134

OTS: $1.00

NASA CONTRACTOR REPORT

NASA CR-39

N64-15969

CODE-1

NASA CR-39

34 p.

double code

0425702

Opsa Mar. 1964 34p Orig ~~Prepared~~ Work performed under contract by Boeing Co.

INITIAL CONCEPT OF LUNAR EXPLORATION SYSTEMS FOR APOLLO.

Volume V - SUMMARY DIGEST

Prepared under NASA Contract No. NASw-792 by
THE BOEING COMPANY
Seattle, Washington
for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, WASHINGTON, D. C. • MARCH 1964

INITIAL CONCEPT OF LUNAR EXPLORATION SYSTEMS FOR APOLLO

Volume V - SUMMARY DIGEST

Prepared under Contract No. NASw-792 by

THE BOEING COMPANY

Aero-Space Division

Seattle, Washington

This report is reproduced photographically
from copy supplied by the contractor.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Office of Technical Services, Department of Commerce,
Washington, D.C. 20230 -- Price $1.00

ACKNOWLEDGEMENT

The assistance of the following associates in this study is gratefully acknowledged.

Consultants	Areas of Interest
Admiral George J. Dufek	Operations and Logistic Support
Prof. Z. K. Kopal	Lunar Topography and Environment
Prof. W. R. Webber	Lunar Environment

Contractors	
American Machine and Foundary General Engineering Division	Lunar Roving Vehicle
Allison Division, General Motors	Power and Fuel
Atomics International, North American Aviation	Power
AiResearch Mfg. Co., Garrett Corp	Life Support
Bendix Radio Division, Bendix Corp.	Communications
Holmes and Narver, Inc.	Base Construction
General Motors Defense Research Laboratories	Lunar Roving Vehicle

CONTENTS

		Page
1.0	Introduction	1
	1.1 Approach	1
2.0	Systems Considerations	2
	2.1 Physical Environment	2
	2.2 Lunar-Base Systems Requirements	2
	2.3 Base Design Integration	3
	2.4 Lunar-Base Construction Concepts	9
	2.5 Lunar-Base Operation Concepts	9
	2.6 Logistics Support Concepts	12
	2.7 Typical Lunar-Base Operations Plans	13
3.0	Subsystem Analysis and Module Configuration	14
	3.1 Lunar-Base Structural Analysis	14
	3.2 Personnel Shelter	15
	3.3 Life Support and Environment Control	17
	3.4 Power	19
	3.5 Communications	19
	3.6 Surface Mobility	22
	3.7 Fuel Subsystem	24
	3.8 Maintenance Subsystem	24
4.0	Problem Areas	26
5.0	Conclusions and Recommendations	27
	5.1 System Requirements	27
	5.2 Mission Operations	27
	5.3 Logistics Considerations	28
	5.4 Base Installation	28
	5.5 System Design	29

1.0 INTRODUCTION

15969

The objective of the study of an Initial Concept of Lunar Exploration Systems for Apollo was to develop the conceptual design of a lunar-exploration support system within the following general criteria established by NASA in RFP 10-1132:

1) Utilization of a modular approach to all subsystems;

2) Flexibility in scope (2 to 18 men), duration (3 months to 2 or more years), and type of mission activity;

3) Maximum lunar logistic vehicle payload weight of 25,000 Earth pounds;

4) Feasibility of development for the 1970 to 1974 time period.

The system and subsystem functional analyses and conceptual design accomplished in this study are summarized in Volume I, and reported in detail in Volumes II and III of the final study report, Boeing Document D2-100057. Significant data abstracted from Volumes II and III are compiled in a data book, Volume IV of D2-100057.

1.1 APPROACH

The basic modular concept, together with the stated ground rules and implied mission objectives, were the starting point for systems analyses aimed at guiding the subsystems investigations and contributing to the overall concept definition. Maximum use of Apollo system elements was considered. As the subsystem aspects of the base concept were developed, meaningful concepts for base installation, operation, maintenance, and logistics support were outlined.

Subsystem analysis effort started with technical investigations of ways to satisfy functional requirements, and proceeded to the selection of specific modular concepts logically matched to the base concept.

Design integration was accomplished by combining the subsystem module information with concepts for base installation, operation, maintenance, and logistic support to synthesize, on a total system basis, an improved definition of the initial base concept. This synthesis included considerations of base arrangements, packaging of base modules into lunar logistics vehicle (LLV) payloads, and resolution of the interface relationships between subsystems and modules of the base complex.

Author

2.0 SYSTEMS CONSIDERATIONS

The overall systems aspects of the lunar-exploration support system concept are reported in Volume II and summarized below.

2.1 PHYSICAL ENVIRONMENT

The specification of the lunar environment was derived principally from NASA RFP 10-1132. The only major deviation from this guidance was an adjustment in the definition of the radiation environment associated with solar flares.

The external radiation environment of the lunar surface consists of primary galactic cosmic rays, which give a dose rate of about 1 rad per month during solar minimum and 0.5 rad per month during solar maximum, and of particulate radiation (primarily protons) associated with solar flares. The flare events occur at random throughout the solar cycle, and the flux is essentially omnidirectional. The results of a new analysis of available data were used to define the probability of encountering a specified integrated solar proton flux.

Estimates of the induced radiation from lunar surface material are 0.5 millirad per week for a quiet Sun and as much as 310 millirads per week for an active Sun (based on February 23, 1956, event). The primary radiation component dose will be between 2.0 (granite) and 0.2 (meteoritic material) millirad per week.

Three exploration sites, representing locations in premare, mare, and post-mare surfaces, were chosen to define a range of surface material parameters for design purposes. The sites are defined in terms of specific assumed stratigraphy of porous material, dust, shock breccia, and rock lithologic units.

2.2 LUNAR-BASE SYSTEMS REQUIREMENTS

Four base models were selected as representative of the range of support-system size and duration, and the implied scope of mission activity specified for consideration in this study. Overall support-system functional requirements were defined in terms of these models to guide subsystem analysis and conceptual design, and base design integration. The study ground rules of 3-man crew delivery increments and 6-month crew stay times were combined with postulated mission operational activities in matching the base models to the range of size and duration parameters.

Both field and laboratory mission operations were studied to assist in determining support-system requirements. Emphasis was placed on the first-named category because field activities are expected to strongly influence the support requirements of mobility, fuel, communications, and portable life support. Mission operations in the field were studied for the adaptation of terrestrial techniques, and are described for the following typical activities:

1) Lunar surface reconnaissance;

2) Geological and geophysical reconnaissance and survey;

3) Geophysical research on mare formation, crater shape, and thermal anomalies;

4) Economic geology.

Laboratory missions were studied in less detail, with emphasis on estimating possible scientific and technological equipment requirements. Data were developed for:

1) Astrophysical research;

2) Chemical synthesis pilot-plant operation.

The base models selected from these studies are summarized below, together with their principal mission support requirements.

			Mission Requirements		
Base Model	Crew Size	Base Duration (months)	Vehicle Mileage	Space-Suit Usage (hours)	Equipment (pounds)
1	3	3	1500	120	880
2	6	6	3000	320	2,527
3	12	12+	4500	750	3,991
4	18	24+	7500	1250	13,650

2.3 BASE DESIGN INTEGRATION

The total support system must provide shelter, life support, power, communications, surface mobility, and fuel to sustain a wide variety of manned scientific exploratory missions on the Moon. All subsystems of the extensive support system are embodied in modules with applications as flexible as possible. These subsystems are categorized as shelter, life support and environmental control, maintenance, mission support, power, communication, mobility, fuel, and engineering construction.

The breakdown of subsystem modules by functional performance increments and the application of these modules to the range of base models are summarized in Table A. The shelter module (S-1), with its supporting subsystem modules, is designed to be a basic, self-sufficient, support nucleus. Further, it is designed to facilitate growth in crew size and duration from one base model to another in increments and on schedules that evolving requirements may later dictate. Figures 1, 2, 3, and 4 illustrate steps in this growth.

Integration of system requirements and subsystem module design provides for the logical assembly of payload within an LLV payload capability of 25,000 pounds,

Table A

MODULE DEFINITION CHART

SUBSYSTEMS		BASE MODEL			
MODULE	NAME	1	2	3	4
S-1	Basic Shelter	★	★	★★	★★★
S-2	Radiation Shielding — Base 1	★			
S-3	Logistics Carrier		★	★★	★★★★
S-4	Resupply Carrier				★
L-1	Basic Life Support & ECS	★	★	★★	★★★
L-2	Supplemental Life Support & ECS		★	★★	★★★
L-3	Life Support Supply — Base 2		★		
L-4	Life Support Supply — Base 3			★★	
L-5	Life Support Supply — Base 4				★★★
P-1	Basic Power Unit (FC + SC)	★	★	★★	★★★
P-2	Construction Power Unit (FC)		★	★	★
P-3	Nuclear Power Unit (10 kw)		★		
P-4	Nuclear Power Unit (100 kw)			★	★★
P-5	Base Substation Module			★	★
C-1	Basic Communication Equipment	★★	★★	★★★	★★★★
C-2	Antenna Set — Bases 1 & 2	★	★		
C-3	Antenna Set — LRV	★	★	★★	★★★
C-4	Emergency/Checkout Set	★	★	★★	★★★
C-5	Communication Equipment — Bases 3 & 4			★	★
C-6	Antenna Set — Bases 3 & 4			★	★
V-1	Basic Lunar Roving Vehicle	★	★	★★	★★★
V-2	Extended Mobility Module		★	★★	★★★
F-1	Basic Fuel Module	★	★	★★	★★★
F-2	Supplemental Fuel Module — Base 2		★		
F-3	Supplemental Fuel Module — Base 3			★	★
F-4	Supplemental Fuel Module — Base 4				★
F-5	Fuel Regeneration Unit			★	★
M-1	Basic Maintenance Equipment	★	★	★★	★★★
M-2	Supplemental Maintenance Equipment — Base 2		★	★	★
M-3	Supplemental Maintenance Equipment — Base 3			★	★
M-4	Supplemental Maintenance Equipment — Base 4				★
E-1	Engineering Equipment — Shielding		★	★	★
E-2	Engineering Equipment — Transportation			★	★
X-1	Mission Support Equipment — Base 1	★	★	★	★
X-2	Mission Support Equipment — Base 2		★	★	★
X-3	Mission Support Equipment — Base 3			★	★
X-4	Mission Support Equipment — Base 4				★
X-5	Fuel Synthesis Experiment				★

Figure 1

BASE MODEL 1

3 MEN — 3 MONTHS

Figure 2
BASE MODEL 2

6 MEN — 6 MONTHS

Figure 3
BASE MODEL 3
12 MEN — 12 MONTHS

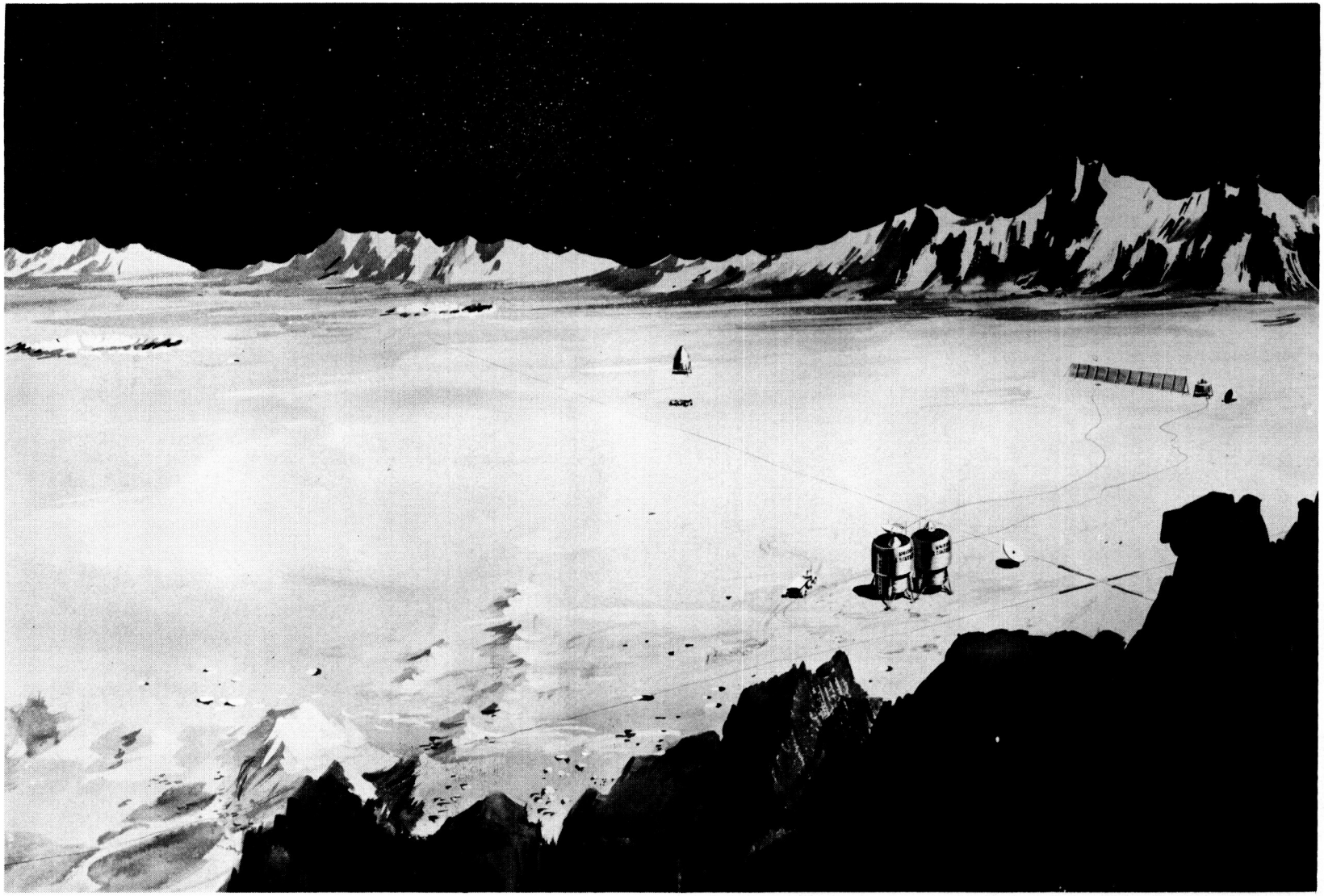
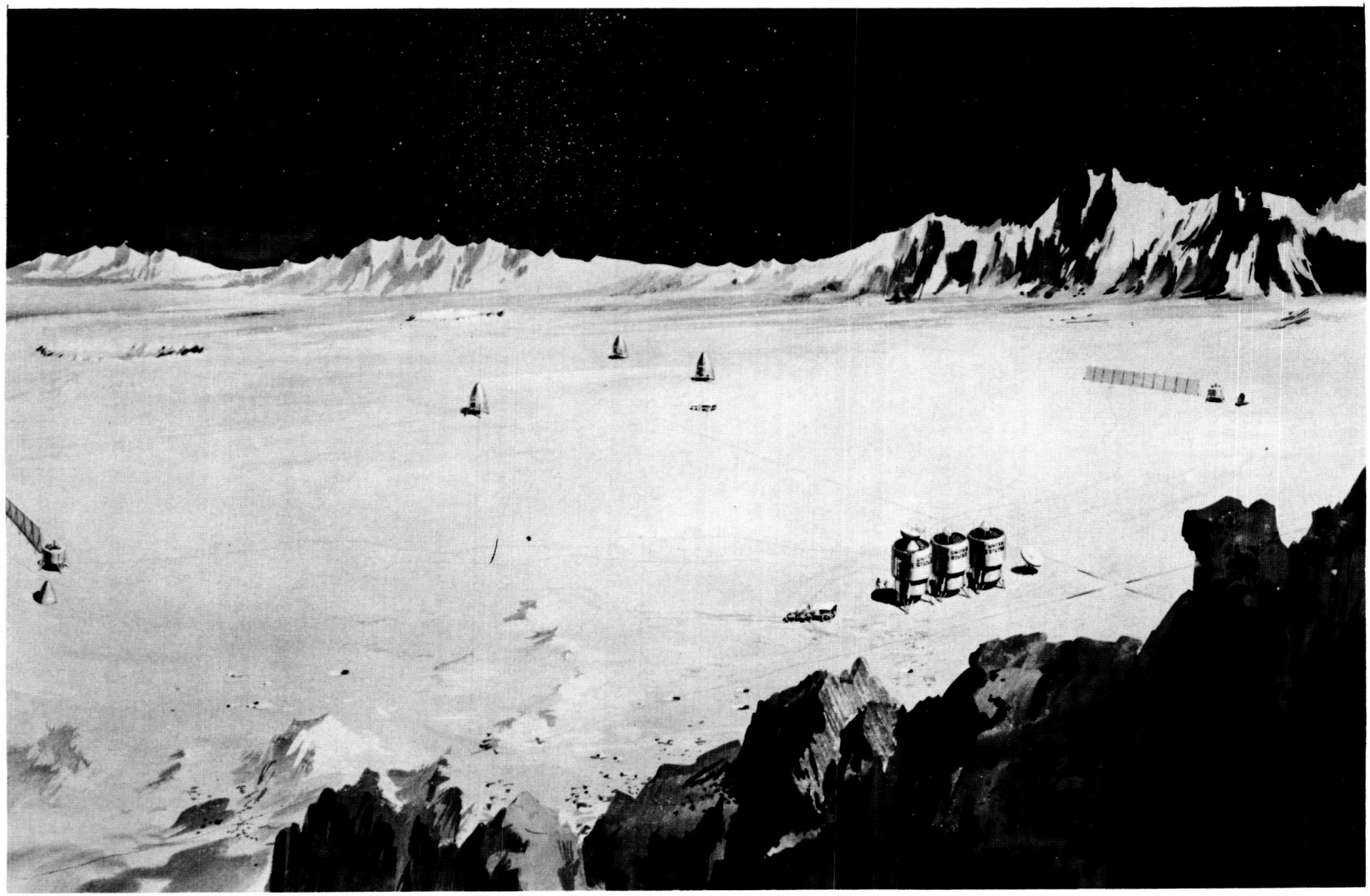


Figure 4
BASE MODEL 4
18 MEN — 24 + MONTHS



as summarized in Table B. The "A" and "B" payloads itemized in this table provide all the requirements for base establishment and operation, except for Base Model 4. A single supplementary "D" payload provides the resupply requirements in that case.

2.4 LUNAR-BASE CONSTRUCTION CONCEPTS

Construction effort required for the assembly and emplacement of subsystem modules into an integrated support system can be broken down into a relatively few distinct operations. Assembly effort includes unloading, moving, positioning, and interconnecting the various components. Emplacement effort includes collecting and placing lunar soil to provide environmental protection. It also includes excavation for, and shielding of, nuclear powerplants and surface modification of routes for moving payloads.

The provision of environmental shielding through construction techniques was the principal subject of this part of the study. Analysis verifies the advantages of soil shielding against radiation and meteoroids (see Figure 5). The integration of construction and shelter design analysis has resulted in the above-surface installation concept shown in Figure 2. This concept features the use of caisson-retained soil shielding (2-foot-thick layer) over the occupied volume. The caisson is provided as an expandable outer shell of the shelter module, and also incorporates the thermal-control radiator system. The shelter is not disassembled from the LLV landing stage, thus avoiding a difficult construction problem.

At present, it is considered premature to select specific construction equipment for assembly and emplacement. The detailed study results are considered useful for the order of magnitude estimates and for emphasizing the areas in which additional lunar data and further studies are required. Figure 6 shows a tentative concept for moving shelters with the use of powered accessory wheels and the lunar roving vehicle. Figure 7 shows a tentative concept for soil excavating and placement. Such equipment should be designed for light weight, low power, easy assembly, and especially so that the operators do not have to wear pressurized space suits. The rotary drum scraper and gravel thrower shown attached to the roving vehicle meet these criteria.

2.5 LUNAR-BASE OPERATION CONCEPTS

Operation of a lunar base in support of exploration and research activities must provide for the efficient use of total program resources, for effectiveness in accomplishing mission objectives, and for safety of the expedition crew. The operation concepts considered include monitoring and control requirements during both occupied and unoccupied periods; the manner of establishing the base by direct buildup or evolution; the mode of surface transportation for mission activities; the performance potential of the crew; and the emergency operations that might be necessary.

Table B

PAYLOAD WEIGHT STATEMENTS — POUNDS

SUBSYSTEMS MODULE	NAME	BASE 1 Payload A	BASE 2 Payload A	BASE 2 Payload B	BASE 3 Payload A-1	BASE 3 Payload A-2	BASE 3 Payload B-1	BASE 3 Payload B-2	BASE 4 Payload A-1	BASE 4 Payload A-2	BASE 4 Payload A-3	BASE 4 Payload B-1	BASE 4 Payload B-2	BASE 4 Payload B-3	BASE 4 Payload B-4	BASE 4 Payload D
S-1	Basic Shelter	6,580	6,580		6,580	6,580			6,580	6,580	6,580					
S-2	Radiation Shielding — Base 1	915														
S-3	Logistics Carrier			4,100			4,100	4,100				4,100	4,100	4,100	4,100	
S-4	Resupply Carrier															2,500*
L-1	Basic Life Support & ECS	3,586	3,586		3,586	3,586			3,586	3,586	3,586					
L-2	Supplemental Life Support & ECS		452		452	452			452	452	452					
L-3	Life Support Supply — Base 2			2,374												
L-4	Life Support Supply — Base 3						5,900	5,900								
L-5	Life Support Supply — Base 4											1,250*	13,283		13,283	12,033*
P-1	Basic Power Unit (FC + SC)	870	870		870	870			870	870	870					
P-2	Construction Power Unit (FC)			1,639			1,639							1,639		
P-3	Nuclear Power Unit (10 kw)			5,030												
P-4	Nuclear Power Unit (100 kw)						12,850					12,850		12,850		
P-5	Base Substation Module					500						500				
C-1	Basic Communication Equipment	342	342		342	171			342	171	171					
C-2	Antenna Set — Bases 1 & 2	85	85													
C-3	Antenna Set — LRV	120	120		120	120			120	120	120					
C-4	Emergency/Checkout Set	44	44		44	44			44	44	44					
C-5	Communication Equipment — Bases 3 & 4				238				238							
C-6	Antenna Set — Bases 3 & 4				128				128							
V-1	Basic Lunar Roving Vehicle	3,765	3,765		3,765	3,765			3,765	3,765	3,765					
V-2	Extended Mobility Module			1,650				3,300				1,650	3,300			
F-1	Basic Fuel Module	6,830	6,830		**5,970	**5,540			6,830	**6,450	**5,970					
F-2	Supplemental Fuel Module — Base 2			3,270												
F-3	Supplemental Fuel Module — Base 3							3,130						3,400		
F-4	Supplemental Fuel Module — Base 4															10,270
F-5	Fuel Regeneration Unit							520							520	
M-1	Basic Maintenance Equipment	400	400		400	400			400	400	400					
M-2	Supplemental Maintenance Equipment — Base 2			600				600					600			
M-3	Supplemental Maintenance Equipment — Base 3							400					400			
M-4	Supplemental Maintenance Equipment — Base 4												400			
E-1	Engineering Equipment — Shielding			1,710				1,710				1,710				
E-2	Engineering Equipment — Transportation							1,475				1,475				
X-1	Mission Support Equipment — Base 1	880	880		880				880							
X-2	Mission Support Equipment — Base 2			1,650				1,650		1,650						
X-3	Mission Support Equipment — Base 3					1,460					1,460					
X-4	Mission Support Equipment — Base 4													2,760		
X-5	Fuel Synthesis Experiment														6,900	
	PAYLOAD TOTAL	24,417	23,954	22,023	23,375	23,488	23,489	22,785	24,235	24,088	23,418	23,535	22,083	23,749	24,803	24,803
	BASE TOTAL	24,417		45,977		94,137						191,714				

* L-5 is separated into 2 packages

** Offloaded per Section 8.2, Volume III.

Figure 5
SHIELDING

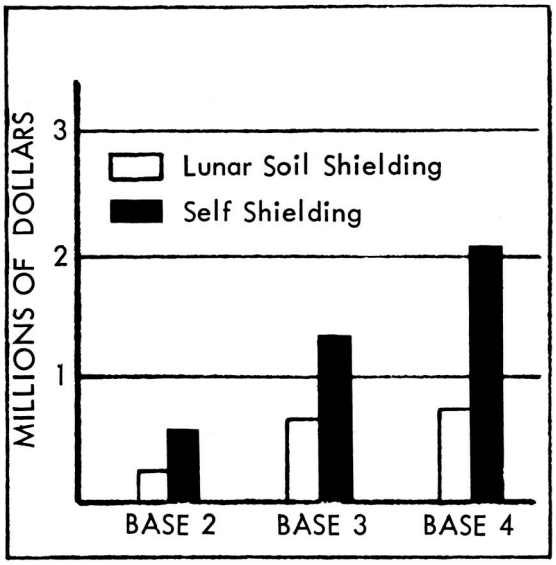


Figure 6
SHELTER MOVEMENT

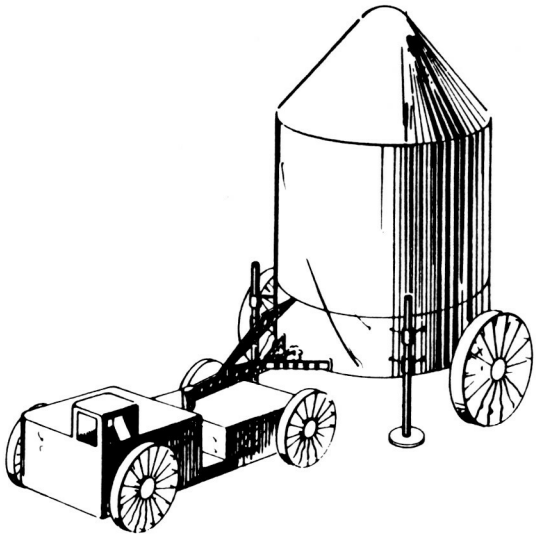
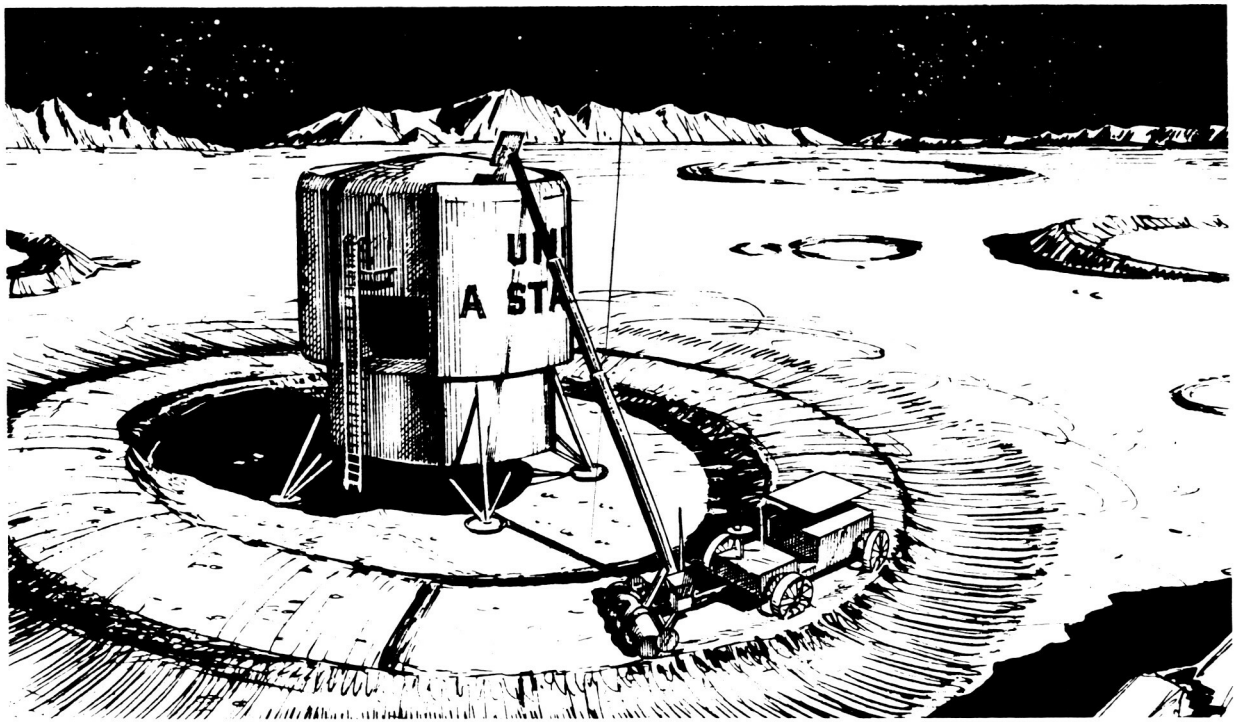


Figure 7
EMPLACEMENT



A communications module (C-4) provides monitoring and control telemetry functions during inactive storage. A communications module (C-1) provides expanded monitoring and telemetry functions during manned operation of the base. Many routine monitoring functions may be accomplished from communications centers on Earth, but crew response must be relied upon for emergency actions.

A lunar base may be established by direct buildup to a specified capability or may grow in size over a period of years. These two modes of base activation are compared with respect to launch schedule requirements, mission effectiveness, and module utilization. Launch rates for the evolutionary mode are considered to be most compatible with the Saturn V launch capability expected in the 1970 time period. On a cost-effectiveness basis as measured by total launches and total base occupation, there is little difference between the two modes for programs involving several hundred man-months of lunar exploration.

A very significant portion of the mission operations will involve travel over the lunar surface. Three conceptual flight-mode vehicles were compared with a surface roving vehicle with respect to mobility, fuel consumption, and mission capability for conducting reconnaissance, survey, and scouting missions. It is concluded that flight vehicles are so severely range-limited by their fuel consumptions that their feasibility will depend on lunar fuel synthesis. Surface vehicles are chiefly penalized by the time required to accomplish a given mission.

Crew performance potential is a major consideration in the assessment of concepts for base installation, base functional operation, and mission activity. Comparisons were made of geological reconnaissance effectiveness when performed in various manual and automated modes. It is concluded that any restrictions imposed by the use of a space suit will greatly degrade performance of this or similar missions.

The consideration of emergency operations encompasses various types of equipment failure, and illness or accidents suffered by the crew. Cost and reaction-time factors dictate that the base and crew must be equipped and capable of handling most of the emergency operations that arise.

2.6 LOGISTICS SUPPORT CONCEPTS

Logistics support concepts have been outlined in terms of the requirements for crew and material supply and resupply, and of the operational aspects of logistics support.

Resupply requirements for base-duration extension were determined for four support systems characterized by different levels of subsystem performance. Equipment and apparatus requirements for direct support of mission activities are outlined in the form of a catalogue of scientific equipment. Fifty-three items are identified and described briefly, including weight, volume, and power estimates.

A study of base-manning requirements delineates the effects of crew size, duration, and delivery increment on the magnitude of the transportation effort involved. This study emphasizes the strong advantage of increased crew-delivery increment, which makes advanced manned crew-delivery systems of great interest. The potential of current and advanced manned spaceflight systems is summarized for both lunar-orbit rendezvous and direct-landing modes of operation.

Trade studies of Earth-Moon transportation systems were made to evaluate system efficiency in terms of total launches normalized to the number of man round trips. The relative efficiency of various cargo-plus-crew systems is a strong function of the required cargo-to-crew ratio.

The potential for obtaining logistics independence through the synthesis of fuel and life-support expendables from lunar raw materials is assessed from the standpoints of chemical feasibility and estimated equipment investment. Processes for hydrogen and oxygen extraction from hydrated rock, oxygen extraction from silicate rock, and hydrocarbon synthesis from a carbonaceous mineral such as calcium carbide are described. Because of the more easily accomplished regeneration of oxygen and hydrogen from the products of their first use (CO_2 and water), it is not clear that a firm requirement for synthesis can be established at this time.

2.7 TYPICAL LUNAR-BASE OPERATIONS PLANS

Typical operations plans describe the steps in the direct buildup to each of four base models and the variations that will result if an evolutionary plan is followed. These plans summarize concepts for crew assignment and activity schedules, base activation plans, mission operations plans, and logistics support plans.

Base activation by the initial crew increment begins with their postlanding checkout of the LEM to prepare for possible early departure if unforeseen emergencies occur. The principal shelter is then entered and all of its subsystems placed in operation. Actual base construction can then begin, with priority given to installing the nuclear power system. The shelters are then positioned with respect to each other, and their caissons expanded and filled with lunar soil to provide the required shielding. The additional equipment and materials carried in the "B" payloads are finally moved to and integrated with the shelter and shelter-contained subsystems.

Mission operations are described in general terms, and some suggested exploration routines in the Alphonsus-Ptolemaeus region are identified. These typical field trips range from 1-day shakedown ventures to 8-day expeditions that explore the Alphonsus rille and trench systems, negotiate the breach in the east wall of Ptolemaeus, and examine the continent outside of the crater.

3.0 SUBSYSTEM ANALYSIS AND MODULE CONFIGURATION

The detailed subsystem analysis and conceptual design aspects of the lunar-exploration support system are reported in Volume III and summarized below:

3.1 LUNAR-BASE STRUCTURAL ANALYSIS

Structural analysis was chiefly concerned with radiation shielding, meteoroid shielding, thermal response, structural concept, material evaluation, and stress analysis.

Aluminum shielding weights per unit of surface area were determined versus exposure time for various probabilities of not exceeding an assumed 200-rad allowable dose. The effectiveness of lunar material in providing radiation protection is assumed to be equivalent to an equal mass of aluminum.

Meteoroid shielding requirements were determined for mission times up to 2 years plus an unattended stay time of 1 year, which establishes the minimum shielding to be included in the shelter module payload. The density and acoustic velocity properties of lunar materials result in considerably less efficiency than aluminum sheet in stopping a meteoroid. A 3-month exposure (beyond 1 year) requires a thickness of 0.2 inch of lunar material at a probability of no penetration of 0.99, as compared to an additional thickness of 0.01 inch of aluminum. Meteoroid shielding weights double for increases in the probability of no penetration from 0.99 to 0.999. Total (radiation plus meteoroids) shield weight with aluminum shielding is governed by the radiation requirement. Total shield thickness with soil shielding depends on the meteoroid requirement.

The critical design point for thermal analysis of the shelter module is that of unattended storage during the lunar night. The shelter can be adequately protected by a semiactive system consisting of about 1 inch of superinsulation, a low emissivity surface coating, and a source of heat (up to 1 kw) within the shelter. Thermal protection using lunar cover material is feasible once the base is operational.

Structural concepts considered were rigid preassembled, rigid expandable, and inflatable. The structural concept comparison was based on equal internal volume, meteoroid shielding for 1 year of unattended stay-time, identical subsystems, and application of lunar material for radiation and meteoroid shielding beyond the unattended period. Although there were marked differences in the shelter struc-

tures, the variation in payload gross weight between a rigid preassembled shelter module and an inflatable shelter concept was approximately 4 percent.

Evaluation of mag-lithium, Lockalloy, and beryllium alloys in place of aluminum for structural and meteoroid shielding indicates the possibility of significant weight savings. Considerable effort is required to extend the art in working with these materials to a point at which their utilization is possible.

Trade studies were performed on basic lunar-shelter primary structure to determine optimum components, sizes, and structural weights, and to aid in the evaluation of structural arrangement and manufacturing feasibility. A sandwich structure provides the most efficient shelter wall for axial loading. A sandwich structure is also readily adaptable to internal pressure and shielding requirements. A truss is proposed to support the shelter and equipment across the 260-inch diameter of the payload envelope.

3.2 PERSONNEL SHELTER

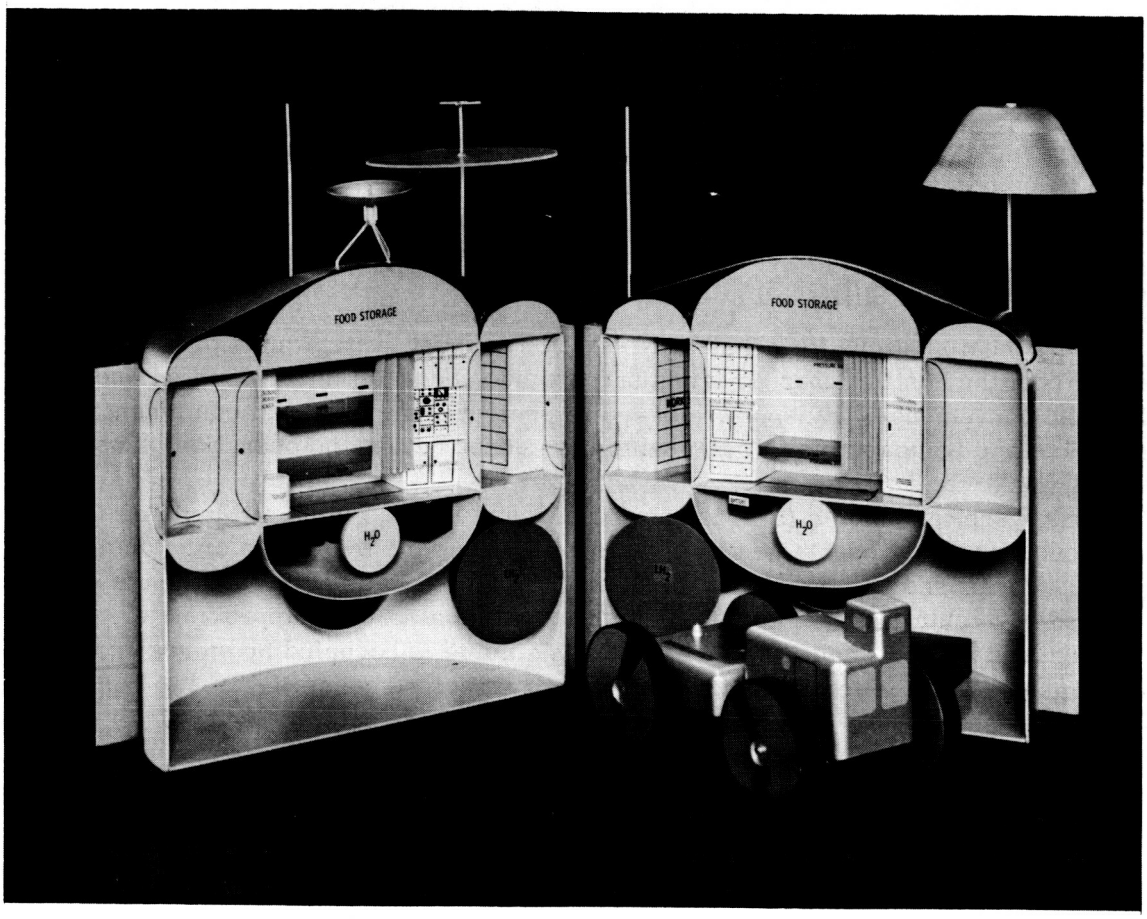
The personnel shelters for a lunar-exploration support system must protect the crew from the hostile lunar environment; provide adequate indoor comfort, security, and convenience; transport, store, and protect other essential equipment and supplies; and be adaptable to reasonable base construction and operation plans.

The basic shelter module (S-1) is shown in Figure 8. Its interior volume of 2813 cubic feet represents generous accommodations for the 6-man crew design point as measured by other lunar-mission estimates. Each of the six men is allowed 469 cubic feet inside the protective shelter; a space of approximately 7.5- by 9- by 7-feet high. About half of this volume is occupied by stores and equipment. The shelter is designed as a rigid structure consisting of two concentric pressure vessels with 0.7 ellipsoidal ends. The outer vessel wall is continuous with a circumferential skirt. Environmental shielding is provided by an outer shell of 0.053-inch aluminum (which expands to form a caisson), 1 inch of superinsulation, and the outer pressure vessel wall consisting of two 0.025-inch skins separated by 1 inch of foam core plus an 0.025-inch directional core web. The basic shelter module can remain unattended on the lunar surface for 12 months after landing. The shelter, which contains food, water, oxygen, nitrogen, and suitable life-support equipment, is ready for occupancy at any time after landing.

The 25,000-pound-payload and 260-inch-diameter constraints determined the general shape of the shelter. The concentric two-chamber plan provides redundancy for pressure integrity and additional radiation protection for the living space. Provision of radiation shielding for a 3-month occupancy requires added mass beyond that needed for other design conditions. This added shielding

Figure 8

SHELTER MODULE



(Module S-2) consists of 0.176-inch-thick aluminum, which is applied to the walls and ceiling of the living space during manufacture of the shelter module for Base Model 1 only.

Supplies and equipment that do not fit into the shelter module payload are loaded onto the logistics carrier (Module S-3). The resupply carrier (Module S-4) is

similar in purpose and form to the logistics carrier. Module S-4 is used once for resupply on Base Model 4 only, after the base is operating. It does not incorporate meteoroid shielding and corresponding weight saving makes possible the payload balance for Base Model 4.

Shelter Module S-1 encloses the modules for life support, communications, power, fuel, and surface mobility.

3.3 LIFE SUPPORT AND ENVIRONMENT CONTROL (FIGURE 9)

Temperature control of the shelter prior to occupancy is required to prevent degradation or failure of equipment. Combinations of thermal insulation, heat storage, and heat generation can maintain the desired control. A small amount of heat is required during the lunar night to counter the effect of thermal shorts in the structural design.

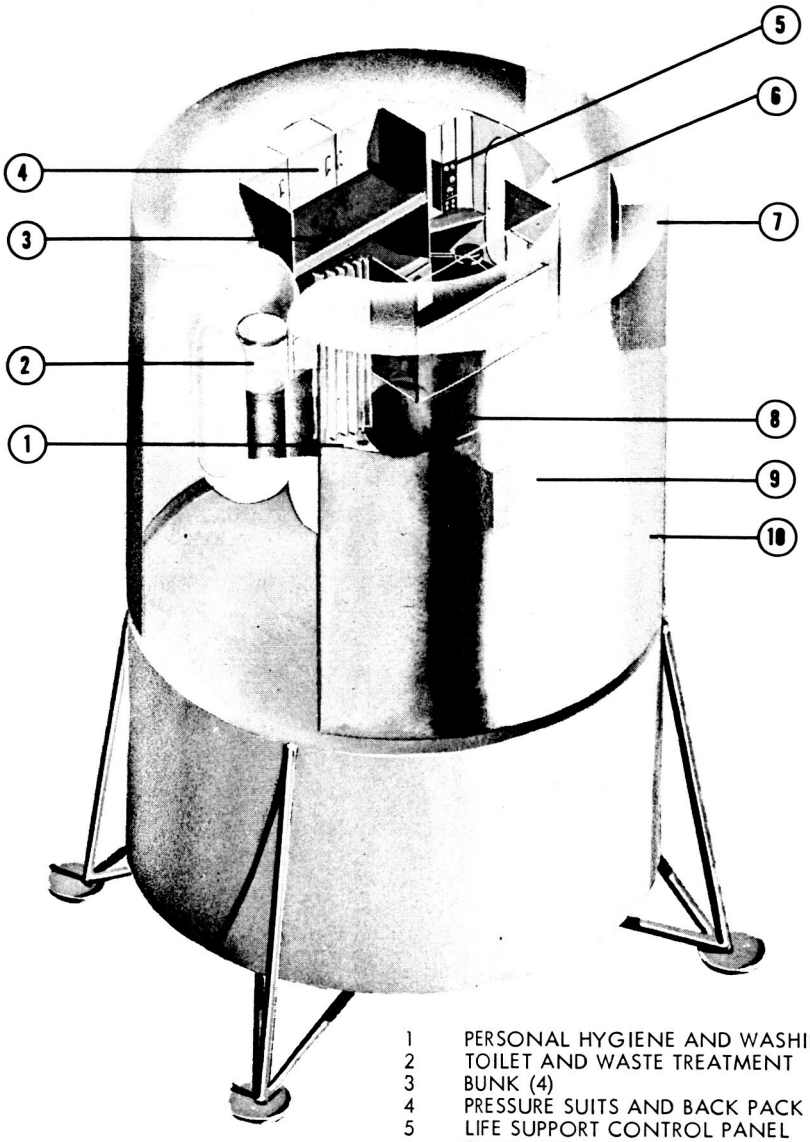
During base operation, space radiators on the caisson will provide the principal heat sink for the shelters. A reflective ground cover deployed around the base of the shelters is proposed for obtaining effective radiator performance.

An oxygen-nitrogen atmosphere at 6.0 psia has been selected for normal operation on the basis of physiological considerations, particularly decompression sickness. A pure oxygen atmosphere at 3.5 psia was selected for emergencies. Design criteria include pressurization to 0.1 psia minimum during storage, gas leakage at 4.0 pounds per day during operation, and one repressurization per month. Pumps are used with airlock operations, recovering approximately 90 percent of the air. Contamination control is achieved by a combination of materials control of contamination sources, filtration, and the use of activated charcoal, an ultraviolet lamp, and a catalytic burner.

An initial supply of liquid oxygen will be required with all base concepts. Where oxygen recovery is employed, part of this initial supply can be used for emergencies. Oxygen recovered from CO_2 will be a useful source, but it cannot supply most of the needed oxygen since the metabolic needs are only a small part of the total life-support oxygen requirement — this percentage ranges from 28 percent of the total for Base Model 1 to 60 percent of the total for Base Model 2. Fuel-cell by-product water is very promising as an oxygen source, and together with oxygen recovered from CO_2, can eliminate or greatly reduce the need for oxygen resupply.

Careful water management will be required because of the large amounts of water used. Water-recovery systems will be used in all the base concepts; the incineration-vapor compression-distillation system is selected for this purpose on the basis of overall performance and assurance of high-quality water. Fuel-cell by-product water is a major water source, and is used primarily to supply makeup oxygen needs. Fecal water recovery is necessary only on the large bases.

Figure 9
LIFE SUPPORT & ENVIRONMENTAL CONTROL SYSTEM



1 PERSONAL HYGIENE AND WASHING FACILITIES
2 TOILET AND WASTE TREATMENT
3 BUNK (4)
4 PRESSURE SUITS AND BACK PACK STORAGE
5 LIFE SUPPORT CONTROL PANEL
6 FOOD PREPARATION CABINET
7 PRESSURE SUIT AND BACK PACK STORAGE
8 WATER TANK
9 ATMOSPHERE CONTROL EQUIPMENT
10 RADIATOR 320FT^2 (TYPICAL)

Freeze-dehydrated food, packaged in individual meal and man-day units, is preferred for the lunar base.

3.4 POWER (FIGURE 10)

Four power modules were selected to provide electric service over the proposed range of base configurations.

1) Power Module P-1 is a 2-kw fuel-cell/solar-cell/battery power supply for Base Model 1, and activation and standby for Base Models 2, 3, and 4.

2) Power Module P-2 is a 15-kw fuel-cell installation and service module for Base Models 2, 3, and 4.

3) Power Module P-3 is a 10-kw nuclear thermoelectric powerplant for Base Model 2.

4) Power Module P-4 is a 100-kw nuclear (Rankine cycle) central power module for Base Models 3 and 4.

General consideration of support-system load requirements are discussed, and specific load requirements and load profiles are presented for the four base models and for vehicle, portable, and outpost concepts.

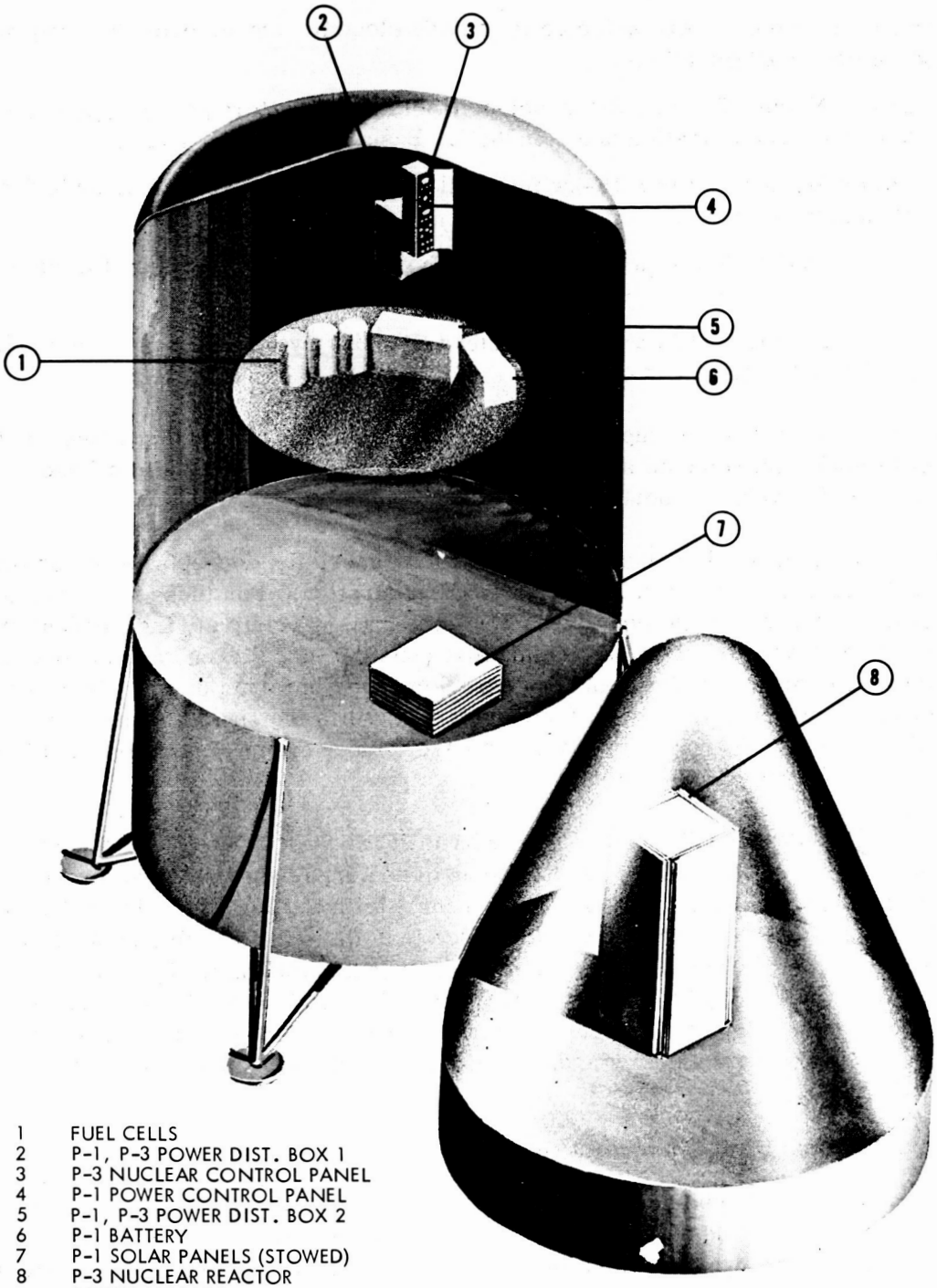
Nine chemical and solar chemical combination generation concepts were compared on the basis of specific weight versus mission duration. For these systems, the specific weight (or weight penalty) in pounds per kw is relatively independent of rated power level for the mission durations considered. Eleven radioisotope and nuclear-reactor generation concepts were compared in terms of specific weight versus kw power level. Except for the short half-life isotopes, the nuclear systems have a weight penalty that is relatively independent of mission duration within the lifetime of the system.

With a 3-foot-depth burial and complete backfill for the 100-kw SNAP-8 power module reactor, a 15-foot exclusion radius is required based on an allowable radiation dose rate of 2.5 millirems per hour. With burials exceeding a 6-foot depth, or with 8 feet of cover over a surface installation, no exclusion area will be required. A nuclear power system with integral shielding designed for an exclusion distance of 250 feet in all directions will weigh about 28,000 pounds. Lunar material shielding configurations are more practical than the integrally shielded system from a cost standpoint and afford minimum restrictions on exclusion areas.

3.5 COMMUNICATIONS (FIGURE 11)

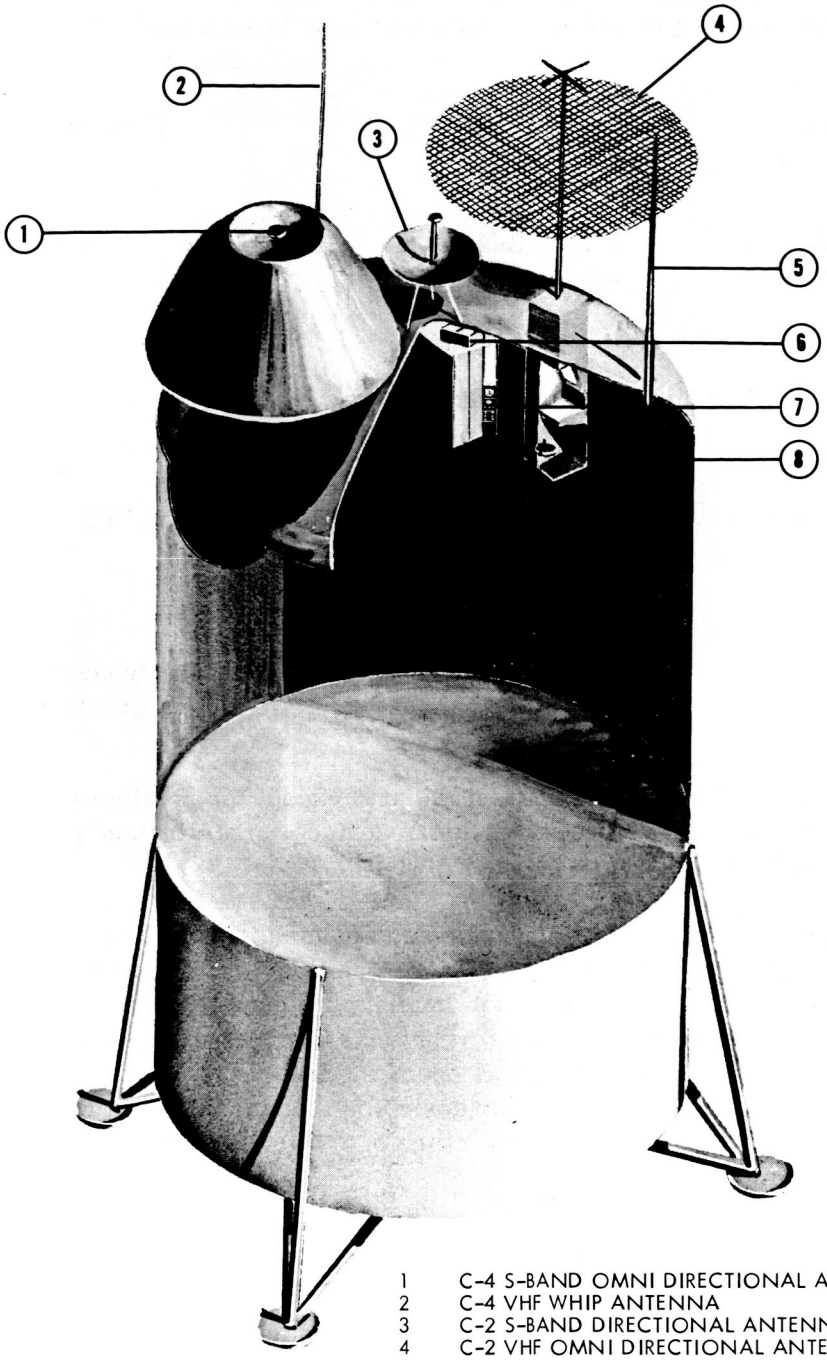
The data link requirements for the support-system communication network were defined in terms of the type of data (voice, telemetry, television, command/control, and tracking), data bandwidth, range, and desired output signal-to-noise ratio. Based on these requirements, a communication subsystem was configured

Figure 10
ELECTRICAL POWER SYSTEM



1 FUEL CELLS
2 P-1, P-3 POWER DIST. BOX 1
3 P-3 NUCLEAR CONTROL PANEL
4 P-1 POWER CONTROL PANEL
5 P-1, P-3 POWER DIST. BOX 2
6 P-1 BATTERY
7 P-1 SOLAR PANELS (STOWED)
8 P-3 NUCLEAR REACTOR POWER MODULE

Figure 11
COMMUNICATIONS SYSTEM



1 C-4 S-BAND OMNI DIRECTIONAL ANTENNA
2 C-4 VHF WHIP ANTENNA
3 C-2 S-BAND DIRECTIONAL ANTENNA
4 C-2 VHF OMNI DIRECTIONAL ANTENNA
5 C-2 VAF WHIP ANTENNA
6 C-4 EMERGENCY CHECKOUT COMMUNICATION EQUIPMENT
7 COMMUNICATION CONTROL PANEL
8 C-1 S-BAND VHF AND LF EQUIPMENT; TV MONITOR; DATA STORAGE ETC.

that provides a basic capability for Base Models 1 and 2 and an expanded capability for Base Models 3 and 4. Circuit-quality charts were derived to ensure that satisfactory performance was achieved within the constraints of Earth terminal instrumentation, state-of-the-art equipment, and mission objectives. Performance of the communication subsystem for the lunar base is summarized below.

Links	Basic	Expanded
Base-Earth		
● Voice/Data (2300 mc)	100-kc Baseband	1-mc Baseband
● Television (2310 mc)	400-kc Baseband	2- to 4-kc Baseband
Spacecraft-Base		
● Voice/Data (240 to 300 mc)	2.5-kc Baseband	100-kc Baseband
Roving Vehicle-Base		
● Voice/Data (50 kc)	2.5-kc Voice at 150 miles	60 wpm TTY at 450 miles
Roving Vehicle-Earth		
● Voice/Data (2290 mc)	65-kc Baseband	100-kc Baseband
● Television (2295 mc)	70-kc Baseband	400-kc Baseband

Techniques used are well within the state of the art, except for point-to-point communications beyond line of sight on the lunar surface. Existing and planned elements of the Apollo network may be used.

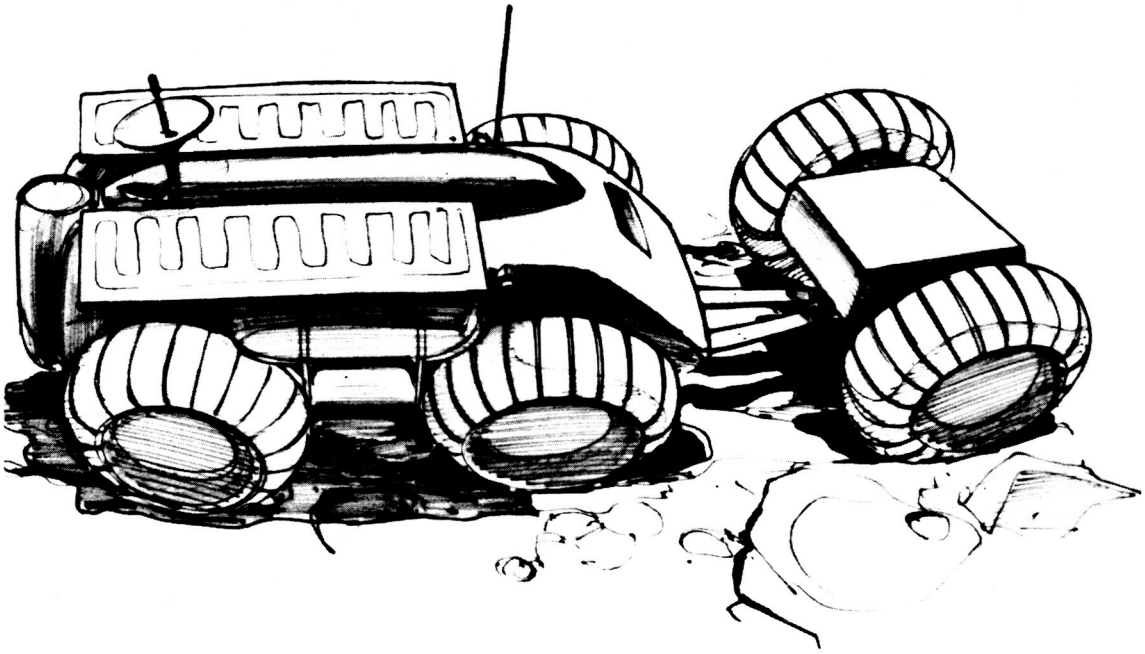
The feasibility of providing surface-to-surface communication via VLF/LF ground-wave propagation was the subject of a special study. This mode appears practical for transmission of voice (2.5 kc) or telegraph data (60 wpm) beyond the line of sight from the lunar base to a roving vehicle or remote outpost. With a horizontal insulated dipole antenna and an operating frequency of 50 kc, a transmitter power output of 10 to 100 watts provides a voice communication range of 160 to 260 miles and a data communication range of 315 to 510 miles.

3.6 SURFACE MOBILITY (FIGURE 12)

Analysis of the surface mobility subsystem indicated.the performance potential of rolling, flying, jumping, and walking modes of locomotion in terms of a broad range of probable tasks, and of the constraints represented by probable lunar surface and soil characteristics.

Figure 12

6X6 SEMIFLEXIBLE LUNAR SURFACE VEHICLE



FROM GMDRL DATA

Effort was concentrated on the rolling mode as the most feasible means for accomplishing a variety of mobility tasks. The locomotive capability as measured by the ratio of draw-bar pull-to-vehicle weight of rigid wheels, flexible wheels, and tracks is as follows.

1) Locomotion performance of the flexible wheel and track configurations is substantially superior to that of the rigid wheel for all proposed lunar sites.

2) The rigid wheel is immobile under conditions estimated for one of the sites.

3) Tracks and flexible wheels are comparable in performance at all estimated sites.

A detailed analysis of flexible wheels shows that large wheel diameters with large deflections and multiaxle vehicles with flexible chassis have superior mobility. Analysis of dynamic characteristics indicates that a flexible wheel or tracked vehicle in the 4000- to 5000-pound gross weight range can perform exploratory missions and construction tasks.

The mobility module designs proposed are illustrated in Figure 12. Module V-1 is a rigid chassis basic vehicle that can use flexible wheels or tracks. Module V-2 is a single-axle, flexible wheel unit attached to V-1 to extend the mobility capability.

Hydrogen-oxygen fuel cells are used as the power source in each module. A final drive composed of a d. c. series motor at each wheel with gated power control is recommended. Steering by a skid system or an Ackerman system is preferred.

The flying, walking, and jumping modes all offer unique advantages for particular mobility tasks and possible extremes of terrain. Further study and preliminary configuration design are justified to better define the performance potential of these modes.

3.7 FUEL SUBSYSTEM (FIGURE 13)

The fuel subsystem was designed to supply both chemical fuels for power generation and the expendables other than food required for life support. Modules were designed for the storage and transfer of liquid hydrogen, oxygen, nitrogen, and water; and for the regeneration of water exhaust products into hydrogen and oxygen for further use.

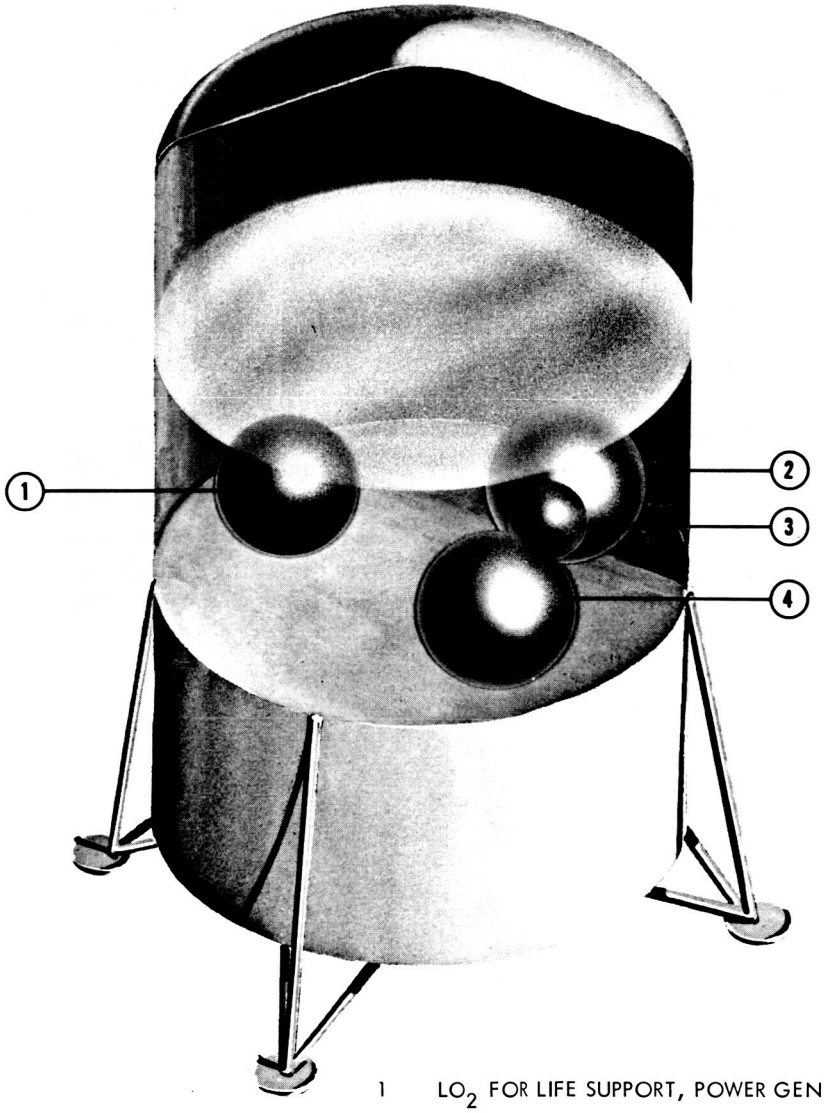
The primary consideration in the design of the fuel storage system was thermal energy management, with the storage of liquid hydrogen for 1 year before base occupancy being the most critical design problem. System trade studies compared vented and unvented designs for 1 year of unattended storage. With no heat-leak penalty, a small weight advantage is obtained with vented designs. Because of possible heat leaks with boiloff plumbing, it is recommended that hydrogen be stored in unvented tanks. To avoid severe weight penalties, the tank plumbing must be disconnected and the initial liquid-hydrogen temperature reduced to at least 31°R.

The hydrogen- and oxygen-fuel regeneration module greatly reduces cryogenic storage requirements for Base Models 3 and 4. The module is sized for 60 pounds per day oxygen and 7.5 pounds per day hydrogen recovery, with a weight of 520 pounds and a power requirement of 16 kw.

3.8 MAINTENANCE SUBSYSTEM

A maintenance philosophy that emphasizes reliance on equipment reliability rather than maintainability has been adopted. The requisite reliability level can be achieved by combining rigorous subsystem development and the provision of adequate redundancy. As a result, preventive maintenance is all but eliminated from the maintenence concept, and the principal emphasis is on replacement at the module or major component levels.

Figure 13
FUEL SYSTEM



1 LO_2 FOR LIFE SUPPORT, POWER GENERATION, AND LRV; 4594 POUNDS IN 66 O.D. TANK
2 LH_2 FOR LRV; 167 POUNDS IN 66 O.D. TANK
3 LN_2 FOR LIFE SUPPORT; 300 POUNDS IN 34 IN. O.D. TANK
4 LH_2 FOR POWER GENERATION, 222 POUNDS IN 72 INCH O.D. TANK

4.0 PROBLEM AREAS

A number of technical problem areas have been identified during this study. Solutions to many of these problem areas are absolutely essential to the development of supporting facilities for extended exploration of the Moon. These questions and preliminary suggestions for appropriate action are described in Section 9.0 of Volume II, in the categories of environment, materials, man, mobility, and missions.

An outstanding example of a problem with repercussions in all categories is that of meteoroid protection. The meteoroid environment on the lunar surface, including the contribution of secondary particles, is completely unknown. Active programs are required to obtain pertinent data. Current lunar support-system designs have been based on extrapolation of the meager near-Earth meteoroid data and the results of limited laboratory research on hypersonic impact phenomena. The latter field requires as much attention as the gathering of valid environmental data. In particular, laboratory research at projectile velocities above 60,000 fps is completely lacking, and will require the development of novel testing techniques.

A second problem of universal concern is that of defining space-suit performance. The entire concept of manned lunar exploration hinges on the ability of man to participate effectively in both base functional and scientific mission activities. Present design goals for the Apollo mission have been assumed in this study as actual performance specifications. However, such achievement depends on technical advances not yet described.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The initial concept of a lunar exploration system developed in this study has been successful in meeting the objectives of defining a family of subsystem modules suited to a wide range of base size and durations, and mission support requirements. This current definition of the initial concept should be further refined through more detailed subsystem studies, accompanied by a continuing system integration effort in preparation for hardware development and testing well in advance of Apollo flight dates.

An orderly extension of the Apollo program will not permit delay. Therefore, not all information on the environment of the Moon will be positively known before lunar exploration support system plans are finalized and actual construction and test of equipment is begun.

When a reasonable amount of environmental knowledge of the Moon is acquired, designs should be completed and hardware manufactured and tested. A reasonable time for completing preliminary studies and starting the R&D phase would be 4 years before the anticipated accomplishment of the current Apollo program. Subsystems would be provided in a timely program, and the base with all its associated equipment should then be assembled and tested in a simulated lunar environment. Plans and equipment should be modified as new lunar environmental data indicates the need for such adjustment. Thus, there would be no appreciable time lag between the completion of the currently planned Apollo launches and the initiation of the more comprehensive phase of the Apollo lunar-exploration program.

Conclusions reached in the technical studies are included throughout the final report document. The principal conclusions and recommendations are summarized in Section 10.0 of Volume II. Of these, the following are considered most significant for continuing studies.

5.1 SYSTEM REQUIREMENTS

Lunar-exploration support-system requirements will vary widely with the type and scope of scientific mission activity planned. This conclusion applies especially to the general parameters of crew size and system duration, and to the specific parameter of lunar-surface mobility capability. Realistic and definitive lunar-exploration mission goals and schedules should be formulated to guide an improved definition of support system requirements. Definitions of goals should include specification of their relative value.

5.2 MISSION OPERATIONS

Lunar exploration may proceed on a gradually expanding evolutionary scale, from a small initial program to an eventual major base installation, without penalty on a gross cost-effectiveness basis. Development of a lunar-exploration support

system should continue to emphasize the modular concept to ensure provision for system evolution potential.

The surface roving mode of lunar mobility is best suited to effective lunar surface reconnaissance. Flight modes are suitable for quick, long-range, point-to-point transportation and for obstacle crossing, but are much less competitive economically for stop-and-go travel and are not too attractive for one-stop reconnaissance use.

Surface roving vehicle development should be emphasized, including the study of means for obtaining vehicle range and crew duration capabilities extending up to a mobile base concept. Flight-mode applications should be analyzed further, and initial system concepts configured.

Quantitative projections of Apollo space-suit limitations should be factored into lunar-mission and support-system planning at an early date. Any resulting indications of incompatibility of these projections with desired mission accomplishments should signal accelerated investigation of automation substitutes.

5.3 LOGISTICS CONSIDERATIONS

A goal of the exploration support-system development should be the reduction of crew transportation traffic through provision of large capacity vehicles and increased allowable crew stay-time. Development of the LH_2/LO_2 multiple mission module concept should be pursued, with possible applications as a lunar logistic vehicle, advanced Apollo service module, and advanced LEM descent stage. Detailed studies of large-capacity Apollo- and LEM-type spacecraft, consistent with advanced Saturn performance in direct flight, Earth-orbit refueling, and lunar-orbit rendezvous modes, should be pursued.

The feasibility of synthesizing fuel and life-support expendables from lunar raw materials is essentially unquestioned from the standpoint of the chemistry involved. However, because of the effectiveness of regeneration of these same materials from most using subsystems, it is not clear that a strong demand for synthesis exists. Further overall mission requirement and support-system analysis is required before development of synthesis equipment can be justified.

5.4 BASE INSTALLATION

Surface emplacement of a base is feasible and is preferable to subsurface emplacement. Surface emplacement does not require unloading the basic shelter from the lunar logistic vehicle. Personnel shelters and other vulnerable elements should be designed to accommodate lunar soil coverage. The concept of an expandable caisson, built as part of the structure of the shelter to hold the soil cover, should be developed.

No single set of construction equipment now seems sufficiently flexible for soil excavation and placement at lunar sites that vary widely in surface and subsurface characteristics. It is premature to select any one type or family for preliminary design.

5.5 SYSTEM DESIGN

Shelter — Design of a basic, six-man, lunar shelter with integrated meteoroid and radiation shielding adequate for 1 year of storage and subsequent 3-month occupancy is feasible within the Saturn V/LLV payload limits. For longer operations, these shelters should be covered with lunar soil for added protection against the environment. A 2-foot-thick layer of soil covering the shelter will provide the necessary shielding for up to 2 years of operations, assuming personnel are rotated at 6-month intervals. Incorporating an expandable caisson in the shelter design to retain the soil cover is feasible.

Life Support — Life-support requirements can be met with the same techniques contemplated for advanced Earth-orbital systems, except for thermal control. New techniques will be required for thermal control. During the lunar day, reflective-radiation concepts may be used for heat rejection. Internally generated heat will be required to assist in temperature control during storage, possibly from an easily shielded radioisotope heat source.

Decompression sickness from pressure suit operation is a major factor in selecting the cabin atmosphere. An oxygen-nitrogen atmosphere of 6.0 psia is recommended for the personnel shelters.

Power — The study confirms that nuclear-reactor power is the superior generation concept for all but the smallest bases. It appears feasible to provide by 1971 any of the four base power subsystems considered in the study.

The SNAP 8 100-kilowatt, two-alternator system appears to be a very practical, reliable power module for application to large central nuclear powerplants on advanced bases. It is recommended that further studies be made to verify a practical module size and that development effort be initiated on the long-lead elements of such a system.

The small integral shelter power system should be developed for the 90-day base application. The fuel-cell/solar-cell system appears to be the most practical concept; however, intensive studies should be made to evaluate and compare radioisotope concepts in the 1.5- to 3.0-kilowatt range.

The use of lunar materials for shielding appears to be more practical and less expensive than the use of Earth-supplied materials.

Communications — Lunar-base communication requirements may be met with techniques that are well within the state of the art, except for point-to-point communications beyond the line of sight on the lunar surface. Existing and planned elements of the Apollo network may be used.

The use of LF (approximately 50 kc) surface-to-surface communication appears feasible and practical for the transmission of voice or telegraphy data beyond the line of sight between the lunar base to either a roving vehicle or a remote outpost. This concept also provides an aid to exploration and a means of navigation on the lunar surface with modest transmitter power and a simply erected horizontal dipole antenna.

Surface Mobility — The concept of a basic four-wheel mobile vehicle with extra pairs of powered wheels that may be attached for extending surface traversing capabilities, and fixtures that may be attached for material handling and construction tasks, should be adopted for the lunar-exploration support application. The vehicle and associated modules should be designed and tested in suitable test areas that most nearly simulate the lunar environment. The flexible chassis principle should be used for the mobility extension module and should be considered for use in the basic four-wheel module.

For exploration trips longer than those described in this study, the advantages that may come out of the development of vehicles scaled to comprise an entire LLV payload should be examined.

Long-range flight-mode propellant requirements are so large that the concept appears to be practical only in combination with the synthesis of propellants from lunar materials.

Fuel — Cryogenics (H_2, O_2, N_2) can be stored on the Moon for 1 year of unattended storage plus base operational periods. Regeneration of water into liquid hydrogen and liquid oxygen is both feasible and desirable for the larger bases. Modular concepts for fuel storage are not entirely practical because fuel requirements do not follow in logical increments from base to base.

Maintenance — The study has revealed both incentive and encouragement for minimizing rather than facilitating servicing and repair. Maximum reliability plus a modest fault-correction capability of the crew, rather than maximum maintainability, should become a major lunar-base design goal. The reduction of maintenance requirements should be pursued through design to eliminate all possible servicing needs during the projected base life, rather than through automated servicing or self-repair, which may degrade rather than improve reliability. The true impact of various maintenance needs on lunar-base operations will remain indeterminate until some conclusive evaluations of space-suit effectiveness in the lunar environment become available.

NASA-Langley, 1964 CR-39