opportunity for descent to the lunar surface will occur for any LSB site within a two-week staytime in lunar orbit. A coplanar descent opportunity for a site on the leading or trailing edge of the moon (270 or 90 degrees longitude) will occur within 0 to 3 days after orbit insertion. It is possible, however, to orient the lunar orbit plane (inclination and node) such that a coplanar descent opportunity to a selected site will occur at a specified time interval after orbit insertion. The LOI maneuver for this case would still be coplanar. The resultant mission delta-V's would differ from those in Figure 2.1-7, but the upper and lower bounds would be about the same. Similarly, it is possible to select the lunar orbit orientation on the basis of maximizing the outbound payload, provided that the resultant orbit inclination is greater than the LSB site latitude so that a coplanar descent opportunity will exist. This method would increase the payloads for some of the intermediate departure opportunities but could also lead to situations in which coplanar descent to the lunar surface does not occur until 3 to 4 weeks after arrival.

2.1.2 Mission Type Variations

During the build-up and resupply of a Lunar Surface Base a number of types of logistics missions will be accomplished. These typically include such variations as manned versus unmanned, initial delivery versus resupply, hardware to be reused versus expended. Each of these variations and combinations thereof places somewhat different requirements on the logistics system, requires different performance, influences the design approach for the logistics elements, and ultimately affects the LSB operations sequence. In order to gain some insight into these effects, some concepts and approaches were assumed as mission rules. It should be emphasized that these represent only one of many feasible sets of assumptions and will have to be reexamined in a later study when more definitive constraints can be established.

Mission Rules

1. A precursor site certification mission will have left a landing aid sufficient to permit an initial unmanned automated landing at the LSB site.

2. The initial manning mission will be off-loaded sufficiently to permit an abort and return to orbit with the full payload.

3. Manned missions subsequent to the first can always land and off-load on the surface prior to returning to orbit.

4. All logistics vehicles are capable of at least ten round trips prior to refurbishment.

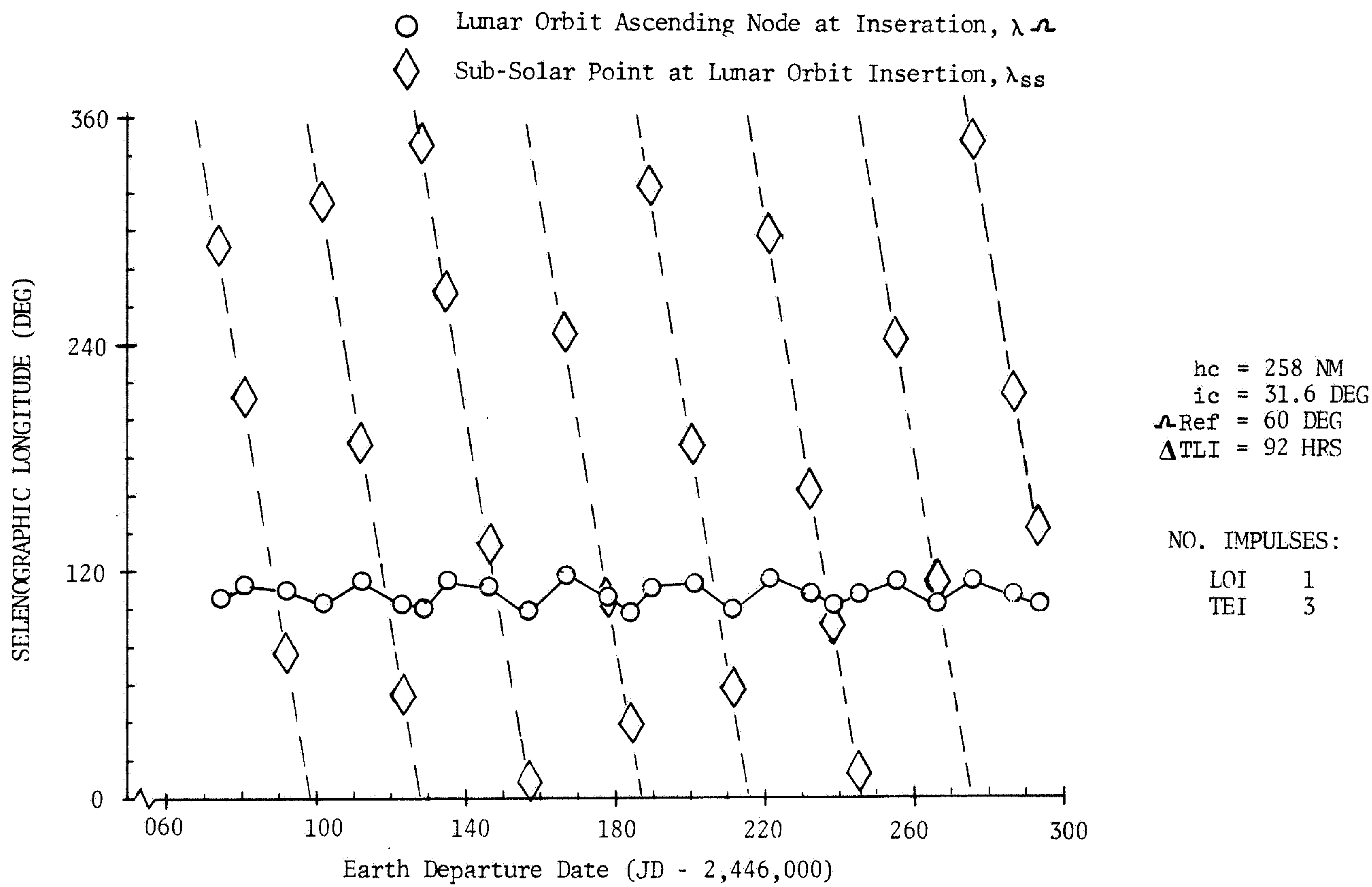


Figure 2.1-9. Lunar Resupply Mission Orbit Orientations - without Constrained Orbit Nodes

5. It is desirable to simplify crew, cargo, and propellant transfer in lunar orbit.

6. Docking operations in lunar orbit will require manned supervision in lunar orbit.

7. It is not necessary to keep a tug on the surface for emergency use as soon as sufficient redundancy is available in the LSB to allow waiting for rescue.

8. If there is a concurrent OLS in a polar orbit, the LSB resupply cargo can be delivered by one of the tugs based at the OLS.

9. If there is no concurrent OLS, the LSB resupply tug will be based on the surface between logistics missions.

10. After initial build-up, one-half of the LSB crew will be rotated on each resupply mission.

11. Crew staytimes of up to one year are acceptable.

Mission Descriptions

Utilizing the above guidelines and considering the variety and quantities of payloads required to be carried (Volume III, Part 3, Section 4), the following mission concepts were synthesized. A subsequent section describes the capabilities of the selected vehicles in performing these missions.

Stage-And-A-Half Tug Concept. One of the concepts which was derived in the concurrent NR study of the Reusable Space Tug (Contract NAS9-10925) involved a small reusable tug which could utilize the propellants from a larger, expendable tank set until they were exhausted, then stage the tank set and complete the mission utilizing the basic stage propellants. This concept arose in the examination of the synchronous earth orbit missions and was sized in the tug study to do that mission. However, this concept appears to offer some significant advantages for the Lunar Surface Base mission also. In particular, in addition to the performance advantage of staging the tank set, it would appear feasible to design the connection between the basic stage and the tank set such that they could be mated by a docking maneuver in lunar orbit. This arrangement would be basically the same as the connections to be made for orbital propellant transfer, but would eliminate the need for zero-g propellant transfer, propellant modules or farms, and the losses associated therewith. The basic mode would be for the tug to dispose of the tank set on the lunar surface and, upon return to lunar orbit, to dock with another tank set brought by the cislunar shuttle. It should be noted that the tanks in the basic stage will essentially be empty when it returns to lunar orbit and the plumbing and tank set sizing has to consider refilling these tanks prior to disposal of the tank set so that the sequence can be continued. Figure 2.1-10 illustrates a potential arrangement for this tug concept.

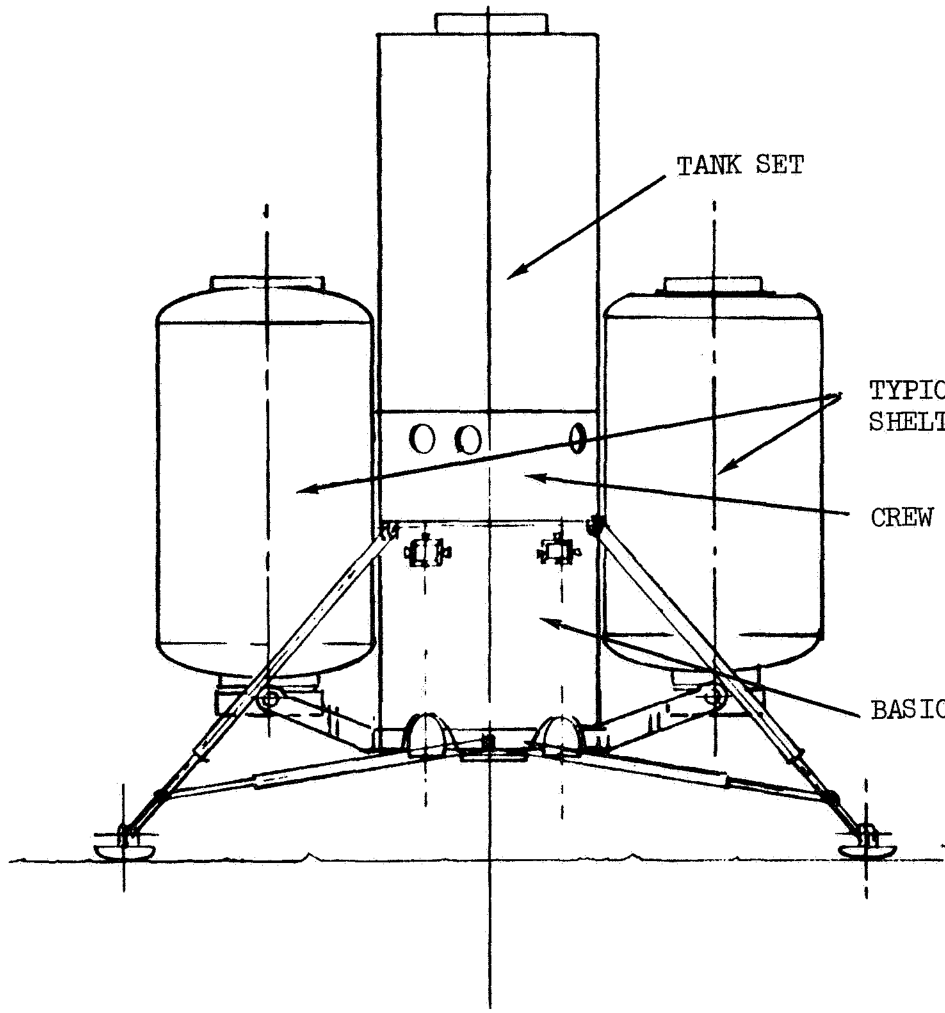


Figure 2.1-10. Baseline Tug Stage and Tank Set Concept

Tug Turnaround. The ascent-descent geometry between a lunar orbit and a point on the lunar surface repeats at intervals of approximately one lunar sidereal month, neglecting lower order perturbations. In addition, for polar orbits, there is an inverse arrangement (northward passage versus southward) at one-half month points which also permits coplanar ascents and descents. Other inclinations exhibit a non-uniform spacing between such opportunities as a function of the site latitude. These times between coplanar occurrences can range from; never, if the site latitude is greater than the inclination; through all combinations of succeeeding intervals which add up to one lunar sidereal month, as the inclination is increased above the site latitude. There are two special cases, at the poles and equator, where every orbit is coplanar if the inclination equals the site latitude. Ascent or descent at times other than the coplanar opportunities will require a plane change maneuver in lunar orbit which causes a performance penalty on the tug. In general, if it is not necessary to interface with an OLS in a polar orbit, an orbit can be selected which will permit coplanar ascent and descent at an interval which is compatible with the docking, propellant, crew, and cargo transfer operations in lunar orbit. Figure 2.1-11 illustrates a typical timeline for cislunar shuttle/tug operations in lunar orbit utilizing the stage-and-a-half tug. This timeline indicates that even with provision for two crew rest cycles for the whole crew in orbit, less than two days are required between tug lift off and landing. During this period the LSB site would have moved approximately 23 degrees. It can be shown that if the inclination is chosen to satisfy the following relationship

$$\tan i = \tan \lambda \sec \frac{\alpha}{2}$$

where: i = inclination

λ = site latitude

α = total angular movement between ascent and descent at approximately 13.2°/day

then coplanar conditions will be satisfied. For this example then, assuming a nominal 20° site latitude, the inclination should be approximately 21.8 degrees.

If it is necessary to interface with the OLS in a polar orbit, e.g., when the tug is based at the OLS or the cislunar shuttle is carrying cargo for both operations, then two basic choices are available for the tug turnaround. The first of these simply leaves the tug at the intermediate station (LSB or OLS) for the approximately 14-day interval between coplanar opportunities. This approach creates a temporary crew overlap at the intermediate station which may not be too serious at the LSB but appears to be wasteful of valuable crew time if the waiting is done in orbit. The alternative is to perform a plane change either during ascent or descent of sufficient magnitude to allow completion of the necessary transfer operations before the OLS/LSB separation angle becomes excessive. Figure 2.1-12 illustrates the performance degradation for the baseline approach where the tug is based at the OLS. The situation depicted assumes that the tug with the replacement crew and resupply

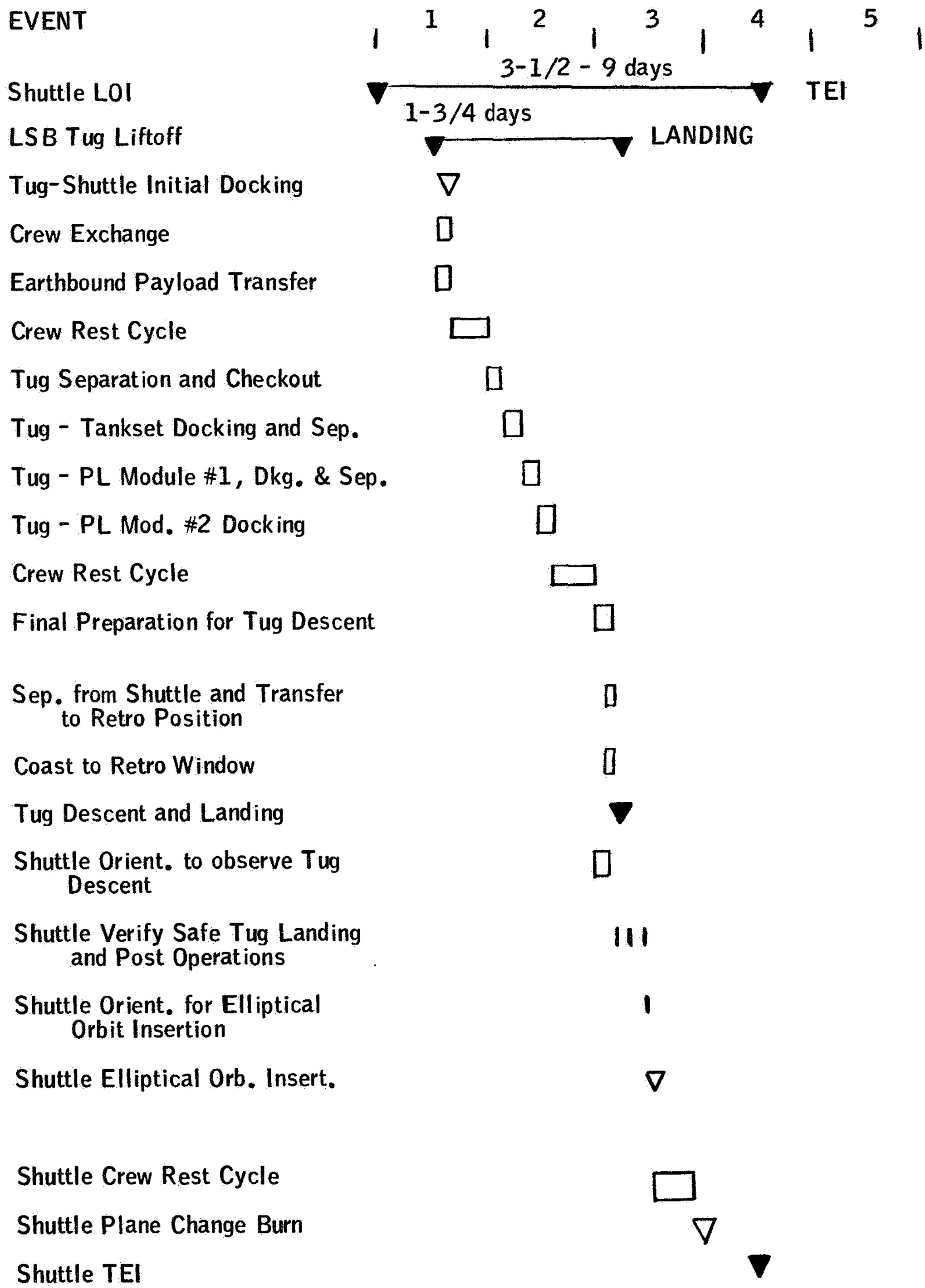


Figure 2.1-11. Cislunar Shuttle/Tug Docking Operations in Lunar Orbit Without OLS

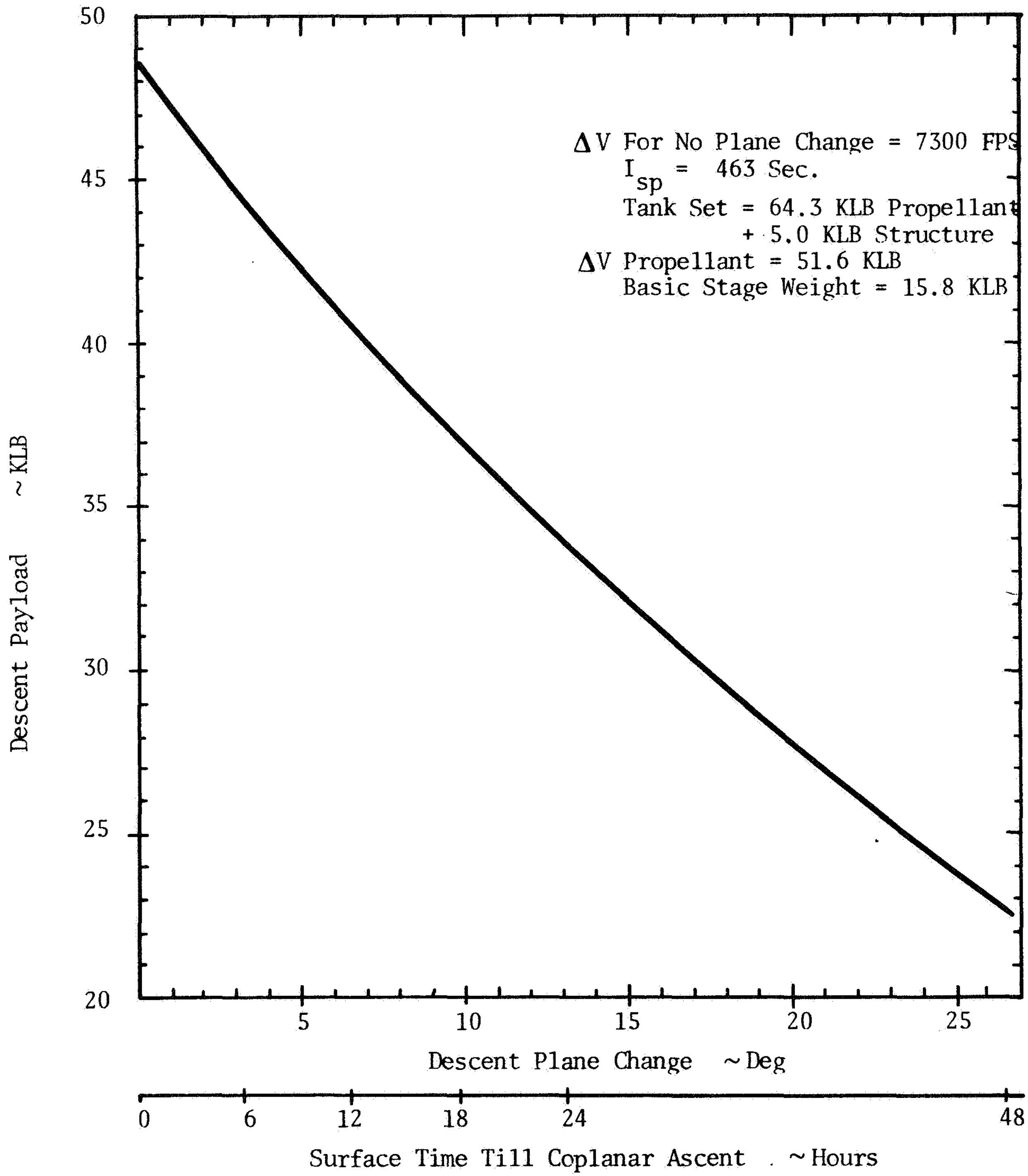


Figure 2.1-12. Loss in Descent Payload to Provide Tug Turnaround

payload makes a plane change and descends to the LSB where the cargo and expended tank set are removed so that the basic stage can make a coplanar ascent to the OLS at the appropriate time. Preliminary estimates for the surface operations indicate that they could be accomplished within approximately ten hours after landing which would involve about a 15 percent reduction in descent payload for the configuration illustrated. In general, it is more efficient by almost a factor of two to make the plane change during ascent but this would involve increasing the capacity of the basic stage which would have extensive ramifications.

Build-Up Missions. In order to achieve an early operational capability, a combination of manned and unmanned missions are utilized to deliver the LSB hardware and crew at a rate which is compatible with the multiple constraints of the logistics system, the man-hours which can usefully be expended on the surface, and the power and equipment available.

The initial delivery to the selected LSB site is unmanned and utilizes a tug which is assumed to be delivered fully fueled and loaded by an unmanned cislunar shuttle. This mission would not necessarily interface with the OLS but would utilize whatever orbit gave the best combination of payload and quick turnaround for the cislunar shuttle. The tug propellant should be sized to maximize payload within the constraints of the cislunar shuttle capacity and provide a propellant reserve to eventually permit returning the basic stage to orbit after unloading, considering propellant boiloff. It is not considered desirable to utilize one of the OLS tugs for this mission since they are a manned configuration which would result in a performance loss due to the added dead weight.

The initial manning flight also is assumed to utilize a tug which is delivered fully fueled and loaded from earth orbit. The tug payload is off-loaded sufficiently to permit an immediate return to orbit with the payload if some unforeseen problem should develop at landing. Subsequent studies may prove this approach to be overly conservative but it was adopted primarily for the program option wherein there is no OLS because there is then no redundant habitation readily available at the time of this first manned landing and rescue would have to come from earth orbit. There appears to be less justification if the OLS can affect a more rapid rescue. One of the OLS tugs could perform this mission if available. The tug would be required to remain on the surface at least until the initial elements of the shelter are habitable and probably until the next crew increment arrives.

Two or more additional unmanned flights will be required to deliver the remaining modules and equipment for the LSB buildup. These missions would utilize the basic unmanned stage which delivered the initial increment, to ascend and rendezvous with the cislunar shuttle and dock successively with the replacement tank set and the payload modules. In view of the complexity of this operation it is considered essential that it be monitored and controlled in lunar orbit. The delays and line-of-sight restrictions inherent in control from earth would further complicate and delay the accomplishment of this transfer. The control could be exercised from the OLS if the transfer takes place in the orbit and vicinity of the OLS. Otherwise, a crew module would be required on the cislunar shuttle.

The last unmanned mission could gain some added performance if it utilizes all of the tank set propellant instead of maintaining a reserve to return the basic stage to orbit again. It is not clear at this time what the economic trades are relative to returning elements of the tug to earth for refurbishment and reuse, but it would seem that some parts would be more expendable than others. If the design approach for the tug continues to emphasize a modular approach, it may not be desirable to expend complete tugs on the lunar surface but to return the high value portions to earth.

The delivery of the rest of the crew will presumably take place before the first increment is ready to return to earth. If it has not already been returned to the OLS, this mission would involve launching the basic manned stage which delivered the first crew, to perform an unmanned rendezvous and dock with the crew module of the cislunar shuttle. The arriving crew could provide the monitor and control functions for this maneuver and for the subsequent docking with the tank set and cargo modules. If the tug basic stage has been previously returned to the OLS orbit, then the tug turnaround could take place as discussed in a prior section.

Resupply Missions. The resupply missions have been implicit in the prior sections and would basically vary only in the location of the tug between missions. If there is no concurrent OLS then the tug would be based on the surface and only the disposable tank set, cargo modules, and crew would makd eht cislunar trip. The six-man crew would be housed in a crew module integrated with the cislunar shuttle. The shuttle enters a specific inclined orbit with inclination and node selected to permit a coplanar ascent and descent. The basic stage of the manned tug ascends with the returning crew and their data and samples and docks with the shuttle crew module. The new crew then assumes control of the tug and successively docks it with the tank set and cargo modules. The tug then makes its coplanar descent while the cislunar shuttle waits in orbit for proper phasing for the transearth injection.

If there is an OLS operating concurrently, it appears desirable to base the tug at the OLS between resupply missions so that it can be utilized for escape or other missions. For this mode, the cislunar shuttle would rendezvous with the basic stage of the tug in the OLS orbit and the new crew would complete the docking maneuvers to configure the tug for descent. When the proper phasing had been reached with the LSB site location, the tug would descend to the LSB, the crew, cargo, and tank set would be off-loaded, and the returning crew would ascend, rendezvous with the OLS, and transfer to the cislunar shuttle to wait for transearth injection phasing. As discussed under "tug turnaround" above, the descent-ascent could be almost 14 days apart or within a few hours of each other if the plane change capability were provided.

2.2 VEHICLE CAPABILITIES

The vehicle capabilities utilized in deriving the operations sequence and traffic model were those which were current in the various studies at NR at the time the LSB study analysis was performed. All of the elements were under active study and new performance calculations and operating modes were derived almost continuously. It is not expected that the performance capabilities described herein will be utilized to draw any conclusions on what the logistic system should be but more what the LSB influences are on the eventual logistic system design.

2.2.1 Earth Orbit Shuttle (EOS)

The EOS configuration utilized is designated the "January Delta-Wing High Cross Range Baseline Vehicle". The allowable payload dimensions are a 15-foot diameter by 60-foot cylinder. Dry payload capability to a 100-nautical mile orbit at 31.6-degree inclination is 38,000 pounds. This same payload can also be delivered to the cislunar shuttle orbit at 258 nautical miles and 31.6 degrees by utilizing the propellant reserved for ascent abort. This propellant (24,500 pounds) is required to be reserved until orbital conditions are reached but can then be utilized for further maneuvers. If the payload contains this amount of propellant and an interface can be arranged to permit the payload propellant to be utilized by the EOS in the event of an ascent abort, the EOS can take a total of 62,500 pounds to the 100-nautical mile by 31.6 degrees orbit. Payloads this large would require use of an earth orbital tug to provide the delta velocity to rendezvous with the cislunar shuttle in its higher orbit. A detailed study would be required to establish the best operating mode. No combination of payload elements for the LSB which fit within the 60-foot bay is projected to exceed the 38,000 pound limit. The expendable tank set for the tug will have to be delivered off-loaded and topped-off in orbit from either a subsequent shuttle or an orbital propellant facility.

A more significant constraint probably occurs in the initial buildup phase of the LSB when it will be important to refuel, refurbish, and load the cislunar shuttle as rapidly as possible. This operation has been analyzed in the other concurrent Integrated Program studies and was not examined in this study. Only the estimated number of EOS flights required for the cislunar shuttle LSB payload were identified.

2.2.2 Reusable Nuclear Shuttle (RNS)

The projected capabilities for the RNS were based on data generated in support of the Nuclear Shuttle System Definition Study (Contract NAS8-24975).

The weight and performance model utilized assumed main propulsion system thrust and specific impulse values of 75,000 pounds and 825 seconds, respectively, and a usable propellant loading of 290,880 pounds. A stage scaling law was applied to the propellant loading to yield a structural weight of 83,424 pounds. Fixed weights of 90, 660, 990, and 640 pounds were assumed to be jettisoned during the pre-TLI, cislunar, lunar orbit, and transearth mission phases, respectively.

A flight performance reserve factor of 3/4 of one percent was applied to all characteristic velocities. Propellant cooldown losses for each maneuver were approximated as a function of the propellant required to execute the maneuver by the empirical relationship:

$$W_{PC} \text{ (pounds)} = 59.5\ W_P - .965\ W_P^2$$

where W_P is in thousands of pounds.

The weights model also assumed a secondary propulsion system (SPS) having an engine specific impulse of 425 seconds. Delta-V values assumed for the SPS are as follows:

Delta-V (fps)	Mission Phase
34	Prior to TLI
80	TLI to first LOI burn
10	Between first and second LOI burns
10	Between second and third LOI burns
50	Circular lunar orbit
10	Between first and second TEI burns
10	Between second and third TEI burns
80	TEI to EOI
34	Post TEI

The return payload was nominally fixed at 10,000 pounds. The weight synthesis process for a given set of mission dependent delta-V's converged on the maximum outbound payload and the secondary propulsion system propellant loading within the two constraints of main propulsion system propellant loading and a secondary propulsion system propellant reserve of zero at mission completion.

By the use of this model the data in Figure 2.2-1 were prepared for the mission delta-V's previously described. Both options are illustrated: where the orbit node is constrained following the initial launch, and where it is not. These data were based on a payload of 10,000 pounds returned to earth. More or less return payload may be desired for some missions. The tradeoff between RNS outbound and return payload is illustrated in Figure 2.2-2. These data are based on the delta-V's associated with the first earth departure opportunity in Figure 2.2-1. The slope of this curve could probably be applied, however, to any of the RNS missions for planning purposes.

One measure of the significance of this pattern of payload capability is illustrated in Figure 2.2-3 where the number of opportunities in a three-year span are plotted against the payload magnitudes at those opportunities. The reduction in payload resulting from the plane changes associated with the constrained orbit node case is evident. However, when the nominal LSB resupply mission requirements are located on this plot (approximately 6 flights at 111 k lb) it can be seen that considerable margin is available in both back-up opportunities and/or payload for either resupply operating mode.

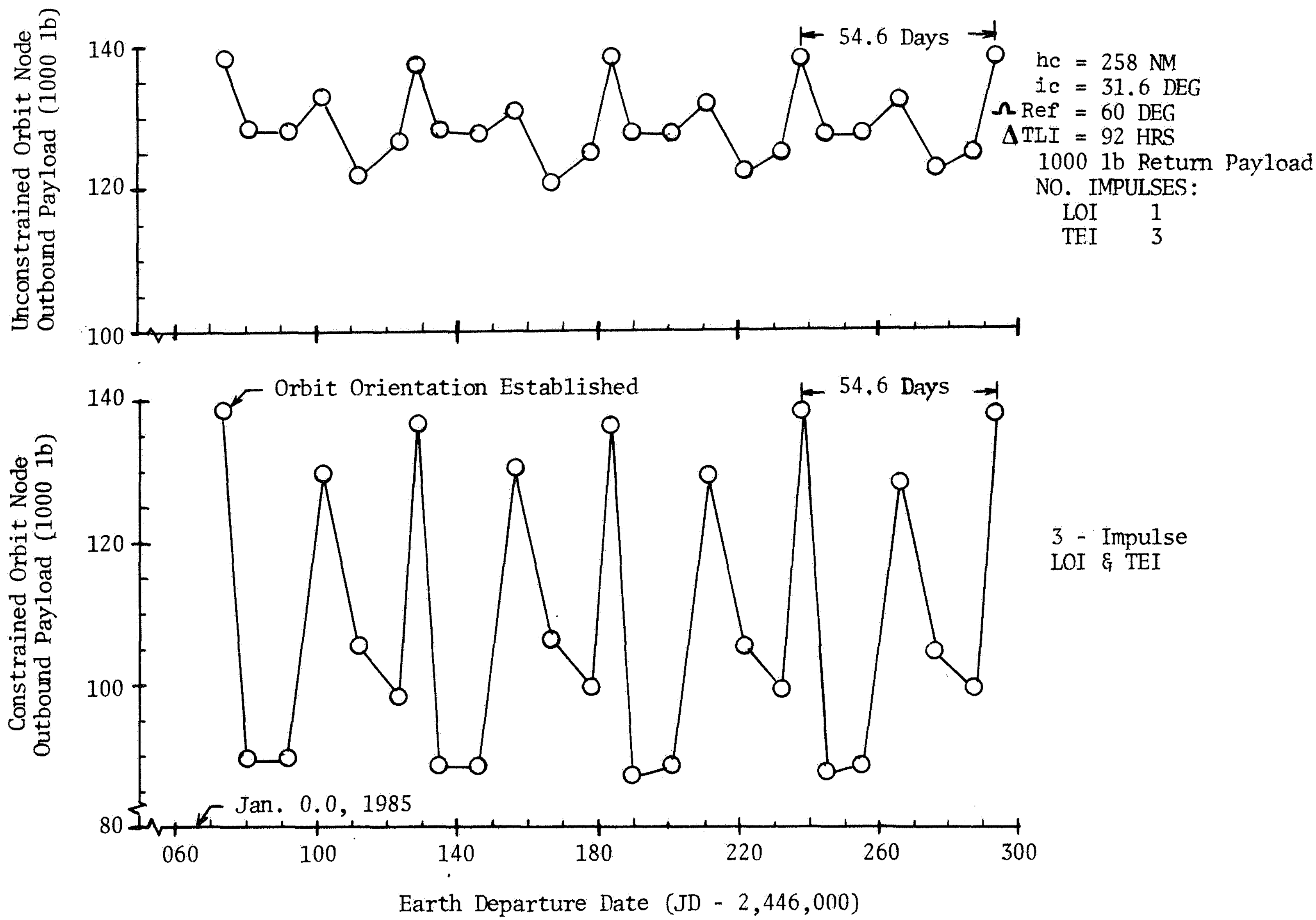


Figure 2.2-1. Typical RNS Lunar Payloads

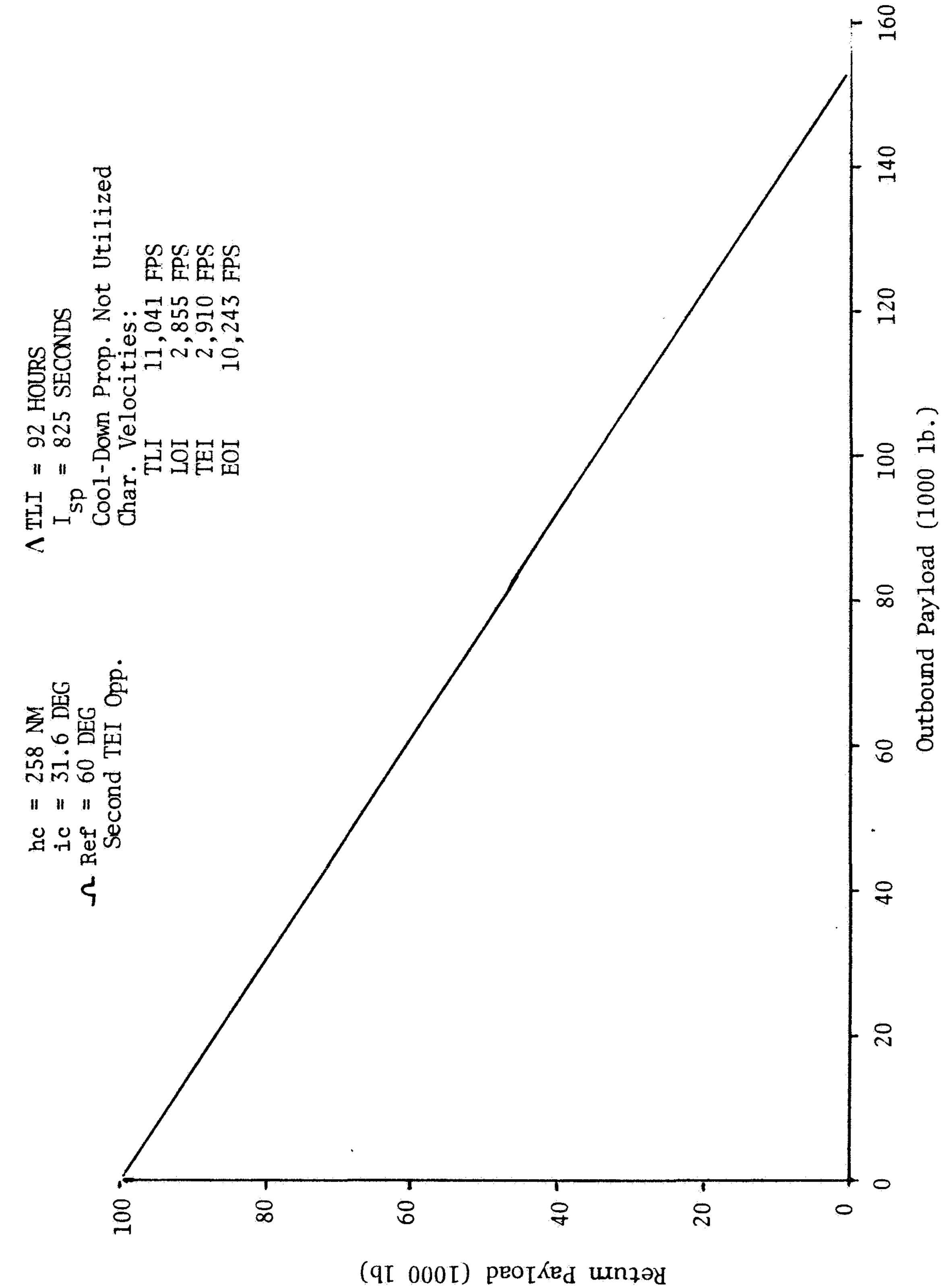


Figure 2.2-2. RNS Outbound - Return Payload Tradeoff

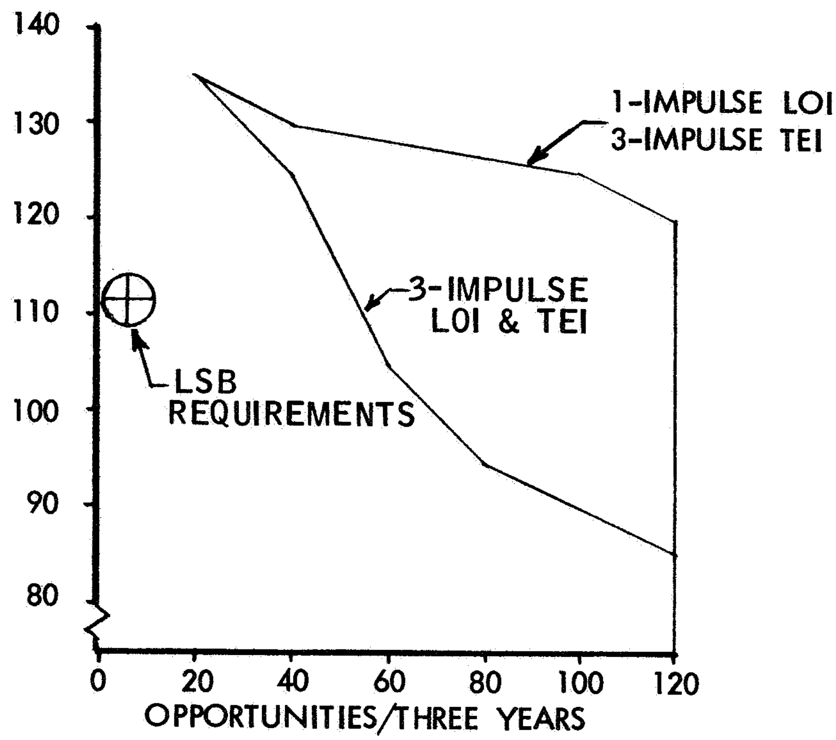


Figure 2.2-3. Translunar Mission Opportunities

2.2.3 Chemical Interorbital Shuttle (CIS)

The capability of the S-II stage as an interorbital shuttle has been analyzed under Change Order 2021 to Contract NAS7-200. As a part of that analysis the capability of the CIS to support a joint LSB/OLS lunar program was examined. The lunar program requirements utilized were those available from the OLS and LSB studies in late January 1971 and are, therefore, representative of the final recommendations. The portions of this mission analysis pertinent to the LSB were abstracted for use in this study and are summarized in a following section.

The analysis was based on a straightforward utilization of the CIS in a single-stage mode with a nominal propellant loading of 1000 k lb and an I_{sp} of 459 seconds. This resulted in a nominal payload capability of 175-k lb outbound with 30 k lb inbound. The trade between outbound and inbound payloads is approximately 2.7 pounds increase in outbound payload per pound of decrease in inbound payload.

The larger lunar payload capability of the defined CIS tends to relieve some of the constraints on the tug flights discussed later. However, it also tends to emphasize the difficulties in earth orbit for the rapid turnaround during LSB build-up. Approximately twice as many EOS flights are required per CIS flight as per RNS flight and the accomplishment of six round trips within the first six months will present a severe problem in the earth-to-orbit delivery of propellants and payload. Some benefit may be derived by utilizing a cislunar shuttle mode which, by incorporating a tug recovery into earth orbit, greatly increases the lunar delivered payload. This increase might reduce the number of flights required which would simplify the earth orbit operations at the expense of lunar orbit operations.

2.2.4 Space Tug

As indicated earlier, the tug configuration utilized for the LSB logistics analysis was one which was derived during the Reusable Space Tug Study (Contract NAS9-10925) for performing a geosynchronous mission. For this study, the propellant tank sizing was adjusted slightly to better match the requirements of the LSB buildup and resupply. The usable propellant in the basic stage was set at 11,940 pounds by the requirement to be able to return a 6-man crew and 2000 pounds of consumables, data, and samples to lunar orbit. The tank set was originally sized at 66.7 k lb capacity to provide a small margin over the estimated resupply payload requirement within the payload limitations of the RNS. Subsequent analysis of the build-up process indicated the desirability of maintaining the higher capacity in the tank set even though the resupply requirements were reduced. Figure 2.2-4 illustrates the capabilities of the selected tug configuration for the various types of missions described earlier. The effects of the payload limitations of the assumed RNS model are shown as upper bounds for each case. The payload is defined for this figure to include all useful delivered weight such as crew, consumables, equipment, and propellant boiloff allowances. The points selected for the three unmanned flights and one of the manned flights during the LSB buildup phase and the regular manned resupply are indicated in their appropriate relationships. The initial manning flight is not shown because of the assumed

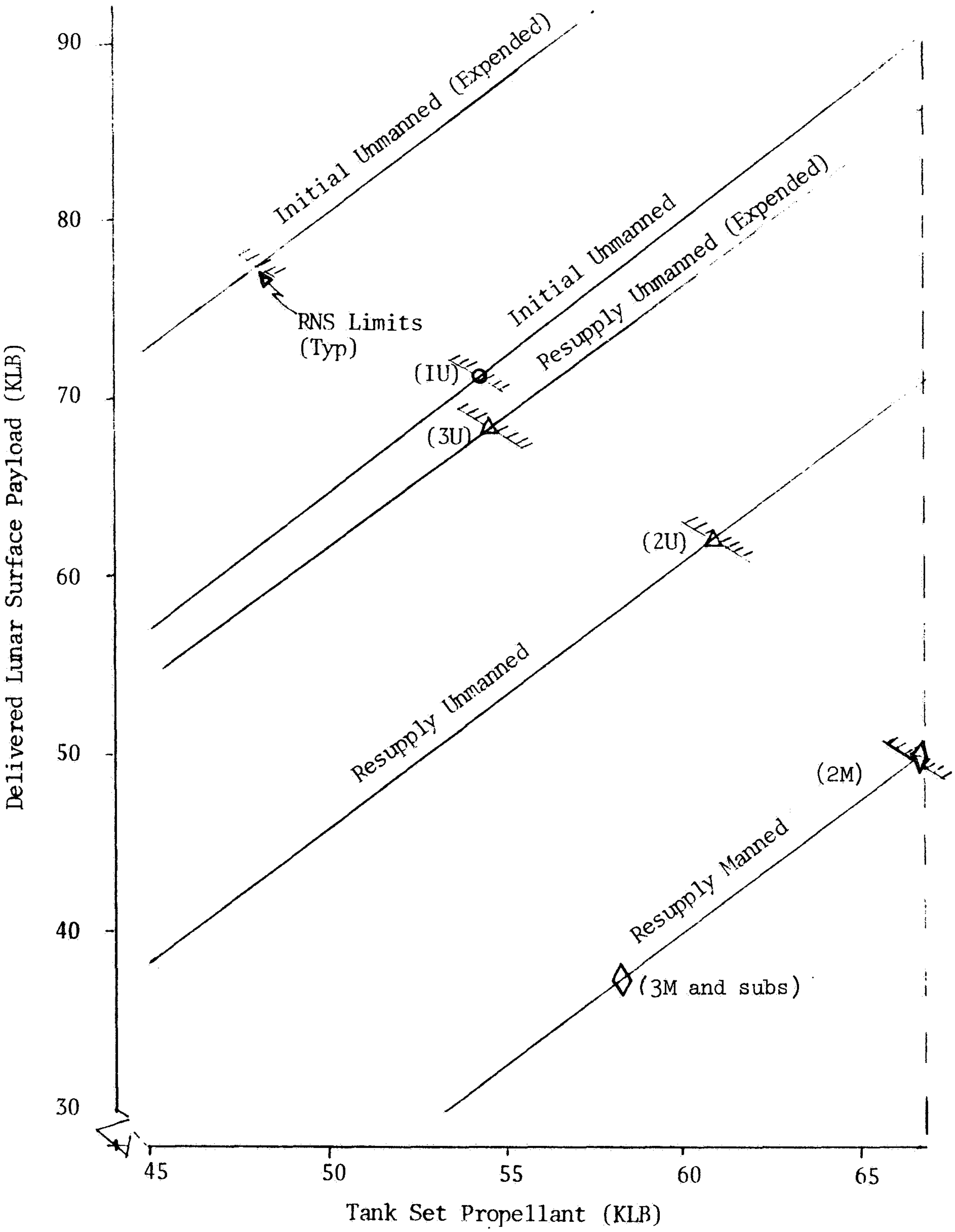


Figure 2.2-4. Tug Capabilities
(See Text for Assumptions)

special mission rule requiring the capability to abort back to lunar orbit without any unloading. Figure 2.2-4 was based on the following assumed weights and capabilities:

Tug Elements	
Basic stage propulsion module (dry)	3.2 klb
Intell. mod., landing legs, and RCS prop.	7.3
Crew Module	5.9
Tank set (dry)	5.0
PM propellant capacity	11.94
TS propellant capacity	66.7
Tug Ascent Payload	
Resupply unmanned	0 klb
Resupply manned	4.3
RNS Delivery Limits	
Initial unmanned	153 klb out, 0 klb in
Resupply unmanned	138 klb out, 10 klb in (RNS manned)
Resupply manned	131.2 klb out, 14.3 klb in

If the characteristics assumed in preparing Figure 2.2-4 were firm, it would appear that a somewhat smaller tank set (approximately 61-klb) capacity might be a better choice to accomplish the mission since only one flight (2M) exceeds this limit. However, it is felt that the analysis illustrates the general relationship between the elements of the logistics system and the LSB logistics requirements and provides a basis for deriving a feasible operations sequence for the no-OLS case.

For the analysis of the concurrent support of the LSB and OLS programs, the same basic modes of operation were assumed except that the tug is based in orbit and a larger tank set is required in order to meet the requirements of the OLS and boiloff from two tugs.

3.0 LSB MISSION SYNTHESIS

The preceding sections have described the selection and optimization of the individual major elements of the LSB; i.e., the surface vehicles and flyer, the observatories' telescopes, the shelter experiments, and the logistics vehicles and the drills. The LSB mission synthesis task is to put them all together into an integrated package of requirements, which then must be accommodated by the design of the shelter.

In this section, the top level functional and performance requirements for the shelter are defined, alternate mission concepts are described, the optimum LSB mission is selected, a specific site is recommended, the relationship between the LSB and precursor missions, concurrent missions (OLS), and succeeding missions is discussed and the LSB program sequence plan is presented.

3.1 SHELTER REQUIREMENTS

The objective of the mission analysis and synthesis tasks is to define the requirements which the shelter must fulfill to enable the lunar exploration mission to be accomplished. The shelter is the primary element of the LSB.

Three kinds of requirements apply to the shelter: functional - the fundamental tasks and operations which must be completed to achieve a viable shelter; performance - the quantitative specifications which size and configure the shelter; and operational - the placards and limitations applied to the performance envelope of the shelter and its subsystems. For this preliminary design study the operational requirements were not considered.

The above requirements must be determined for both the mission of the shelter and for the shelter as an overall system. Mission requirements arise from the path which the shelter follows in reaching its ultimate lunar position and are concerned with timing, loads, and environments. System (shelter) requirements are derived from the necessity to optimize the size of the shelter as a piece of hardware.

Some of the requirements developed here are considered firm in the sense that every LSB concept must conform to them. Other requirements are based on logical desires which may not be quantitatively justified in some cases. Included here are safety requirements such as the need for dual exits from a single module. Still others resulted from assumptions that were made for this study. These latter requirements are not essential to every LSB and are identified as requirements in order to provide visibility of the thread of subsequent decisions.

The top level requirements on the shelter are listed in Table 3.1-1. Other lower level requirements are in the RAS's of Appendix C.

Table 3.1-1. Shelter Top-Level Requirements

LSB Shelter Requirements (1)

1. Mission Functional Requirements

1.1 Initial mission

1.1.1 Boost shelter to earth orbit EOS

1.1.2 Mate shelter and cislunar shuttle (CS) in earth orbit

1.1.3 Boost shelter on translunar trajectory

1.1.4 Translunar coast

1.1.5 Deboost shelter into lunar orbit

1.1.6 Mate shelter and tug in lunar orbit

1.1.7 Deboost shelter from lunar orbit

1.1.8 Land shelter on lunar surface

1.2 Resupply Missions

1.2.1 - 1.2.8 Same as 1.1.1 - 1.1.8 for shelter cargo and cargo modules

1.2.9 Load and return cargo aboard tug

1.2.10 Boost return cargo to lunar orbit

1.2.11 Transfer cargo to CS

1.2.12 Boost cargo on transearth trajectory

1.2.13 Transearth coast

1.2.14 Deboost cargo to earth orbit

2. Shelter Functional Requirements

2.1 Provide shelter support to surface operations

2.1.1 Remote exploration sorties

2.1.1.1 Provide support to remote exploration sorties by providing the following personnel, equipment, or operations: crew quarters and consumables, equipment storage, field communications, sample analysis, data reduction and transmission, technician support, sample return, and crew rotation

2.1.1.2 Surface vehicle maintenance between sorties to be done as IVA operations

2.1.1.3 Maximum overlap between remote sorties shall be two weeks

2.1.2 Observatory operations

2.1.2.1 Provide support to observatory operations by providing the following personnel,equipment, or operations: crew quarters and consumables, data reduction and transmission, tech. support and crew rotation

2.1.2.2 The shelter shall be located in close proximity to the observatory to provide maximum support

2.1.2.3 The observatory shall be automated to minimize routine crew support requirements, but to utilize crew for complex operations

2.1.3 Shelter experiments

2.1.3.1 Provide support to the experiments program at the shelter by providing the following personnel, equipment, or operations: crew quarters and consumables, equipment storage, remote equip displays and controls, data reduction and transmission, expmt power, technician support, sample return, and crew rotation

2.1.3.2 Provide a contamination-free area accessible to the shelter for external experiments

2.1.4 Deep drilling

2.1.4.1 Provide support to the drilling operations by providing the following personnel, equipment or operations: crew quarters and consumables, equip storage, communications with field, sample analysis, drilling power, rig and crew transportation, data analysis and transmission, sample return, and crew rotation

2.1.4.2 Deep drilling operations are to be conducted as IVA operations to reduce drilling time

2.2 Shelter functions

2.2.1 Up payloads

2.2.1.1 Ingress personnel in shelter living quarters

2.2.1.2 Stow cargo in shelter warehouse

2.2.2 Routine operations

2.2.2.1 Perform housekeeping operations

2.2.2.2 Inspect, maintain, repair and check out shelter subsystems

2.2.2.3 Assemble and check out post-buildup shelter modules for subsequent growth

2.2.2.4 Inspect, maintain, repair and check out mobility equipment, suits, and science and support equipment

2.2.2.5 Inspect, maintain, repair and check out tugs which support LSB

2.2.2.6 Provide laboratories for geosciences, photography, and data analysis

2.2.2.7 Provide living quarters, workspace, medical facilities, galley, recreation,and control center

2.2.2.8 Provide storage volume for scientific and support equipment, suits, and crew and equipment consumables

2.2.3 Management

2.2.3.1 Monitor and contr l landing and launch operations

- Timing
- Flight parameters
- Tracking
- Communication

2.2.3.2 Monitor and control the experiments program

- Sci. payload composition (in and out)
- Experiment sequencing
- Data evaluation

2.2.3.3 Monitor and control LSB operations

- Support equipment payload composition (in and out)
- Task scheduling

2.2.3.4 Perform autonomous operations. Shelter must be capable of 180 days operation without resupply

- Increased spares requirements
- Increased computer support requirements
- Increased crew skills mix
- Increased subsystems and experiment equipment and operations data bank
- Increased surf. comm. requirements (no manned earth relay)
- Increased req. for auto. on-board checkout and displays

(1) Final MSS Requirements = EOS/MSS Requirements + LSB/MSS Requirements (SD 70-546-1, January 1971)

Table 3.1-1. Shelter Top-Level Requirements (Continued)

2.2.3.5 (Ref. 1.2.03) (1) Management of long-range general mission planning for the shelter will be done on the ground

2.2.3.6 Principal investigators will not, in general, be located at the LSB

2.2.4 Safety functions

2.2.4.1 Protect personnel, cargo and equipment from lunar environment
- Radiation
- Meteoroids
- Seismicity

2.2.4.2 Provide alternate operational capabilities in event of equipment loss, malfunction, or failure

2.2.4.3 (Ref. B 2.11) (1) Hazardous material, potentially explosive containers, or volatile gas containers shall be structurally isolated from crew living and operating quarters, and shall be protected so a failure of one will not propagate to another

2.2.4.4 (Ref. B 1.3) The shelter shall be divided into pressurized areas so that any damaged module can be isolated as required. Accessible modules will be equipped and provisioned so that the crew can safely continue a degraded mission and take corrective action to repair or reduce the damaged module

2.2.4.5 (Ref. B 2.6) Two or more entry-access paths shall be provided to and from every compartment or other area with restricted access

2.2.4.6 (Ref. B 2.8) Primary pressure structure materials shall be nonflammable. Interior walls and secondary structure shall be self-extinguishing

2.2.4.7 Provide capability to rescue personnel and equipment from remote and inaccessible locations

2.2.4.8 All walls, bulkheads, hatches and seals whose integrity is required to maintain pressurization shall be readily accessible for inspection and repair by crewmen in pressurized suits

2.2.4.9 (Ref. B 2.14) All EVA and unpressurized compartment IVA shall be conducted using the "buddy system". The buddy system shall also be used during shirtsleeve operations in hazardous areas.

2.2.4.10 Contingency provisions and habitable facilities shall be adequate to sustain the primary crew plus a replacement crew for one CS minimum turnaround cycle (Ref. B 1.4)

2.2.4.11 (Ref. B 1.5) Atmospheric stores and subsystem capacity sufficient for one repressurization shall be maintained on the shelter to independently supply each pressurized volume to sustain the entire crew

2.2.4.12 (Ref. 1.110) As a goal, no single malfunction or credible combination of malfunctions and/or accidents shall result in serious injury to personnel or to crew abandonment of the shelter

2.2.5 Down payloads

2.2.5.1 Package, store, and unload cargo from shelter for return flight

2.2.5.2 Egress personnel from shelter for return flight

3.0 Mission Performance Requirements

3.1 Earth orbit parameters for EOS and CS shall be 258 n mi altitude at 31.6° inclination to equatorial plane

3.2 Lunar orbit parameters for CS shall be 60 n mi altitude with inclination a function of site latitude

3.3 Shelter launch date shall be January, 1985

3.4 Shelter resupply interval shall be 164 days

3.5 Half of each crew will be rotated every resupply interval

3.6 Individual crew stay times will be 328 days

3.7 Shelter shall be capable of normal internal operations and external mission support throughout lunar day and night, particularly surface EVA

3.8 Shelter will be delivered unmanned

3.9 Directional orientation of the shelter on the surface is not critical from a mission viewpoint and may be determined by the local terrain; therefore, no orientation restrictions shall be imposed by shelter subsystems

3.10 Shelter shall be capable of full operations at any accessible, nonhazardous location on the lunar surface

(1) MSS Guidelines and Constraints Document, MSC-03696, Rev. 1, 8 Feb. 1971

Table 3.1-1. Shelter Top-Level Requirements (Continued)

4.0 Shelter Performance Requirements

4.1 Shelter useful life on lunar surface shall be 10 years with resupply of consumables and replaceable equipment

4.2 Shelter shall be designed for a normal crew complement of 12

4.3 The shelter and its resupply cargo modules and crew shall be delivered to the lunar surface via the EOS, CS and space tug. Crew and cargo will be returned to earth in reverse order

4.4 Maximum cargo module weight shall not exceed 20,000 pounds

4.5 Maximum integral shelter component dimensions are limited by EOS to a cylinder 15 ft dia x 60 ft long

4.6 Boost loads and attach points shall match EOS capabilities

4.7 The shelter shall be capable of quiescent operation; i.e., subsystem and equipment shutdown and subsequent restart for multiple period up to one year each

4.8 The shelter reliability over the 10-year mission shall be sufficient to preclude premature termination of the mission, or serious injury to any crewman, or severe damage to equipment

4.9 Shelter design will not preclude growth to a larger size base

4.10 Solid and liquid waste material will be stowed in sealed, unpressurized containers and transported to a remote area for disposition

4.11 Shelter design will permit continuous shirtsleeve operations in a 3.5 psia O_2 - 6.5 psia N_2 atmosphere

4.12 Shelter hardware interchangeability with the modular space station hardware is a design goal to minimize development costs. Primary objective is common housing and cargo modules and subsystems

4.13 Continuous two-way voice communications capability will be maintained between the shelter and earth and between the shelter and remote exploration crews

4.14 Shelter buildup operations to the 12-man capability will be completed within 6 months from initial launch

4.15 Shelter shall be firmly anchored to lunar surface to minimize relative motion of modules

3.2 LSB CONCEPTS

The LSB elements selected previously can be phased into the lunar base schedule simultaneously or individually. The observatory, particularly the optical telescopes, and some of the shelter experiments which operate outside the shelter, are sensitive to subsurface vibrations, dust, and atmospheric contamination. As the primary causes of these unfavorable environments are associated with deployment and assembly tasks in the buildup phase and local geoscience exploration such as seismic surveys and drilling, one LSB concept would be to complete buildup and local exploration prior to operating the telescopes.

The above concept assumes that a common LSB site could be found which would satisfy all experiment site requirements, and that all three surface missions are to be carried on essentially concurrently. However, it is possible to restrict the LSB to a mutually exclusive concept of observatory operations alone or to geoscience (remote sorties and deep drilling) alone, particularly if a common site cannot be found or if both disciplines are not funded. While the advantages of an absolutely clean and quiet observatory environment are desirable, there are increased costs associated with it if it is separated from the shelter as was shown previously in the trade study. There are no corresponding constraints by the observatory on the geosciences.

The great variety of bioscience, lunar atmospheres, particles and fields, aerospace medicine, and the engineering, technology, and operations experiments can be performed either at an observatory or a mobile geosciences shelter although an observatory would be preferred because of its quiescent nature.

3.3 OPTIMUM LSB SELECTION

Since no quantitative limits can be established at this time, it is concluded that, for planning purposes, the initial concept of concurrent science with maximum data gathering and the lower program costs outweighs the potential environmental disadvantages. To offset this contamination somewhat, however, it is possible to schedule the deep drilling experiments ahead of optical astronomy.

The drilling equipment will be delivered early in the buildup cycle, and assuming a suitable drill site can be found quickly utilizing precursor mission site photographs, the drilling can begin at essentially the same time as the large telescope is being assembled. Drilling the two deep holes will take about 300 days in total and the observatory will be completed long before since it is estimated that one month is required for assembly. If the drilling environment is unacceptable, observatory operations can begin intermittently during drill down times but full operations would wait until drilling was completed.

In this optimum LSB concept, the non-site dependent experiments program will be performed at the shelter due to accessibility of labs and manpower.

3.4 LSB SITE SELECTION AND LAYOUT

The geoscience site criteria are inherently dependent on the location of their observables; i.e., on surface and subsurface phenomena. The observatory site criteria are also strongly dependent upon the location of their observables; i.e., the celestial sphere, and therefore are concerned with where the telescopes can be located for the most advantageous viewing. Generalized astronomy site criteria are discussed in the following and were developed quantitatively in Table 5.2-1 of Part 1.

For a single observatory maximum coverage is achieved if the site is on the equator since the rotation of the moon will bring the entire sphere into view over a period of 27.3 days, the sidereal month. The limb or far side is desirable for radio telescopes to block earth-generated RF noise. For the same reason particle flux measurements should be made on the limb or far side. X-ray measurements are not sensitive to near or far side location but positioning the telescope inside a large smooth-walled crater will permit measurement by path occultation. A near side location is most suitable for cislunar wave propagation measurements. Since the optical, radio, X-ray, and IR telescopes have the highest potential subobjective yield, their criteria were given precedence for a centralized observatory and, therefore, an equatorial, site on a limb or far side location was selected for the astronomy mission.

Each of the observatory elements has a set of requirements relative to its location, orientation, and interfaces with the LSB. The layout depicted in Figure 3.4-1 represents a blending of the individual requirements of the experiments identified in the study. The arrangement shown represents a near optimum condition and compromises can be expected for the actual site. The figure indicates the site on the leading limb of the moon, slightly south of the equator, which ideally contains a 60-statute mile diameter crater with 0.5-statute mile walls. The crater floor should be as smooth as possible, particularly in the central 25 x 40-statute mile section. If these features were all present in a single site, then the observatory and LSB elements could be colocated, as shown, along an east-west line to ensure minimum mutual shadowing. The 100-inch telescope is shown connected by a pressurized tunnel to the LSB shelter to allow shirtsleeve operations. The tug landing sites should be located either north or south of the site east of the north-south line through the 100-inch telescope and at least a mile away to minimize the dust contamination.

Although the recommendation of a preferred LSB site was not a study requirement, one was selected to focus the remaining design tasks toward the solution of a quantitative, representative lunar site problem. With the selection of such a site, the mathematical model could be used, since it is nondimensionalized, to give the important mission parameters directly and thus avoid the necessity of additional route analyses.

The site which best satisfied all criteria was a moderate sized unnamed crater in Mare Orientale shown in Figure 3.4-2. This location does not satisfy all site requirements in that the diameter is below the X-ray occultation requirements, it does not have the ultimate radio range growth capability of 40 x 25 miles, the walls are even but higher than desired which will obstruct

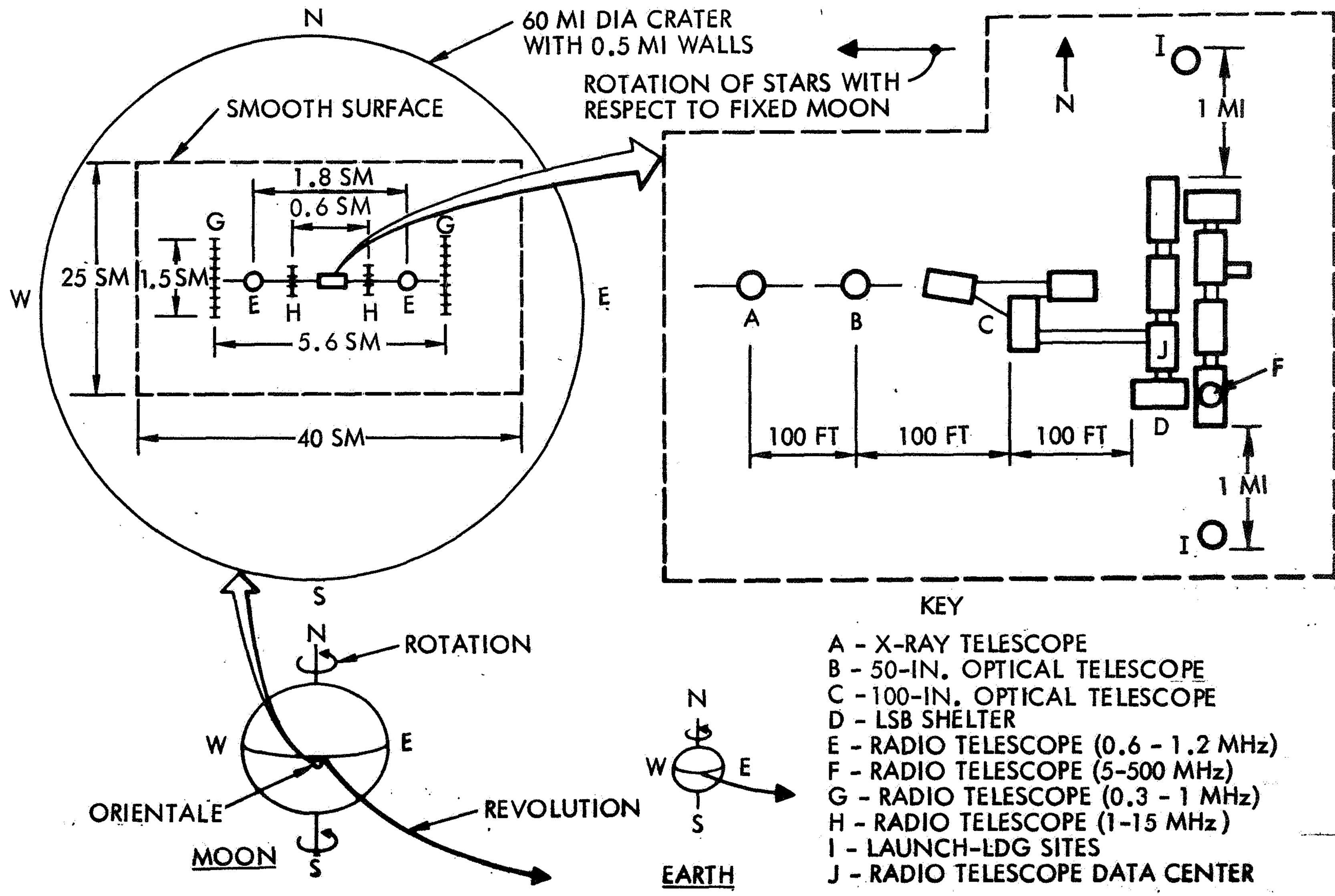


Figure 3.4-1. Site Orientation Requirements

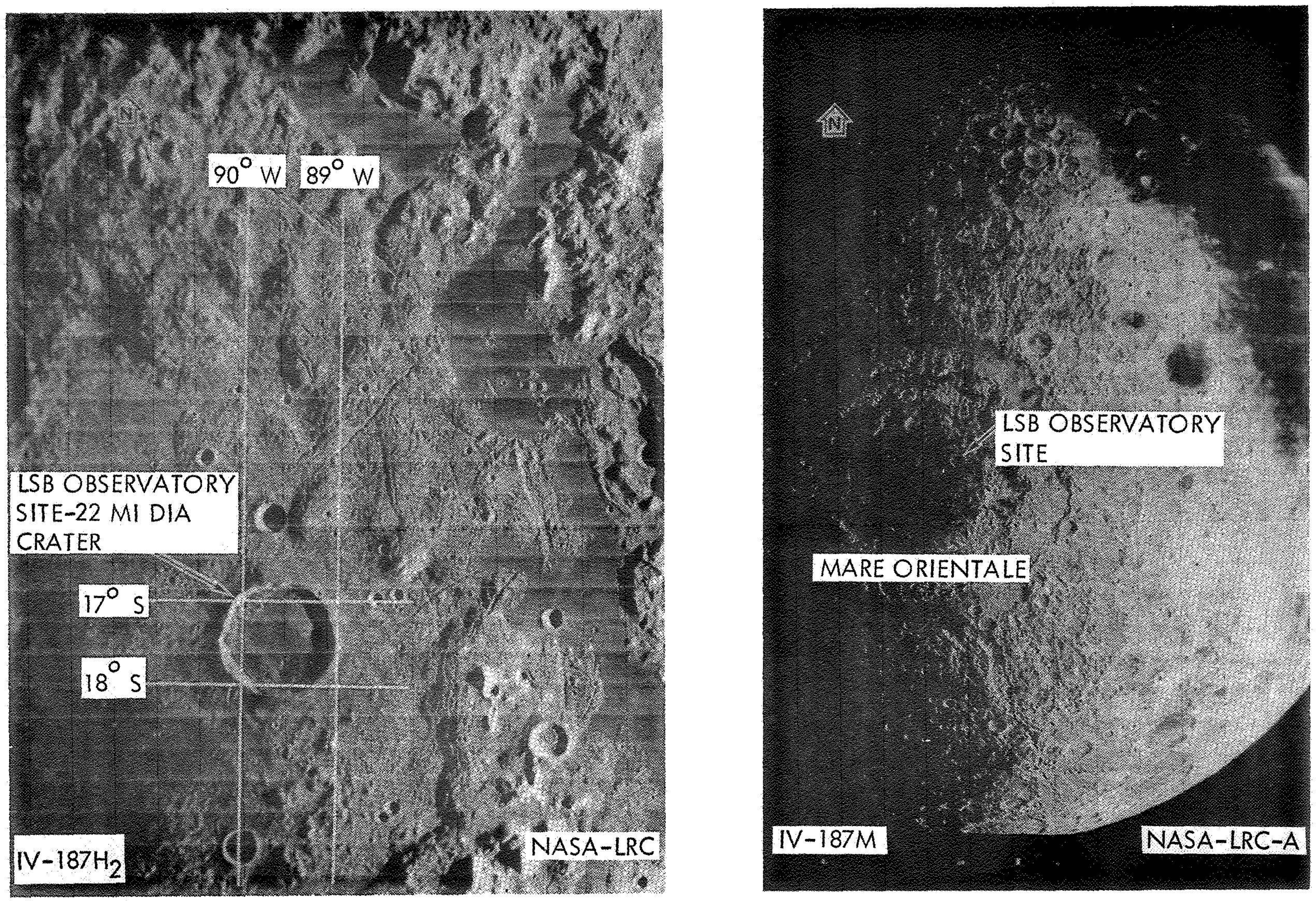


Figure 3.4-2. LSB Observatory Site Selection

the north-south view by about 5 degrees, the walls will increase the surface view factor which will increase the daytime heating, the walls may also be difficult to drive over on the remote sorties (but slumping which can be observed at the south rim may relieve this problem), and lastly, the site is 9 to 10 degrees beyond the desired southern latitude limit of 8 degrees, which was recommended to permit viewing of the Magellanic Clouds in the southern hemisphere. It is, however, the largest, smooth floor (from Lunar Orbiter high-resolution photographs) crater with access to the central Orientale region.

3.5 PRECURSOR MISSIONS

Requirements for precursor missions for the Lunar Surface Base have been identified and include orbital mapping of potential LSB sites and manned missions to promising sites for site selection evaluation and engineering performance data.

The timing of the precursor missions is primarily associated with the process of accumulating data to permit selection of the best location for the LSB. The base shelter will be designed to be compatible with any location and it is expected that the scientific equipment complement will be basically the same for all sites of interest. However, the site selection will involve a detailed tradeoff of the desires of various scientific disciplines, mobility constraints, and operational considerations. It is anticipated that the accumulation of additional data (beyond that presently available) to aid in accomplishing this programmatic decision would require approximately two years. Adding one year lead-time for final detailed planning results in initiating the precursor missions three years prior to the establishment of the LSB. This schedule is described more fully in the following paragraphs. Obviously, this schedule could be shortened considerably by events within the next decade and/or by assuming a somewhat higher risk in site selection.

The orbital mapping mission is suggested to be accomplished approximately three years prior to the initial LSB landings to provide sufficient time for photo analysis and map making. The mission requirements include photographing potential LSB sites to 10-foot resolution for approximately 230 statute miles radius about each site. From these data, complete geophysical and topological site maps will be prepared.

The manned landings could begin one year later, after the primary LSB sites have been selected from the photos, and could be expected to be completed within six months assuming visits to three sites. Completion of the site measurements and engineering performance data would thus be available at the end of the second precursor year to provide at least one year lead time for incorporating the results into science equipment designs and final site selection.

The manned landing missions will conduct observatory site evaluation measurements including long term seismic, thermal, and outgassing measurements, 360-degree horizon photographs, soil and rock samples, determination of bedrock depth, and surveying to prepare detailed maps for LSB site layout. Radio beacons will be deployed in suitable locations to simplify later landings.

Also included in these missions are the engineering measurements which are gathered in ten experiments from four disciplines. These experiments are primarily associated with astronomy and should be performed at the intended observatory site. Payload requirements for these experiments are: weight 2122 pounds, maximum power 350 watts for 25 hours, continuous power 120 watts for one year, volume 350 cubic feet, data rate 300 bits per second. A long-life, RTG-powered transmitter and command receiver will transmit experiment measurements at scheduled intervals during lunar day and night, lunar passage through earth's magnetosphere, solar flares, and micrometeoroid showers. Also, antennas and optical systems will be deployed at one or more of the sites to determine long term environmental influences on performance. About 75 statute miles of surface travel will be required to deploy antennas but the crew will not exceed a 15-statute mile maximum radius from the lander.

The specific precursor experiments are listed below:

No.	Experiment No.	Discipline	Experiment Title
1	4003	Bioscience	Terrestrial contamination
2	4009	Bioscience	Reduced gravity effects on man
3	4017	Astronomy	Optical effects from environment
4	4021	Astronomy	Noise survey
5	4022	Astronomy	Radio propagation
6	4023	Astronomy	Impedence measurements of antennas
7	4024	Astronomy	Lunar plasma effects
8	4025	Astronomy	Antenna dust accumulation
9	4026	Astronomy	Cislunar wave propagation
10	4087	Engineering, Technology, & Operations	Lunar dry cement and concrete

3.6 UNMANNED SURFACE MISSIONS

The scope of exploration and exploitation tasks presented in this study requires manned supervision, analysis, decisions, and control at the site. The design concept for the LSB requires optimum utilization of the crew and provides for maximum automated support for all the simple, repetitive, long duration, or hazardous experiments in inaccessible locations or where the presence of man with attendant heat, suit gas leakage, and mechanical disturbances may be disadvantageous.

The traverse sortie as shown on Functional Flow Diagram 4.24.1.6 (Figure 5.1-13) most closely fits requirements for potential automation except for experiments No. 4046, Active Seismic Investigations and No. 4033, Drilling and Subsurface Sampling. As they have been defined, these experiments appear too complex to automate but simpler experiments might be devised to replace them for unmanned sorties.

Another consideration applies to the overall exploration rather than the individual sorties. For many traverses, the initial and final points are themselves discrete experiment sites which require additional experiments over those on the traverse and these, such as drilling 100-foot holes, cannot be readily automated. Since the beginning and end points cannot be automated, there seems little advantage to automating the traverse connecting them. This, of course, assumes that the initial and final points are visited by surface vehicle and not by tug flights.

In total, only five out of the 32 traverses appear to be adaptable to automated missions even if the seismic profiling and drilling problems could be resolved. There appears to be a tradeoff here between scientific return and cost. Unmanned missions can provide a wealth of narrowly predefined data for a lower initial investment, but once a capability is established for the manned conduct of the traverse sorties, at the LSB site, the logical extension would be to do them all in a manned mode.

The missions which might be automated are noted on the Site Measurement Plans of Section 5.1.2 in Part 1 of this Volume.

A mission concept which does lend itself well to automation, however, is one of global exploration. Assuming that an LSB is operational on the lunar surface in accordance with the plans of this study, it is doubtful if any one site will yield all the answers relative to the origin and evolution of the moon. No one site was found which had all the desirable features which is the starting point in the investigation. Many of the other LSB sites have unique features such as Schröter's Valley at Aristarchus, the North Pole itself, and the elongated crater Schiller.

One way to visit these sites would be with an unmanned, highly instrumented, surface vehicle. It could be used alone or in conjunction with manned tug landing missions at the principal sites. The continuous reading measurements could be used to form a total picture of the moon from a network of geological, geophysical, and geochemical data.

The unmanned surface vehicle missions could transmit video, magnetometer, gravimeter, radiometer, gamma ray spectrometer, mass spectrometer, and atmospheric pressure measurements. Rock and soil samples could be collected and stored for pickup at the next manned landing site where the surface vehicle could also be resupplied and reprogrammed for the next traverse. These missions could originate with the initial manned mission and continue throughout the pre-LSB and LSB period until the lunar network is completed.

3.7 SUCCESSOR MISSIONS

The relationship between a single LSB site and the overall Lunar Exploration Program objectives was briefly presented in the preceding section. This is an important question and its answer can have a significant effect on LSB design.

The LSB elements have been synthesized into an LSB program which envisions orbital mapping of potential LSB sites, manned tug landings at selected sites for certification to geoscience and astronomy site requirements, deployment of unmanned surface vehicles to tie LSB sites together geophysically and to perform science and engineering experiments which will provide data for the design of future experiments and equipment to be used at the LSB for lunar exploration.

Following completion of the manned geoscience exploration, deep drilling and remote sorties, a major decision point appears for the lunar exploration program. The direction the program will take from that point will depend on the results achieved. Several alternates are possible but assuming the results are positive, additional sites can be explored using manned tugs or deploying additional LSB's.

Since the astronomy site is fixed, only geoscience operations need to be relocated. This alternative would require resupply to two surface sites, the observatory operating with a crew of 5 to 6 and utilizing the initial shelter, and the new shelter for geoscience with a crew of 6 to 7. Both sites could be resupplied on a single cislunar shuttle flight utilizing a lunar polar orbit. Alternately, manned tugs could be used to perform the geoscience extension.

The first decision will determine whether to proceed or not with lunar exploration and will be decided by the results from the initial LSB experiments. The second decision, at the same time, is which program model to use--orbital or surface, and this will be decided by the dispersion of and experiments to be performed at future sites. These sites will also be selected on the basis of initial LSB results. The initial LSB selection is, therefore, doubly important.

3.8 OLS CONSIDERATIONS

The LSB program of surface missions and logistics missions was separately defined under two program models. One included an OLS in a 60-nautical mile polar orbit and the other was based on an LSB alone for lunar exploration.

The distribution of experiment sites over the lunar surface and the duration of science time at each site are the governing factors in the utilization of a single fixed site shelter (LSB) or the use of manned tugs operating from an orbital base (OLS) as the most feasible model. The LSB is best suited to many closely spaced sites within the radius of action of the mobility systems with each requiring staytimes in excess of the manned tug capability for a single mission. The converse is true for the OLS/tugs.

Based on the capability of the selected LSB concept, three potential interfaces were defined but no primary role for the OLS was established. These considerations assumed that the experiment site requirements justified the use of an LSB initially and the OLS concept was examined for any functions, primary or secondary, which it could perform in support of the LSB mission.

It was determined that the OLS could potentially support the LSB as a logistics way station, as a communications relay, and as a source of recuse aid in the vent of an LSB emergency.

The role of a way station depends primarily on the logistics concept selected. If rendezvous with the OLS is required on all flights then the lander which logistically supports the LSB would be based at the OLS for OLS use as an escape vehicle or other missions. Otherwise, it would remain quiescent on the surface and an additional rescue tug would be required at the OLS. Surface rescues with this mode would be accomplished by walkback, flyer, or surface vehicle depending on the range from the LSB. If rendezvous with OLS is not required, the cislunar shuttle will utilize the inclined orbit for the particular LSB site with the inclination and node which will permit coplanar ascents and descents. In this case the tug is based on the surface and there is no logistics interface with the OLS.

It is reasonable to assume, however, that if an OLS is operating in lunar orbit the logistics system will be designed to resupply both OLS and LSB simultaneously, due to the high cost of the cislunar flights. In this case there will generally be a layover after rendezvous of the shuttle and OLS for orbit phasing with the LSB site. During this interval and another similar one after LSB crew rotation the incoming and/or outgoing crews may wait at the OLS prior to transferring to the tug or the shuttle. These intervals may range up to 12 days. This concept assumes that it would be more desirable waiting in the OLS than waiting in the tug or shuttle crew module. The LSB design is not directly affected by this layover in orbit but may have to supply the consumables and space for the period when the LSB crews overlap on the surface.

The communications relay support would not be acceptable in a normal LSB operating mode as the planned 60 n mi altitude and polar orbit of the OLS result in very short LSB viewing times. This might supply a back-up communications mode, however, in the event of an LSB communications system failure from a far side site.

The third potential support area for the OLS is to provide rescue and emergency medical facilities for the LSB crew prior to return to earth or during major repairs to the LSB. The current design of medical facilities at the OLS is equivalent to that at the LSB, however, and the modular shelter approach will result in a number of independent living modules at the shelter. Thses features indicate that a safer mode of operation would be to wait at the shelter until a shuttle arrived for the immediate return to earth of the LSB crew.

The precursor missions described earlier are of course well suited to the OLS/tug mission capabilities but this utilization would not represent OLS support to the LSB during the LSB mission and would not influence the LSB design.

3.9 LSB PROGRAM SEQUENCE PLAN

The LSB program sequence plan is a schedule of program activities on the lunar surface for the LSB throughout its mission.

Figure 3.9-1 presents the Program Sequence Plan for the LSB and contains a great deal of information on the selected concept condensed into a few pages. This plan treats the "no OLS case" only and does not cover the precursor or second LSB missions. It displays on a one-day scale interval, all major tasks for the initial LSB. In addition to lunar day and night cycles at Hadley, the RNS payload capability (for 10,000-pound return) and launch opportunities are shown along with an RNS timeline for each mission, tug ascent and descent flight dates, cumulative count of unmanned (U) and manned (M) tug flights, RNS actual outbound payloads and corresponding tug descent payloads, tug ascent payloads and the corresponding RNS inbound payload, the number of EOS flights required per RNS flight, the crew complement on the lunar surface, the base buildup timelines, the science program's major experiment timelines, and the remote sortie timelines including flyer utilization, driving time, and science (work) time. Note that the remote sorties are sequenced to return to the shelter prior to the tug landings for crew rotation.

The principal elements of the Program Sequence Plan are the cislunar flight schedule, the corresponding lunar landing tug schedule, manpower level and rotation dates, and the buildup and major experiment schedules. This plan is based on the RNS as the cislunar shuttle to the extent that it can deliver the required payloads. Only one RNS is ever required. Two tugs are used initially, one manned and one unmanned, but only the manned one after the buildup is completed. In the resupply phase the manned tug is replaced after it completes its 10th flight in the fourth year. An average of 14 EOS flights are required for each RNS flight. Since the RNS remains in earth orbit for about 150 days between resupply flights a maximum average of one EOS every 10 days is possible. This is within the EOS' current turnaround capability. The buildup phase may require some alternate approach. The base buildup is completed in five months at which time the major experiments are begun. The large optical telescope does not start until the 455th day if the deep drilling disturbances are excessive. The logistics operations in lunar orbit and details of the buildup and resupply missions were given earlier in Section 2.1. The RNS flights, except for the five buildup missions, are scheduled every six sidereal months (164 days) thereafter. This results in two RNS and two tug flights per year. This interval was selected to minimize the number of RNS flights required to support the shelter. It is generally more effective in the absence of any other constraints to utilize the fewest flights with the maximum payload on each outbound leg and the smallest possible return payload. This interval, when coupled with a 50 percent crew rotation at each resupply; results in a crew stay time of twice the interval or 328 days. Overlapping the crews is desirable to maximize the learning rate by providing direct on-site training by and observation of experienced crewmen. The long duration is comparable to the Antarctic Expeditions and twice as long as currently planned for EOSS. However, the confinement of the former and the weightlessness of the latter are not present at the LSB and an extension of the duty cycle was considered

Figure 3.9-1a.

LSB PROGRAM SEQUENCE PLAN

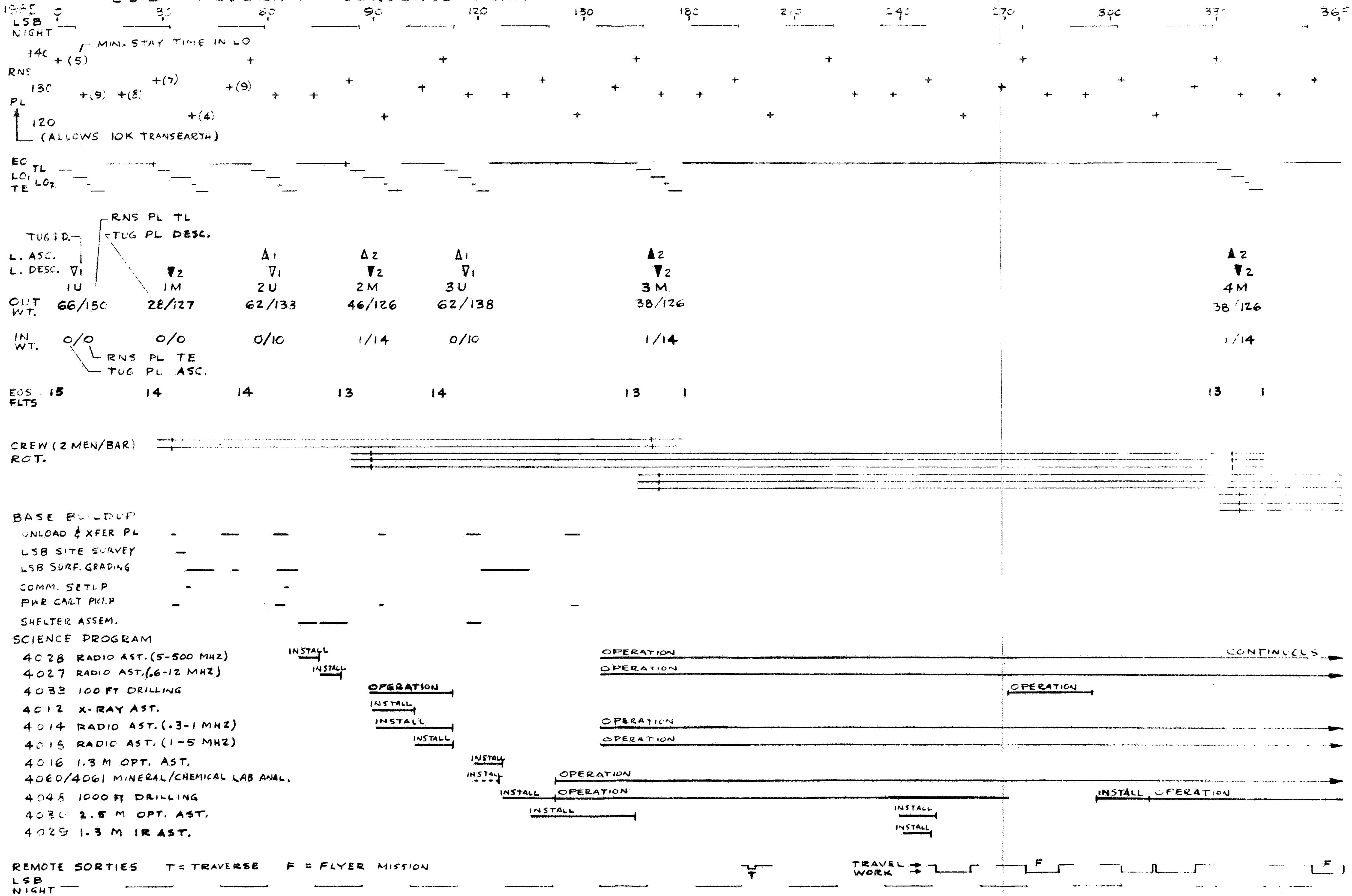
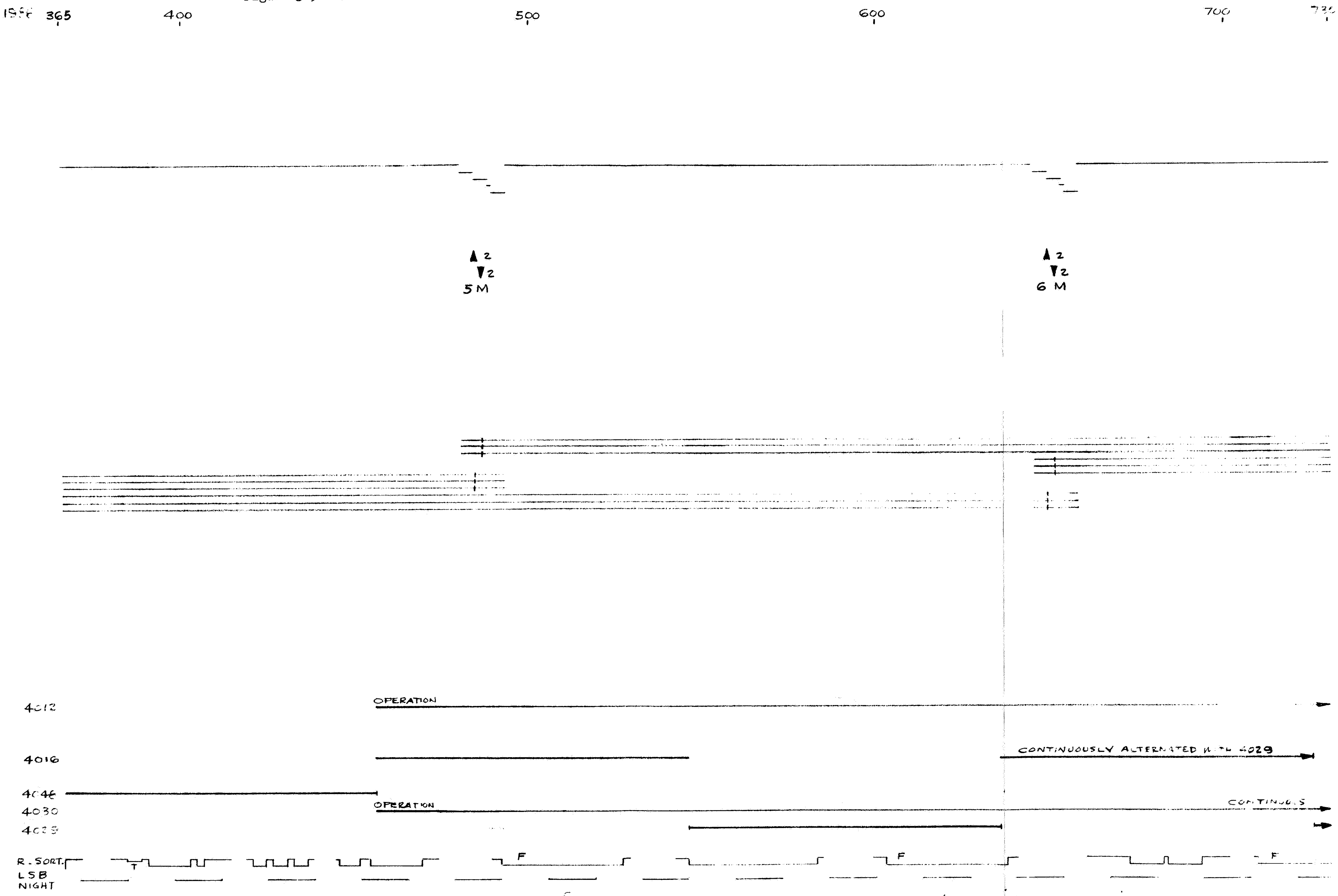


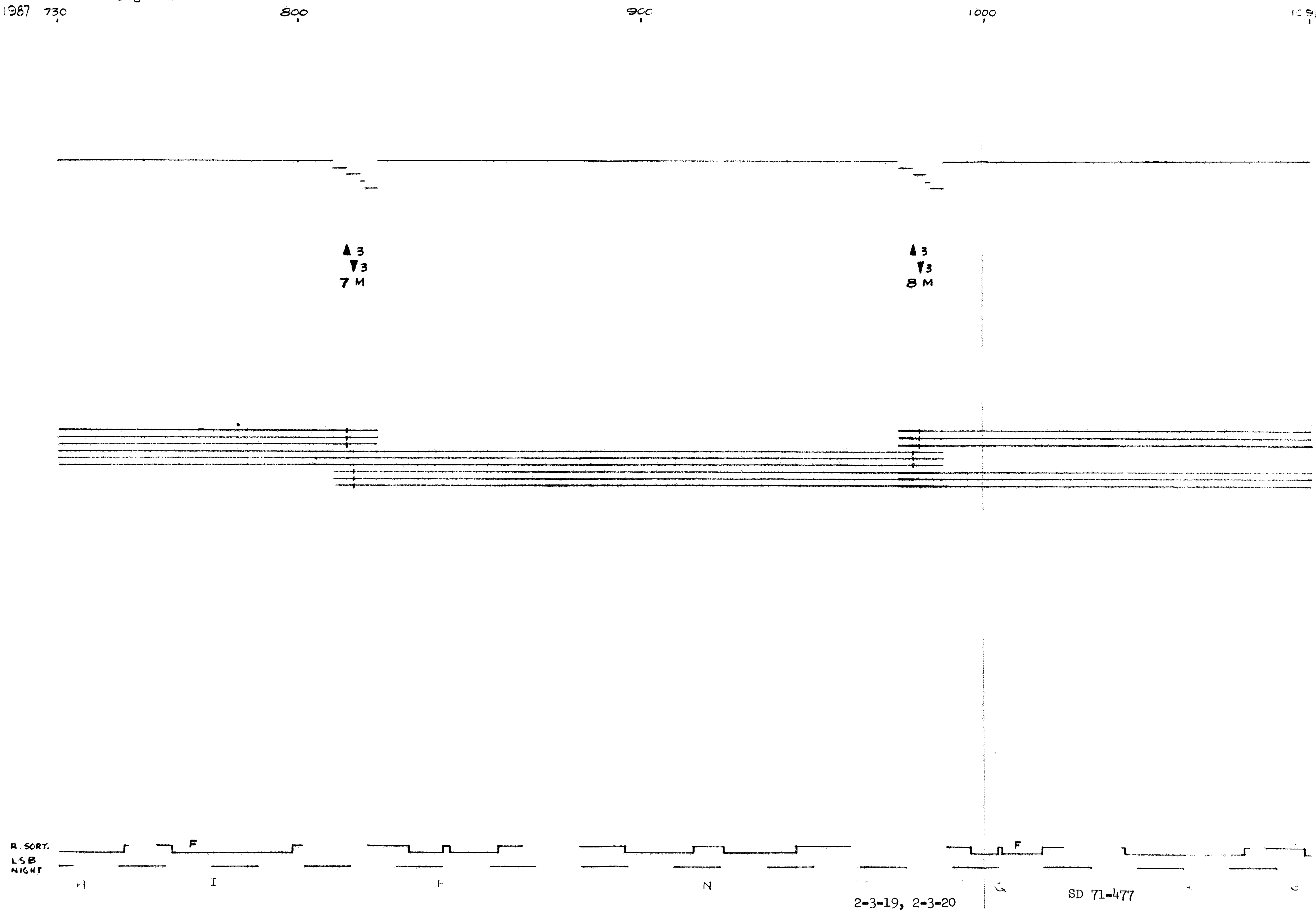
Figure 3.9-1b.



2-3-17, 2-3-18

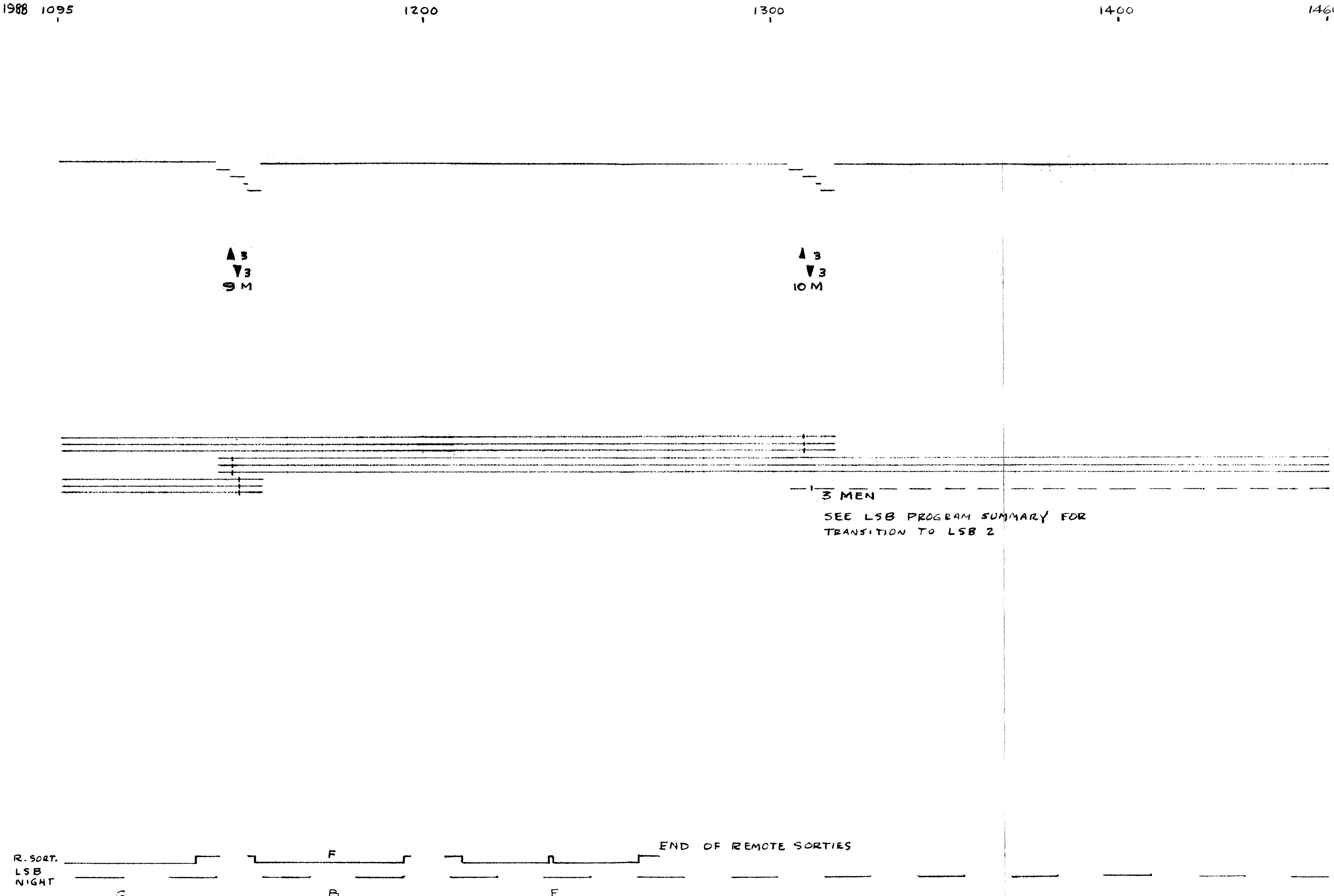
SD 71-477

Figure 3.9-1c.



SD 71-477

Figure 3.9-1d.


1988 1095
1200
1300
1400
1460
▲3
▼3
9 M
▲3
▼3
10 M
3 MEN
SEE LSB PROGRAM SUMMARY FOR
TRANSITION TO LSB 2
END OF REMOTE SORTIES
R. SORT.
LSB
NIGHT
F
G
B
E

warranted. Also, this resupply interval will result in a normal lag time of at most six months between the conduct of experiments and the receipt of the raw data and samples by the principal investigators. The mission duration illustrated here corresponds to the LSB site at Hadley Rille, the longest mission of the five sites studied in detail, and requires 1150 days to complete the remote sorties. The sortie schedule is shown at the bottom of the Sequence Plan along with an indication of the traverses and flyer missions. This mission lasts a total of 1309 days (3.6 yrs).

A Lunar Program Summary is given in Figure 3.9-2. This is a condensed version of the Program Sequence Plan and lists the primary events for both program models - with and without OLS - and schedules these events for the precursor missions, the initial LSB mission, and startup of a potential second LSB mission. The tug identification number shown is a serial number which can be traced through the mission. Manned and unmanned tug flight dates are indicated by solid and open triangles respectively. Also shown are the three surface sorties - deep drilling, observatory, and remote sorties. This timeline illustrates an optimized, integrated concept for lunar surface exploration which utilizes the maximum performance of all systems with adequate growth margins to support the lunar exploration program at minimum cost.

The three-year precursor program is shown beginning in 1982. This provides vitally needed site characteristics and equipment design data in time for incorporation in the final design of experiment hardware, e.g., telescope optics, shielding, and foundations.

A second LSB site is shown being activated in the fourth year in order to continue the geoscience exploration which is completed at the first site. Based on the buildup and operations manpower levels derived earlier, the lunar population need not exceed 12 with both sites operational. The original site continues indefinitely as an observatory while the new site relocates the geoscience equipment at unexplored features not available at the initial site. Since the new site does no astronomy its crew size need only be six and it can be correspondingly smaller - perhaps completely mobile and thus capable of visiting additional LSB sites. A crew of six is also retained at the original site - four for the observatory and two for shelter maintenance and the shelter experiments program.

In addition to this relatively complete program, the Program Summary also shows the LSB operating simultaneously with an OLS for reference purposes. The precursor missions are the same in this case as the non-OLS case above.

The major difference in this program model is the use of the Chemical Interorbital Shuttle (CIS) as described in Section 2.2.3 to replace the RNS as the cislunar shuttle. The CIS, operating in Mode 1, is capable of 175,000 pounds outbound and 30,000 pounds inbound payloads or 250,000 pounds one way. This payload capacity is capable of supporting the logistics requirements of the OLS and LSB simultaneously. The CIS flights are scheduled at 109-day intervals to satisfy OLS resupply intervals. This schedule somewhat compromises the previous LSB resupply schedule which was based on six sidereal month intervals (164 days) between missions. The 109-and 164-day cycles are in phase every 324 days and it would be possible logistically to resupply the

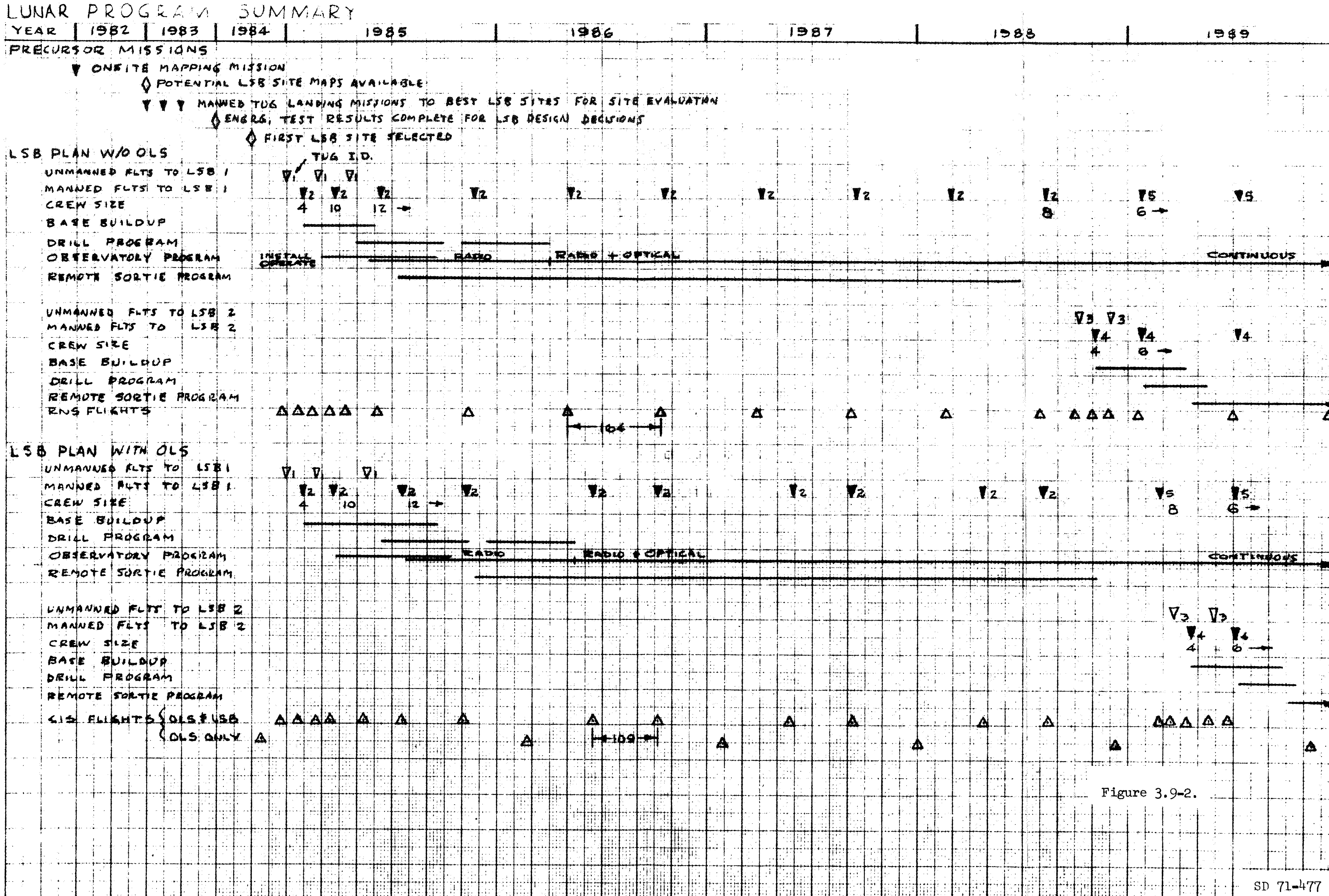


Figure 3.9-2.

SD 71-477

LSB once per 324 days. Operationally this is not desirable because it would mean a full crew rotation each time, if their duty cycle remained the same, with the resultant loss of on-site training. Therefore, this 324-day resupply mode was not utilized in planning the OLS-LSB logistics mission but it may be a cost effective alternate for the LSB. Interim CIS flights at greatly reduced payloads would still be required for the OLS (assuming its resupply cycle cannot be extended) which might not result in an overall economical solution to this combined logistics problem.

Utilizing the combined support 109-day cycle, the CIS would deliver unmanned and manned tugs in the buildup sequence described earlier. Buildup would be completed in five CIS flights over a 136.5-day duration. The first four flights (No. 1 unmanned (1U), No. 1 manned (1M), 2U, & 2M) are separated by 27.3 days each with the 3U flight following 2M at 54.6 days. The manned flights also deliver six men each, a slightly faster buildup rate than before and the buildup crew only remains 164-days, departing on the 3M flight.

This logistics model results in 3.3 CIS flights to the LSB/OLS per year in the normal resupply mode versus 2.2 RNS in the non-OLS mode. With the combined mode, of course, all flights would be to and from polar orbit. The maximum interval between resupply flights to the LSB increases to 218-days although the average resupply interval remains the same (164-days).

REFERENCES

1. Paone, J. & Schmidt, R. L., Bureau of Mines, Twin Cities Mining Research Center, from Proceedings of the Working Group on Extraterrestrial Resources, NASA SP-177, Feb. 1968

2. Hampe, W. R., Lunar Drill Utilization, Aerospace Division, Westinghouse Defense and Space Center, Sept. 1969

3. Candidate Experiement Program for Manned Space Stations, Draft Copy, NASA NHB 7150, xx, Sept. 15, 1969

4. Study of Mission Modes and System Analysis for Lunar Exploration, (MIMOSA), Exploration Equipment Data Book, Vol. II, Part 2, (MSC-A 847943, 30 April 1967

5. A Study of Scientific Mission Support for Extended Lunar Exploration, SID 66-957-3, Dec. 1966

6. Farquhar, R. W., The Utilization of Halo Orbits in Advanced Lunar Operations, Goddard Space Flight Center Report X-551-70-449, Dec. 1970

7. Weidner, D. K., Space Environment Criteria Guidelines for Use in Space Vehicle Development (1969 revision), NASA TM X-53957 2nd Edition, 26 Aug. 1970

8. Ulrich, G. E., Advanced Systems Traverse Research Project Report, Intelligency Report No. 7, U.S. Dept. of Interior, Geological Survey, July 1968

9. H. Moore, R. Pike, G. Ulrich, Lunar Terrain and Traverse Data for Lunar Roving Vehicle Design Study, Draft Copy, U.S. Dept. of Interior, Geological Survey, March 1969

10. Journal of the American Medical Association, Vol. 212, p 1047-1051, May 11, 1970

11. Siple, Paul, 90° South, G. P. Putnam's Sons, New York, 1959

12. Lunar Science and Exploration, 1967 Summer Study of University of California - Santa Cruz, NASA SP-157, August 1967

13. Deployment Procedures, Lunar Exploration Systems for Apollo (MSC-665606 (DA-49-129-ENG-534)), 15 Feb 1965

14. Final Report: Lunar Surface Mobility Systems Comparison and Evolution (MOBEV), Bendix Aerospace Systems, BSR 1428, Nov. 1966

15. Morgan, C. T., Human Engineering Guide to Equipment Design, McGraw-Hill Book Co., New York, 1963

16. Webb, P. and Anms, J. F., The Principle of the Space Activity Suit, NASA CR-973, Dec. 1967