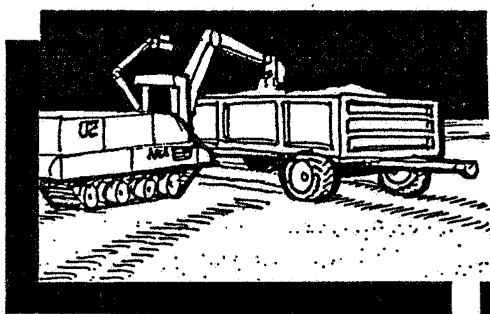
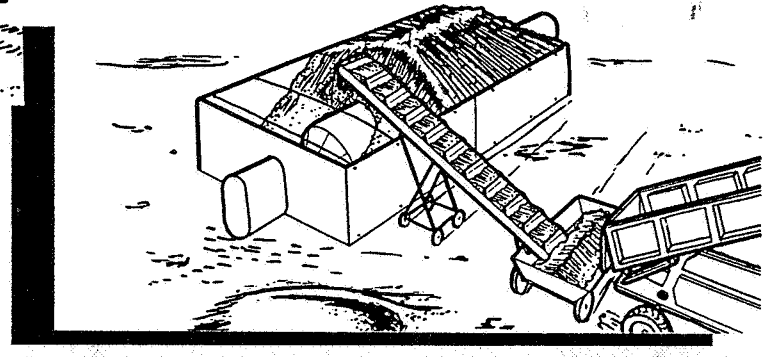
CR-172050

LBSS

Lunar Surface Operations Study

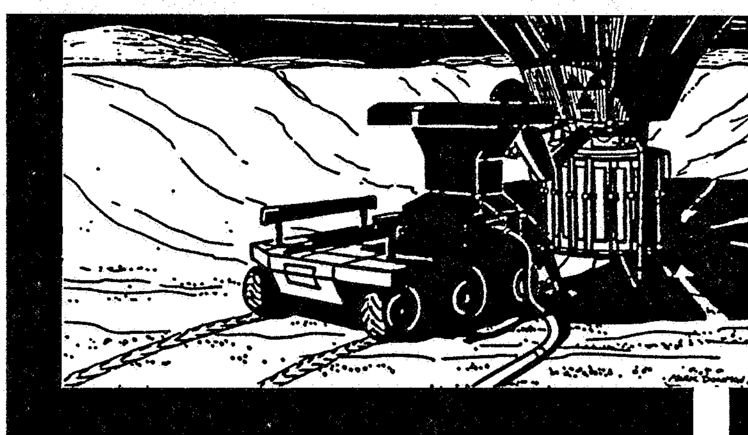


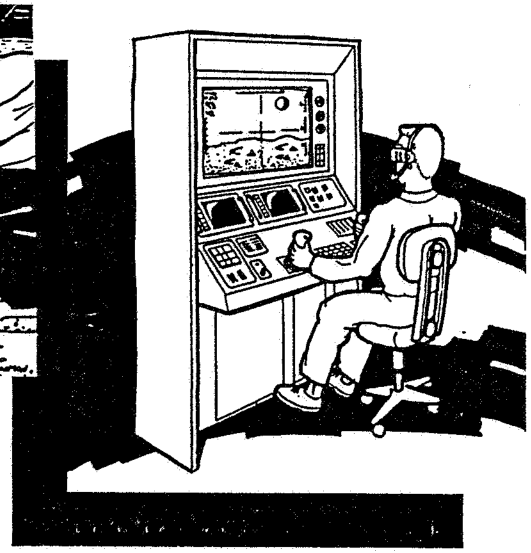


(NASA-CR-172050) LUNAR BASE SURFACE MISSION OPERATIONS. LUNAR BASE SYSTEMS STUDY (LBSS) TASK 4.1 (Eagle Engineering) 161 p CSCL 03B

N88-25415

Unclas
G3/91 0142696





NASA Contract Number NAS 9-17878

EEI Report # 87-172

December 1, 1987

EAGLE

Lunar Base Surface Mission Operations

Lunar Base Systems Study (LBSS) Task 4.1

Prepared under Contract to the

Advanced Programs Office

at the

Johnson Space Center

by

Eagle Engineering, Inc.

Houston, Texas

NASA Contract No. NAS9-17878

Eagle Contract No. TO-87-57

Task 4.1 Report

Eagle Report No. 87-172

December 1, 1987

Foreword

This study was conducted between October 19, 1987 and December 1, 1987 by Eagle Engineering, Inc. for the Advanced Programs Office of the Johnson Space Center (JSC). The Lunar Surface Mission Operations task was performed to support the JSC Lunar Base Surface Systems (LBSS) study intended to provide planning for a Lunar Base near the year 2000. The purpose of this study was to (1) develop a mission manifest for a selected Lunar Base scenario, (2) determine the nature of surface operations associated with this scenario, (3) propose concepts for utilizing machines/remote operations to perform repetitious or hazardous surface tasks, and (4) present a preliminary crew EVA/IVA time resource schedule for conducting the missions.

Dr. John W. Alred was the NASA technical manager for this study. Mr. Kyle O. Fairchild was the NASA task monitor. Mr. James Sturm (NASA JSC) also contributed.

Mr. W. B. Evans was the Eagle Project Manager and Mr. William R. Stump, Jr. was the Eagle Deputy Project Manager. Mr. Eric L. Christiansen was the Eagle task manager. Technical contributions were made by Ms. Carolynn L. Conley, Mr. William L. Davidson, Mr. John K. Hirasaki, Mr. John D. Overton, and Dr. Charles H. Simonds. Art work was produced by Mr. R. Patrick Rawlings, Mr. Mark W. Dowman, Mr. John R. Lowery, and Mr. Mike Stovall.

Table of Contents

Table of Contents

Page

List of Figures

List of Tables

Executive Summary

The purpose of this study was to perform an analysis of the surface operations associated with a human-tended lunar base. Specifically, the study (1) defined surface elements and developed mission manifests for a selected base scenario, (2) determined the nature of surface operations associated with this scenario, (3) generated a preliminary crew extravehicular and intravehicular activity (EVA/IVA) time resource schedule for conducting the missions, and (4) proposed concepts for utilizing remotely operated equipment to perform repetitious or hazardous surface tasks. The operations analysis was performed on a 6-year period of human-tended lunar base operation prior to permanent occupancy. The baseline scenario was derived from a modified version of the civil needs database (CNDB) scenario. This scenario emphasizes achievement of a limited set of science and exploration objectives while emplacing the minimum habitablity elements required for a permanent base.

Groundrules defined for the study include: (1) lunar manned and unmanned cargo flight rates are assumed to build from 2 to a maximum of 8 per year in the human-tended base period, (2) initial surface operations are based from a manned module attached to a lunar lander and are therefore limited in surface stay times to the life support capability of the lander's manned module, presumed in this case to be 8 days for 4 crew, (3) the operations center shifts to the base and stay times are increased to 24 days after the following surface elements become operational: solar flare radiation shelter, habitation module, interface node, airlock, power system, thermal control system, and communications relay station.

Lunar base crew shift schedules were formulated from Shuttle guidelines and Space Station crew plans, and from them, time allocations for operational tasks were determined. For instance, of the 768 person-hours available on 4 crew, 8-day surface stay missions, only approximately 228 hours are actually available for surface operations after accounting for sleep, meals and personal time, spacecraft housekeeping and systems monitoring, arrival and departure spacecraft checks and preparation activities. Out of this 228 hr surface operations resource, 6 two person EVA's were planned to provide 72 hrs of EVA operations. IVA maintenance/refurbishment and ingress/egress activities required to support these EVA's consume 49 hrs, yielding 107 hrs for other IVA activities, such as teleoperation of base site surface preparation and construction equipment.

Specific surface operations addressed in this report include IVA support activities for EVA, landing/launch site preparation, cargo handling equipment and activities, radiation shelter emplacement, exposed (non-buried or covered) module emplacement, construction equipment and operations, science operations, resource utilization operations, logistics and maintenance activities, manual/telerobotic division of labor, and contingency operations. For instance, the possible methods to provide 700 g/cm^2 of radiation protection (approximately 4 m of regolith overburden) for a solar flare shelter are surveyed, and the EVA/IVA time required for the baseline concept utilizing a bulkhead arrangement is determined.

A major conclusion of the study is that 4 person crews on approximately 1 month missions can accomplish significant science and resource development objectives while constructing a permanent base, but that teleoperation of soil moving and construction equipment from the lunar lander, lunar base, and Earth is required to leverage limited EVA time resources. Teleoperation is particularly important during short duration early missions for site preparation and solar flare shelter emplacement. Technology development in automation and robotics (A&R) applications to surface construction vehicles is considered essential, especially to allow lunar teleoperations from Earth with the imposed communications delay. It was also concluded, after estimating EVA/IVA time requirements for various surface activities, that providing radiation protection for all modules (by burying or covering with soil) should wait until the base is permanently occupied, when sufficient time resources are available. In addition, a concept for a lunar surface telerobotic servicer was proposed to perform inspection and maintenance activities.

1.0 Introduction

This study is an initial attempt to develop a framework for describing surface operations associated with a manned lunar base. The study encompassed the period from the first manned landing to establish a lunar base until the base grows into a permanently manned outpost (1). Specific objectives of the study were to:

1) Produce a lunar base scenario with enough definition to provide the basis of a surface operations study. This definition was to include flight rates and manifests.

2) Determine the nature of surface mission operations including construction/assembly sequencing, human/machine division of labor, and resource scheduling.

The study methodology is described in more detail in Section 2. Section 3 provides a list of the major assumptions developed prior to the study. Section 4 defines the scenario used in this study and its major differences from the proposed scenario in the civil needs database (CNDB). Surface operations are summarized in Section 5.1 and described in more detail in the remainder of Section 5.

2.0 Methodology for Surface Operations Study

Surface operations can be effectively studied only within the context of a defined lunar base program. Thus, the first step of this study involved the definition of a baseline scenario. The CNDB and other previous government and contractor reports (2-5) provided the basis for the scenario definition task. This scenario included a clear description of goals and expected benefits; list of assumptions; definition of surface elements and science experiments; a schedule and manifest of all flights to the surface; and definition of surface element deployment options or trades in areas recognized as major drivers of surface operations.

The second study task was to define major surface operations associated with this scenario. Preliminary estimates of EVA and IVA crew time requirements were determined from a systematic approach for many of these operations. A crew manning schedule was defined including available resources to support the surface operations. This allowed a comparison of available and required crew hours to fulfill mission objectives, thus producing a first order assessment of crew size and stay time requirements.

Because many options are available for carrying out individual mission objectives, the conclusions on required crew size and surface stays made by this study that are based on one scenario should be considered preliminary until trade studies have provided more detailed and optimized designs. Of more use is the scenario definition as a baseline for later studies or comparisons, the identification of options and trades, and the definition of crew time requirements for specific mission operations for use in later studies.

A third task not attempted in this study is to develop an integrated operations plan for each of the manned missions in the scenario. This final step would be more efficiently completed at the conclusion of the current LBSS studies (1), and could be a particularily effective tool to integrate the results of the entire effort.

3.0 Groundrules and Assumptions

The following assumptions and groundrules were established prior to this study activity.

1. Lunar surface operations will be studied for the second of a three phase return to the Moon. Phase I is a precursor, unmanned exploratory phase (1992-1998) consisting of orbiters, rovers, and other surface missions designed to provide information necessary for lunar base site selection and to initiate site preparation. Phase II begins with the first manned mission to construct the lunar base and ends when the base is capable of supporting a permanent crew (1999-2005). The lunar base will be configured for potential growth as required during the permanently occupied Phase III.

2. No water ice or other volatiles are found at the lunar poles during phase I exploratory activities. The base is assumed to be located at Lacus Veris (87.5W, 13S), a limb site near Orientale with farside access.

3. Telerobotic operation of routine and repetitious tasks from either the Earth or lunar base is possible.

4. It is assumed that the Advanced Space Transportation System (ASTS) will be able to support the following maximum lunar landing flight rate:

Landing Type	1999	2000	2001	2002 - 2005
Manned	1	2	3	4
Unmanned	1	3	3	4
Total	2	5	6	8

5. Three stages in the phase II base are assumed:

Stage	Operations Center	Max. Staytime (days)
1 - Establish Human Tended Base	Lander manned module	8
2 - Human Tended Base	Base habitation module	24
3 - Establish Permanent Occupancy	Base habitation module	180

It is assumed the transition from stage 1 to stage 2 can take place only after the following surface elements are operational: solar flare storm shelter, habitation module, interface node, airlock, power system, thermal control system, and communications relay station. The third stage of phase II starts when crew stay times are increased to 180 days. It also signals the beginning of the Phase III permanently manned base when, 90 days later, a second crew lands to start their 180 day surface stay. It is assumed that permanently manned base becomes necessary after a full-scale lunar oxygen production plant becomes operational.

6. The scenario developed for this study includes objectives in the areas of human presence, science, resource development, and technology development, and political. Achieving objectives during Phase II in each of these areas is assumed to be important in generating broad based support for a lunar base program.

7. A pressurized shelter for protection from solar flare radiation will require 700 g/cm^2 of regolith overburden (approximately 4 m).

8. Resource utilization will focus on oxygen extraction from ilmenite. Oxygen extraction will be verified on a pilot plant level first, with product used in the base environmental life support system and fuel cells. Two years of pilot plant operation will be required prior to delivery of a production plant sized to provide LOX refueling of a reusable Lunar lander on the surface. Refueling facilities will also be delivered during the human-tended base phase for a demonstration of LOX loading. Full scale LOX production for supplying reusable lunar landers and refueling operations begin in the permanently occupied base phase. Eventually, depending on economics, the production plant will be expanded to supply LOX for orbital transfer vehicles. An orbital refueling station to refuel OTVs in Lunar orbit will be needed.

9. Maximum cargo capabilities:

Base Phase	Vehicle	Max. Cargo (mt)	Propellant	LOX (mt)
II	Expendable Lander	17.5	LOX/LH_2	12
II	Ascent Stage	0.5	Storable	NA
III	Reusable Lander	17.5	LOX/LH_2	26

10. Locations for the following elements are assumed for this study:

Landing Site: close to base (~1 km) since early crews will have to walk to base site or will need rovers located at landing pads. Exhaust plume deflection structure made from piled local materials could be constructed between landing site and base elements.

Oxygen Pilot Plant: close to or attached to base to facilitate hands-on trouble-shooting and problem resolution.

Oxygen Processing Plant: close to Launch pads to shorten distance for refueling lander. Liquid oxygen product from plant will be stored in tanks, a tank car will pump LOX from storage tanks to refuel reusable lander. A more compact operation will shorten time and/or reduce mass for refueling operation.

Optical Interferometer Experiment: some distance (several km's) from base or behind hills to avoid contamination from rocket exhaust, dust, and base lights.

11. Expended materials and other waste are assumed discarded or stored at surface site and not returned to Earth. Materials returned to Earth will only consist of scientifically valuable materials.

4.0 Lunar Base Description

The Lunar base mission set presented in the civil needs database (CNDB) (Ref.2) provided the starting point for this study. Some refinements to the CNDB lunar base scenario were thought necessary to allow earlier science and mobility capabilities (earlier Geophysical laboratory, life sciences laboratory, and pressurized rovers), to phase in lunar oxygen utilization at a more restrained pace (pilot plant to surface refueling of lander instead of pilot plant to orbital refueling of landers and OTVs), and to provide crew contingency support (redundant return vehicle, solar flare shelter). Both the CNDB and the alternative scenario are described in the following sections.

4.1 CNDB Scenario

The CNDB lunar base model was derived from previous NASA (4,5) and Eagle (3) studies. It consists of a set of payloads designated for delivery to destinations on the lunar surface, lunar orbit, and elsewhere during specified years in the 1992-2010 time period. As part of this study, these payloads were manifested on separate missions and sequenced during each particular year. A summary of the lunar surface and lunar orbit manned and unmanned missions in the CNDB is given in Table 4-1 while a complete list of the derived CNDB mission set is given in Appendix A.

The CNDB lunar base initiative consists of a three phase program. The basic purpose of the first phase is to search for valuable resources, particularly water ice or other volatiles, and locate possible sites for the base. The CNDB's first phase begins in 1993 by placing a Lunar Geoscience Observer (LGO) satellite in low lunar polar orbit to conduct preliminary geochemical mapping of the entire surface. Depending on the findings of the observer mission, other unmanned probes and landers might also be included in this phase to search for water ice at the lunar poles. Additional years of surface investigations and site selection via unmanned, teleoperated lunar rovers would follow the LGO mission. Phase I in the CNDB continues through 1998 with an advanced lunar geoscience orbiter mission; several surface penetrator, rover, and sample return missions; and insertion of a lunar communications satellite into a halo orbit about the Earth-Moon farside L2 Libration point.

Phase II of the CNDB begins with the return of a 4-person astronaut crew to the lunar surface in 1999 for an 8-day surface stay (lunar daylight). Additional 8-day manned missions are conducted for another 2 years. Man-tended base capabilities are established after a habitation module and associated support equipment are emplaced to allow longer surface stays (extended to approximately a lunar day-night cycle). The lunar base transitions to permanently manned status in 2005, when oxygen production facilities are started up and orbital refueling facilities deployed in anticipation of refueling reusable landers and Orbital Transfer Vehicles (OTV's) beginning in 2006 (start of Phase III).

The CNDB Phase II base emphasizes an aggressive lunar derived oxygen utilization program and early deployment of near-side and farside astronomy payloads. Unmanned missions use an expendable lander to deliver cargo elements weighing up to 18.1 metric tons (40,000 lbm) to the surface. The same expendable lander is used on manned missions to deliver a reusable manned module (sized for 4 crew, 14-day missions, 8-day surface stays), expendable ascent stage, and approximately 3.3 metric tons (7,200 lbm) of cargo, experiments, and lunar surface consummables. By the end of Phase II (2005), the base elements listed in Table 4-2 have been delivered.

In the first year (1999), an unmanned and a manned mission is landed at the base site selected by previous orbital and unmanned surface missions to complete site certification. Only the discarded descent stages are left at the base site.

In 2000, a communications relay station, initial power plant, unpressurized rover, and a collection of vehicles including crane with trailer, pressurized soil mover, and prototype drag scraper are delivered by unmanned landers to the base site. Two 8-day surface stay manned missions are flown: one to the base site while the other lands at a farside location for the purpose of constructing a farside UV Telescope and a radio astronomy system designed to search for extraterrestrial intelligence that were both delivered in separate modular missions (see detailed descriptions given in Appendix B).

In 2001, landed elements include the first pressurized module (a module interface node), a pilot plant to produce liquid oxygen, two more power plant modules, and an optical interferometer telescope. The optical interferometer is a major scientific initiative consisting of a collection of 27 manueverable telescopes and a central aperture synthesis station that requires deployment in a Y-shaped array measuring 6 km along each arm. The CNDB shows three manned sorties with an 8-day surface stay in this year.

The following year (2002), a habitation module is delivered enabling surface stay times to be increased to 24 days. In addition, mining equipment consisting of various excavation and soil moving vehicles are landed. Four manned sorties are flown.

In 2003, the set of pressurized modules grows with the delivery of a geochemical and materials science laboratory and another module interface node. An advanced, nuclear power plant is landed, as is a third of the full scale oxygen production plant. Four manned, 24-day surface stay, missions support lunar surface activities. A total of 7 lunar landings are flown.

The majority of the lunar oxygen production plant is landed (two missions) in 2004. One of four manned missions lands on the farside to service the UV Telescope. A second unpressurized rover is delivered to the lunar base.

In 2005, crew stay times are extended to 180 days. Since four manned missions are flown, the lunar base population jumps from a previous man-tended crew size of 4 to a permanent staff of 8 after the second manned mission of the year. A propellant depot/-refueling station becomes operational in low lunar orbit. The module set grows at its fastest rate with the delivery of two full-size life science laboratories, a life science interface node, and a standard module interface node. Another major science effort is represented by the delivery of deep drilling equipment. A second communications relay station is landed.

The CNDB designates payloads through the year 2010, with emphasis on operation of a reusable lunar lander, growth of the base staff to 12, addition of two full-size pressurized modules (habitat and shop), and emphasis on additional large science missions as well as servicing of existing science payloads.

Table 4-1. Summary of CNDB Missions during Man-Tended (Phase II) Lunar Base Phase

Year	Mission Type	Lander Type	Number of Missions	Manned Surface Stay, days	Destination
1999	Unmanned	Std. Expended	1		Lunar Base
	Manned	Std. Expended	1	8	Lunar Base
2000	Unmanned	Std. Expended	2		Lunar Base
	Manned	Std. Expended	2	8	LunarBase(1toFarside?)
	Unmanned	(Not Specified)	2		Farside (CNDB did not specify lander type or manned support missions)
2001	Unmanned	Std. Expended	3		Lunar Base
	Manned	Std. Expended	3	8	Lunar Base
2002	Unmanned	Std. Expended	2		Lunar Base
	Manned	Std. Expended	4	24	Lunar Base
2003	Unmanned	Std. Expended	3		Lunar Base
	Manned	Std. Expended	4	24	Lunar Base
2004	Unmanned	Std. Expended	2		Lunar Base
	Manned	Std. Expended	3	24	Lunar Base
	Manned	Std. Expended	1	24	Farside
2005	Unmanned	Dedicated	1		L1 Libration
	Unmanned	Dedicated	1		Lunar Orbit
	Unmanned	Std. Expended	3		Lunar Base
	Manned	Std. Expended	4	180	Lunar Base
SUBTOT.	Unmanned	Dedicated	1		L1 Libration
	Unmanned	Dedicated	1		Lunar Orbit
	Unmanned	(Not Specified)	2		Farside
	Unmanned	Std. Expended	16		Lunar Base
	TOTAL UNMANNED		20		
	Manned	Std. Expended	6	8	Lunar Base
	Manned	Std. Expended	11	24	Lunar Base
	Manned	Std. Expended	1	24	Farside
	Manned	Std. Expended	4	180	Lunar Base
	TOTAL MANNED		22	Man-days = 4224 (4 man crew)	

Table 4-2. CNDB Surface Elements by Jan.1, 2006

		Mass (lbm/ea)	Year(s) Landed
Science			
1.	(2) Surface Penetrator Networks	4,400	1996,1997
2.	(2) Polar Sample Returns	8,800	1996,1997
3.	(3) Unmanned Surface Surveying Rovers	2,200	1997-1999
4.	(7) Lunar Science & Field Geology	500	1999-2005
5.	Farside UV Telescope	10,000	2000
6.	Farside SETI	20,000	2000
7.	Optical Interferometer Telescope	15,000	2001
8.	Deep Drilling	4,000	2005
9.	Service Geochemical/Materials Lab.	500	2004,2005
Mobility			
1.	(2) Unpressurized Rovers	4,000	2000,2004
2.	Pressurized Soil Mover,Crane,Excavator	38,500	2000
Communications, Power			
1.	(3) Initial Power Plant	7,000	2000,(2)2001
2.	Advanced Power Plant	38,500	2003
3.	(2) Communications Relay Station	2,500	2000,2005
Pressurized Modules			
1.	(3) Module Interface Nodes	8,200	2001,2003,2005
2.	Habitation Module	38,500	2002
3.	Geochemical/Materials Laboratory	38,500	2003
4.	(2) Life Science Research Laboratory	40,000	(2)2005
5.	Life Science Research Node	8,200	2005
Resource Facilities			
1.	Liquid Oxygen Pilot Plant	38,500	2001
2.	Oxygen Mining Equipment	38,500	2002
3.	(3) Liquid Oxygen Production Plant	33,333	2003,(2)2004
4.	(In LLO) Orbital Propellant Depot	40,000	2005

4.2 Alternative Phase II Lunar Base Scenario

The CNDB scenario combines the goal of establishing early resource development with a strong science emphasis during a steady build-up of human habitability elements. Transitioning to a permanently occupied base in less than 7 years (1999-2005) appears possible, but at the expense of science and resource utilization payloads. It is easier from an operations planning standpoint to focus on one objective at a time. First, deliver the modules and support equipment for a permanent base. Then, land and operate science and resource utilization equipment. However, as with Space Station, early realization of science and resource objectives may be required by a lunar base program to generate wide support and acceptance. In this scenario, science objectives will not be neglected during the transition to a permanent base, even though it is recognized that combining objectives slows establishment of a permanent base.

The authors of this report did see the need for some adjustments to the scenario prior to in-depth study of surface operations. In particular, very early science missions were postponed in favor of earlier emplacement of a habitation module to allow longer surface stays. Science missions were added to extend sampling to the farside and poles and to place geophysical stations far enough apart that they could sound deep into the interior. Pressurized rovers were delivered to increase the mobility of the crew and to allow other science missions such as crater dating, which requires longer traverses than possible by unpressurized rovers.

4.2.1 Comparison of Alternative and CNDB Scenarios

As given in Table 4-3, the scenario used in this study has many similarities with the CNDB. All differences and rationale follow:

Science

1. Added mass of Lunar Science & Field Geology (LS&FG) experiments and servicing equipment for collecting samples (core tubes, sample bags and boxes, spare tools, and other "consumables") to every manned mission over the Phase II time period instead of just one per year. It was assumed that every manned mission should be fully capable of the range of geology studies and experiments defined in the LS&FG description in Appendix B (although the actual type of science experiments carried in each package will probably evolve over the program).

2. Added four geophysical research stations. These are unmanned missions landed on dedicated landers at a variety of widely distributed sites. A network of geophysical stations was highlighted as a basic need for future lunar missions by an internal Eagle study (14). The mission's mass budget included an unmanned rover (400 kg Mars rover size) and sample (5 kg) return system. Deployment by dedicated landers allows this science mission to proceed independently from the lunar base.

3. The optical interferometer telescope was postponed a year to allow earlier emplacement of a habitation module (allowing increased surface stay times). Also, the optical interferometer had to wait until pressurized rovers were delivered in 2002 to allow its deployment. Several manned traverses of approximately 15 hrs duration and 50-100 km round-trip will likely be required to inspect and survey the sites of this large astronomical array (Refs. 16, 17, and this report - see Section 5.5 and Appendix D).

4. Deep drilling was moved up from 2005 to 2003 because pressurized rovers had been delivered which were expected to assist in this long-duration extravehicular experiment.

5. A crater dating experiment was added to the 2003 mission list. Pressurized rovers will be needed for this experiment which will require traverses of 400 km and nearly 30 days to sample 50 craters greater than 5 km in diameter (Ref. 18, and this report).

6. Servicing of the geochemical/materials laboratory and the life sciences laboratory was added in the years 2002-2004 because these modules were emplaced earlier than in the CNDB.

7. Deployment of the Farside astronomical payloads (UV Telescope and SETI) was postponed three years (until 2003) to redirect a manned servicing mission and another possible manned deployment mission to lunar base missions. The CNDB had apparently designated manned farside missions which seemed more appropriate for later in a scenario when the lunar base has some capability to directly service these payloads (depending on distance). The current scenario assumes these farside science missions take place independantly from lunar base activities, and are capable of remote deployment.

Mobility

1. An unpressurized rover was delivered 5 years earlier (1999 vs. 2004). The CNDB had only 1 unpressurized rover for a four man crew until 2004. Rover weight estimate was dropped substantially from the CNDB estimate of 4,000 kg based on Apollo Lunar Rover weights of just over 200 kg (13). This weight savings allowed manifesting of additional materials needed to bury the radiation shelter.

2. The CNDB pressurized soil mover was remanifested as a teleoperated unpressurized prime mover with attachments and attachment change fixture (Construction vehicles are described in more detail in Section 5.5). The mass of the prime mover, trailer, cart, and crane was kept constant with the total mass of the equivalent CNDB system.

3. A bulkhead and hopper/conveyor system was added to payloads delivered in 2000. These elements are required for one option studied to bury a module for radiation protection (Section 5.5).

4. A light-weight, unpressurized storage shed was added as a place to store the prime mover attachments, to allow a protected (from thermal cycling, UV radiation, dust carried by nearby operations, etc.) area for storage of all surface vehicles, and to provide a source for utility outlets to recharge vehicle fuel cell systems.

5. Two pressurized rovers were delivered in 2002 (instead of one pressurized rover delivered in 2007 as called for in the CNDB). Two pressurized rovers, each carrying one crew person (and an EMU) but capable of carrying two, were considered essential. In the event of failure of one rover during a long traverse away from base, the affected person would don their EMU suit and transfer to the redundant rover. Or alternatively, the other rover (w/ capacity for 4) could traverse out and pick up

the stranded crew. Rover masses were based on estimates for pressurized rovers studied as part of a recent Mars systems study (25).

Surface Elements

1. Two radiator systems were added to provide thermal control of the pressurized modules (especially since the CNDB assumed all modules would be covered). Masses were derived from Space Station data (6,9).

2. The advanced power plant was postponed a year (until 2004) because lunar oxygen production was also postponed a year.

Pressurized Modules

1. A covered radiation shelter was added. Size and weight is comparable to a standard pressurized logistics module (6,9,26). The radiation shelter was considered essential for extending crew stay durations beyond 8 days.

2. Emplacement of a Module Interface Node was moved up a year (from 2003 to 2002) to allow earlier build-up of the pressurized module set.

3. Two airlocks were added. The CNDB claimed the interface node acted as both a berthing fixture and airlock. However, this is contrary to Space Station design which requires the interface node volume for resource storage as well as to contain data management and control workstations for the station (6-9). With the expected greater requirements of a lunar airlock system in controlling dust, including an airlock (and redundant system) seemed justified. The weights were derived for completely loaded station airlocks (including EMUs and EVA tools) (Ref. 27).

4. Habitation module was moved up a year (2001 from 2002) to allow earlier transition to 24 day surface stays.

5. The Geochemical materials laboratory was emplaced 2 years earlier (2001 from 2003) to allow earlier Lunar planetary science. This was in partial response to science objectives raised in another study (14).

6. One of the two life science research laboratories was emplaced 3 years earlier (2002 from 2005) to carry-out research on the long-term effects of low gravity on plant, animal, and human physiology. Data derived from low gravity life science research is needed to allow additional extensions of human stay times and may influence designs of interplanetary spacecraft.

7. A pressurized garage was added to allow ingress and egress from the pressurized rovers without donning a suit and to allow maintenance and consumable resupply in a shirt-sleeve environment.

8. A Logistics module was added to the pressurized module set to reduce the logistics requirements carried on each mission and to provide enough of a supply buffer in case of logistics disruption. Exchanging logistics modules once a year or so would follow Space Station logistics philosophy and could possibly benefit from commonality with S/S systems.

Resource Facilities

1. All resource facilities (pilot plant, production plant, mining equipment) were postponed a year to allow earlier emplacement of the modules and systems required for transitioning to longer crew stay times.

2. A large oxygen production plant (massing 100k lb) was not emplaced. This plant produces enough oxygen for a reusable lunar lander and orbital transfer vehicles. Instead, this study's scenario calls for emplacing about a third of this plant to provide oxygen for the reusable lunar lander. Then, and only after economic viability is reasonably assured, emplacing a larger production plant and orbital refueling facilities to supply oxygen for OTV's and the LEO market. Past studies have indicated that serving a LEO market with lunar oxygen may not be economically justifiable depending on actual production and launch costs (23,24). Therefore, a more gradual approach to utilizing lunar oxygen is indicated.

3. A lunar orbital propellant depot is not needed until oxygen loading for OTV's is considered economical. However, surface refueling facilities (a loading area and "thermos bottle" truck) are required.

Landing/Launch Facilities

1. Landing instrumentation and landing lights are included. They are needed to ensure accurate landings, reduce mission risks, and allow for night landings/launches and cargo handling operations.

2. A contingency ascent vehicle is delivered in 2000, after which, the lunar crew can always count on a way to lunar orbit if their primary ascent vehicle fails to ignite or is unusable due to other problems. This lander does not sit idle. Typically the crew would leave in the ascent vehicle left by the previous crew while the lander they arrived in would be left for the next crew.

4.2.2 Mission Manifest

A summary of the manned and unmanned missions for the scenario used in this study is given in Table 4-4. As in the CNDB scenario, one manned mission lands in the first year (1999) to survey the proposed base site. Unlike the CNDB, this mission prepares landing sites for the next missions and leaves behind an unpressurized rover.

During the second year (2000), two unmanned landers deliver construction and cargo handling equipment, a solar flare shelter, power and thermal control systems, and a communications relay station. Both manned landings in this scenario are to the lunar base where they begin the base assembly sequence by emplacing and covering the solar flare shelter. A spare ascent vehicle is also delivered in 2000 for contingency purposes.

Three unmanned and three manned missions in 2001 emplace a module interface node, airlock, habitation module, a geochemical laboratory, and additional power systems. Crew stay times are extended to 24 days. Low-level lunar planetary science is carried out by deploying a geophysical station near the base, and by conducting a similar unmanned science mission to another lunar site.

In 2002, more ambitious science and resource experiments are initiated after a oxygen pilot plant, life science research laboratory, and optical interferometer are delivered. In addition, the lunar base grows by another module interface node, airlock, and pressurized garage. Crew mobility capability is greatly expanded after two pressurized rovers are landed. A total of 8 missions (4 unmanned) comprise the heaviest launch rate scheduled in the Phase II period. In addition, another dedicated, unmanned geophysical station is landed at a remote lunar site.

In 2003, only one cargo lander to the lunar base delivers equipment necessary to begin crater dating traverses and deep drilling experiments. A life science research node (module interface node connecting two life science modules) is emplaced. The four manned landings to the base continue a variety of scientific endeavors in lunar geoscience, low gravity materials research, astronomy, and life science. Three unmanned missions to the farside deploy a UV telescope, SETI radio astronomy observatory, and a geophysical network station. A second communications relay satellite is launched into halo orbit about the Earth/Moon L2 libration point (joining the satellite launched there in 1994) to handle increased data load from the farside science missions.

Three cargo missions in 2004 land an advanced power plant, oxygen mining equipment, and an oxygen production plant. Four manned missions are also carried out.

The pressurized module "racetrack" is completed after cargo deliveries in 2005 of a module interface node, logistics module, and the second life sciences research laboratory. Stay times for the four manned landings have increased up to 180 days by 2005, representing the beginning of a permanently manned base. A tank car and liquid oxygen loading facilities are delivered and oxygen production/refueling capability is demonstrated prior to delivery of the first reusable lander in 2006.

Table 4-5 lists the payloads delivered to the surface, while Figure 4-1 shows a schematic representation of basically the same information. A complete list of each mission's payload manifest is given in Appendix B. Payload definitions are in Appendix C.

Table 4-3. Similarities between the Scenario used in this Study and the CNDB Scenario

1. **Timing.** Both scenarios have a 5 year man-tended period leading to a permanently manned Lunar base.

2. **Base Character.** Single, fixed base with limited mobility (rovers) from base.

3. **Modules.** Same basic 4 module/4 node set delivered in 5 year period. Modules remain: Habitat, Geoscience & Materials Lab, and two Life Sciences Labs.

4. **Science.** <u>All</u> science in CNDB (field geology, deep drilling, optical interferometer, farside UV telescope, and farside SETI) is also in alternative scenario. Alternative <u>adds</u> science missions, <u>doesn't</u> take any science away.

5. **Landers.** Both scenarios assume 1 basic type of lander for delivering cargo and crew to Lunar base. Expendable lander/ascent vehicle used during first 6 years, then switch to reusable lander using Lunar produced oxygen after Lunar LOX plant startup.

6. **Crew.** Both scenarios have the same number of manned missions to the Lunar surface, size of crew, and surface duration (exception: in 2001 for the alternative scenario, mission duration and surface stays are extended to 30 & 24 days, respectively, after habitat module is emplaced, instead of 2002 for the CNDB).

Year:	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Number of Manned Missions:	1	2	3	4	4	4	4
Size of Crew:	4	4	4	4	4	4	4
Duration of Mission, days:	14	14	14/30	30	30	30	180
Duration of Surface Stay, days:	8	8	8/24	24	24	24	180

Table 4-4. Summary of Alternative Phase II Lunar Base Missions

Year	Mission Type	Lander Type	Number of Missions	Manned Surface Stay, days	Destination
1999	Unmanned	Dedicated	1		Lunar Base
	Manned	Std. Expended	1	8	Lunar Base
2000	Unmanned	Std. Expended	3		Lunar Base
	Manned	Std. Expended	2	8	Lunar Base
2001	Unmanned	Dedicated	1		Polar Region
	Unmanned	Std. Expended	3		Lunar Base
	Manned	Std. Expended	1	8	Lunar Base
	Manned	Std. Expended	2	24	Lunar Base
2002	Unmanned	Dedicated	1		Near Side
	Unmanned	Std. Expended	4		Lunar Base
	Manned	Std. Expended	4	24	Lunar Base
2003	Unmanned	Dedicated	1		L2 Libration
	Unmanned	Dedicated	1		Farside
	Unmanned	Std. Expended	2		Farside
	Unmanned	Std. Expended	1		Lunar Base
	Manned	Std. Expended	4	24	Lunar Base
2004	Unmanned	Std. Expended	3		Lunar Base
	Manned	Std. Expended	4	24	Lunar Base
2005	Unmanned	Dedicated	1		L1 Libration
	Unmanned	Std. Expended	3		Lunar Base
	Manned	Std. Expended	4	180	Lunar Base
SUBTOT.	Unmanned	Dedicated	2		L1 & L2 Libration
	Unmanned	Dedicated	3		Polar,NS,FS
	Unmanned	Dedicated	1		Lunar Base
	Unmanned	Std. Expended	2		Farside
	Unmanned	Std. Expended	17		Lunar Base
	TOTAL UNMANNED		25		
	Manned	Std. Expended	4	8	Lunar Base
	Manned	Std. Expended	14	24	Lunar Base
	Manned	Std. Expended	4	180	Lunar Base
	TOTAL MANNED		22	Man-days = 4352 (4 man crew)	

Table 4-5. Alternative Scenario Surface Elements by Jan.1, 2006

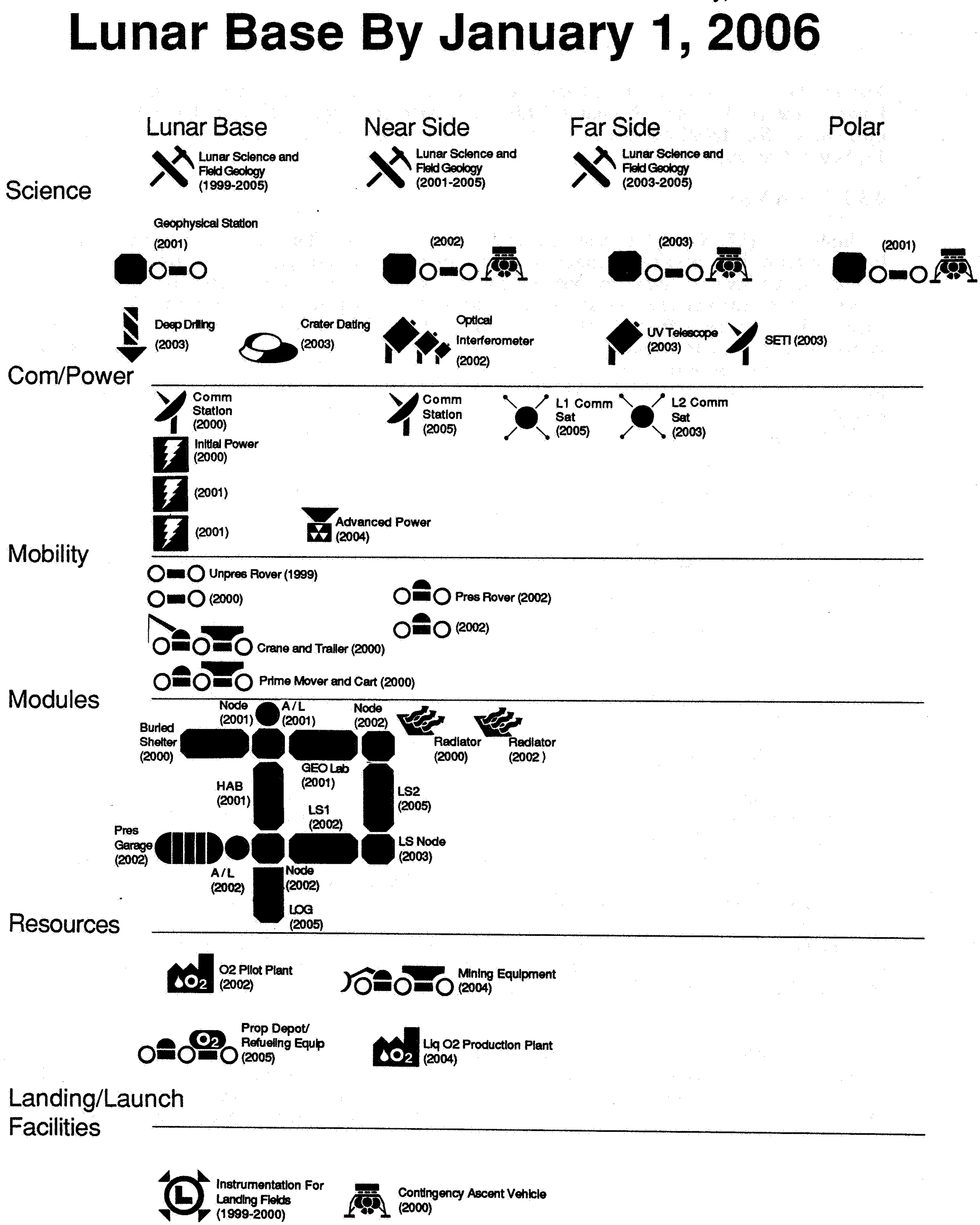
Science		Mass (lbm/ea)	Year(s) Landed
1.	(2) Surface Penetrator Networks	4,400	1996,1997
2.	(2) Polar Sample Returns	8,800	1996,1997
3.	(3) Unmanned Surface Surveying Rovers	2,200	1997-1999
4.	(22) Lunar Science & Field Geology	500	1999-2005
5.	(4) Geophysical Research Stations	8,000	2001-2003
6.	Optical Interferometer Telescope	15,000	2002
7.	Deep Drilling	4,000	2003
8.	Crater Dating	1,000	2003
9.	(4) Service Geochemical/Materials Lab.	500	2002-2005
10.	(3) Service Life Sciences Lab.	500	2003-2005
11.	Farside UV Telescope	10,000	2003
12.	Farside SETI	20,000	2003
Mobility			
1.	(2) Unpressurized Rovers	1,000	1999,2000
2.	Teleoperated Unpressurized Prime Mover, Attachments, Crane w/ trailer	38,500	2000
3.	Bulkheads, Hopper/Conveyor System	3,000	2000
4.	Unpressurized Storage Shed	2,000	2000
5.	(2) Pressurized Rovers	4,180	2002
Communications, Power, Thermal Control			
1.	(2) Radiator Systems	3,400	2000,2002
2.	(3) Initial Power Plant	7,000	2000,(2)2001
3.	Advanced Power Plant	38,500	2004
4.	(2) Communications Relay Station	2,500	2000,2005
Pressurized Modules			
1.	Radiation Shelter (Covered)	20,000	2000
2.	(3) Module Interface Nodes	8,200	2001,2002,2005
3.	(2) Airlocks	6,800	2001,2002
4.	Habitation Module	38,500	2001
5.	Geochemical/Materials Laboratory	38,500	2001
6.	(2) Life Science Research Laboratory	40,000	2002,2005
7.	Pressurized Garage	15,000	2002
8.	Life Science Research Node	8,200	2005
9.	Logistics Module	19,220	2005
Resource Facilities			
1.	Liquid Oxygen Pilot Plant	38,500	2002
2.	Oxygen Mining Equipment	38,500	2004
3.	(1) Liquid Oxygen Production Plant	33,333	2004
4.	Propellant Refueling Facilities	38,500	2005

Table 4-5 (Cont). Alternative Scenario Surface Elements by Jan.1, 2006

Landing/Launch Facilities

1.	(2) Landing Instrumentation/Beacons	2,000	1999,2000
2.	Contingency Ascent Vehicle	16,275	2000

Figure 4-1. Surface Infrastructure At End of Phase II
(Note: Date Landed is Indicated Parenthetically)



4.3 Site Sensitivity on Surface Operations

The location of the base site affects surface operations in several areas: Communications, Power, Science Missions, Resource Utilization, Module Emplacement, and Landing/Launch operations. Site locations to be considered for this study are (Ref. 1): Lacus Veris, Apollo 17, South Pole, and Mare Nubium.

4.3.1 Lacus Veris

A limb site (87.5W, 13S) near Orientale, Lacus Veris offers unique opportunities for lunar science but presents certain surface operations challenges. The rotation of the Moon on its axis is uniform but its angular velocity around its orbit is not since it moves faster near perigee and slower near apogee. This permits as much as 7.75° around each limb to be seen from Earth in a month (28, p.327), although the maximum amount varies from month to month (29). Because of the apparent libration of the Moon as it revolves about the Earth, the Earth as seen from Lacus Veris is below the horizon for as long as 10 days of the lunar synodic month (29.53 days), and out of direct line-of-sight communications. Either communications relay stations or communications satellites (or both) will be required for a Lacus Veris base to maintain an uninterrupted communications link with Earth.

With a 29.6 km/degree of longitude distance at 13S latitude, a communications relay station would have to be 155 km due East from the base at 87.5W to always be in line-of-sight with Earth (assuming a spherical Moon). This is too far to string cable or for an unpressurized rover traverse early in a base buildup phase. A communications tower at the base or a local high point would have to be over 7,000 m (4.5 miles) high to be in Earth communications continuously. However, the mass of a given height tower on the Moon could probably be substantially reduced from the mass of an equivalent height Earth tower due to the gravity difference.

Communications satellites seem the best alternative. However, the Earth/Moon Libration points at L1 and L2 are both below the lunar horizon for at least part of the month (there is always a 3.3° gap between coverage of a pair of satellites right at L1 and L2 that Lacus Veris turns through). Halo satellites in orbit about L1 and L2 are a possibility, but multiple satellites will be required to maintain constant communications (and two more are needed if an extra one at each location is required for contingency backup). A satellite at the L4 libration point is always in sight of both Earth and Lacus Veris. However, the Earth/Moon round-trip communication time from an L4 satellite doubles to over 5 sec from the normal Earth/Moon delay time of nearly 3 seconds (because L4 is as far from the Moon as Earth is). Although lunar surface-to-surface communications will utilize communications towers near the base, some far-ranging traverses or traverses in mountainous regions will require communicating through the satellite net or Earth. Communicating through the longer distance to an L4 satellite will place a greater design burden on sender or receiver systems, or both. The special problems for communications at a limb site base deserve additional study.

Farside access from Lacus Veris is simple; it is on the farside for part of the month. This is a real advantage for science experiments that require farside access (several astronomical observatories), especially if they do not require it continuously. A typical farside science scenario might call for locating the experiment to the West of the base to maximize farside time (it is over 300 km to always farside from Lacus Veris), operating at full capability storing data until Earth rise, than transmitting stored data and shutting down or degrading operation until Earth set.

The Lacus Veris landing site is located on a Mare region; however, the limited resolution of the available imagery is not suitable for the subtle distinction between the more heavily cratered older mare and the less cratered younger mare (15). Because a Lacus Veris base would be sited on a Mare region, it would be a good candidate site for oxygen extraction from ilmenite, and it is reasonably flat site providing few terminal launch/landing difficulties. Launch/Landing window sensitivities are being worked by a parallel transportation issues study.

The thickness of soils in Mare regions are typically much thinner than highland soils, extending only 2 to 5 meters before hitting bedrock (11, 14). This is important when considering the best way to provide radiation protection for a module, and whether to bury the module in a hole or to cover it over. Obviously, digging into bedrock would be a time consuming activity, thus mitigating against strategies calling for digging holes deeper than 2-5 m in mare regions unless soil depths and subsurface structure are known.

4.3.2 Taurus Littrow - Apollo 17

The Apollo 17 landing site is obviously well characterized. The landing site was in a flat mare floored valley with average slopes of 5-7° while the slopes of the flanking North and South Massif have slopes of 20-30°. Success of Apollo 17 indicates that landing approaches over mountainous terrain is possible. A Taurus Littrow site in a Mare region would make it a good source of ilmenite for oxygen production. Farside access would be far more difficult from a base site located near the Apollo 17 landing site (~2000 km away) than from Lacus Veris or the south pole.

4.3.3 South Pole

Poor imagery exists for the South Pole, but indications are that it is in a extremely rugged highlands region. This, in addition to a very low (1.5° or less) sun angle, will make both site selection and visual landing design particularly challenging.

However, a south pole site would have all sorts of favorable advantages in other areas (30). Because areas of the polar regions are in constant shade, water ice and other volatiles may have been trapped and could be found a short distance beneath the surface. This would provide a bonanza for lunar base development. In addition, certain polar areas are in nearly perpetual sunshine allowing the possibility of constant use of photovoltaic arrays and the attendant power system savings (by reduced power storage system requirements and smaller array sizes). Certain astronomical experiments such as cryogenic telescopes could take advantage of a location in continuous darkness to view continuously while requiring little servicing of lost cryogenics.

If highland soils predominate in the south polar region, production of oxygen from ilmenite will be less feasible. Water ice, found in quantity, will obviate this concern.

Since the terminator is always present in the polar regions, small particles that are associated with the terminator and which move a few meters above the surface in electrostatic suspension may always be present. This could be a problem if they coated sensitive scientific equipment such as optics, or thermal control surfaces. However, with a constant low sun angle and possible permanently shadowed areas, heat rejection will be easier than from a equatorial site.

4.3.4 Mare Nubium

A Nubium landing site is in an area of fairly young mare basalts, making oxygen production from ilmenite a good candidate. The surface conditions of the landing site would be similar to the near by Apollo 12 site (15). As with an Apollo 17 base site, farside access from the base is difficult due to the distance involved (2400 km away).

4.4 Permanently Manned Base

Continued emphasis on science, resource development, and expanding human presence and capabilities will play predominate roles during permanently manned lunar base operations. Additional major lunar astronomy missions are anticipated, such as a low frequency radio array and radio interferometer. Ambitious, long-range manned surface traverses are possible. The required lunar base crew size will be determined largely by the servicing requirements for on-going scientific experiments and observatories.

Servicing and refueling landers with lunar derived oxygen will reduce Earth launch requirements. Lunar resource utilization would be expanded as experience in lunar surface operations builds confidence, and as economics are better understood. Expansion of lunar oxygen production to provide propellant for Earth/Moon Orbital Transfer Vehicles and for manned Mars missions is possible. Another potential resource field is in producing qualified ceramics and ceramic composites from lunar derived materials for construction materials.

An early major goal in the permanently manned phase is to provide radiation protection for larger areas of pressurized volume while still leaving uncovered berthing areas to allow further expansion of the base.

A list of missions for the first 5 years in Phase III is given in Appendix B-2.

5.0 Lunar Base Operations

Mission operations and the available crew time for these operations are defined in the following two sections. The next sections describe lunar base operations in support of EVA, launch/landing operations, construction and assembly, science and resource utilization, and maintenance and resupply.

5.1 Mission Operations

The surface operations assigned to each of the manned missions for the Phase II base (see Appendix B) are listed below. Because there are often many options for performing a given requirement, an effort was made to generalize the operations. However, in some cases a single option is assumed. For instance, the operation to emplace a base solar flare shelter is described as using a bulkhead to minimize the amount of soil required, although as given in Section 5.5, other methods to provide soil overburden for habitat radiation protection include 1) putting a module at the bottom of a hole and backfilling, 2) covering a module emplaced on the surface by piling soil over the module, 3) covering the module with sandbags filled with regolith, 4) piling bricks made from hot-pressed soil materials around the module, 5) winching blankets filled with soil over the module, 6) utilizing carefully directed shaped explosive charges to blow material over the module. For each of these, the quantity of soil moved, surface operations, and labor will vary. These operations, however, were selected as the baseline operations for this particular scenario.

<u>Year 1999</u>

Mission 2 (4 crew, 8 day surface stay)

1. Flight certification of manned Earth-Moon transportation systems in first manned landing since Apollo. Navigation aids emplaced or carried by the unmanned rover of the previous mission could assist landing by the manned lander on the selected base site.
2. Make a manned on-site evaluation of the optimum base location.
3. Survey and mark locations for major surface elements (modules, power, communications).
4. Collect surface samples with the Lunar science/field geology equipment/tool package carried on the lander.
5. Select and prepare <u>two</u> landing sites for the following missions. The landing instrumentation/beacon package would include electronic navigational aids.

The crew would use an unpressurized rover for surface exploration and sampling, and perhaps to assist in landing site preparation if it was outfitted with a light weight bulldozer blade. Finding and marking two flat clear areas will probably be enough; in which case, a rover pulling a blade and going around in circles would be able to mark the landing spot. The rover would remain on the surface near the prepared landing sites.

<u>Year 2000</u>

Mission 4 (4 crew, 8 day surface stay)

1. Lands on site selected/prepared in the previous manned mission (other occupied by unmanned mission 3 lander).
2. Unload the crane from the mission 3 lander.

3. Use the crane to unload other equipment: crane cargo carrier (trailer), prime mover (PM), PM attachments, PM cart (soil carrier - dumpable), fixture to store and exchange PM attachments.
4. Check out equipment construction.
5. Begin preparation of the site selected for the pressurized modules: Earth teleoperation of PM, EVA during final site grading/leveling, Lunar teleoperation of utility trenching operations.
6. Monitor start of excavation of shallow trenches for emplacing modules.
7. Prepare landing sites for next two missions. Landing site preparations could involve preparing permanent sites (4 needed at least) or selecting new landing sites suitably spaced from each other. The launch/landing pads would require navigational aids such as radar transponders and lighting. The lights would assist manned vehicles visually locate the landing sites in the event of failure of electronic navigational aids, allow manned night landings/launches, and allow night unloading of cargo. Preparation of permanent pads could involve construction of a blast shield/wall of local materials using the prime mover through teleoperation from Earth.
8. Collect additional surface & subsurface samples for analysis back at Earth that will lead to selection of the optimum site for collecting feedstock material for an oxygen extraction pilot plant and full scale processing plant.
9. Recharge or replace all vehicle fuel cells before departure. May need to provide protective shelter for thermal control during lunar night. Leave rovers near landing site (but protected from descent engine exhaust) for next crew.

Mission 6 (4 crew, 8 day surface stay)

1. Land on landing site prepared by the previous manned crew. Recover unpressurized rovers and checkout systems.
2. Unload the unmanned lander from Mission 5. Crane setup may be the biggest part of this job.
3. Finish installing utility-ways to complete module site preparation.
4. Begin preparations to bury/cover module for radiation protection from solar flares: setup bulkheads around shallow trench dug on previous mission (and by teleoperation), emplace the solar flare shelter and tunnels, complete bulkhead construction, and position hopper/conveyor system, monitor teleoperation of Prime Mover loading hopper with soil and conveyed over/into bulkhead. Connect all utility interfaces with the shelter (through berthing ring of tunnels).
5. Setup/checkout the initial power plant (photovoltaic arrays) and distribution system.
6. Emplace the thermal control system (radiator, sun screens, and control systems) and connect interfaces with module site and solar flare shelter.
7. Setup/checkout the communications relay station.
8. Prepare landing sites for next three missions by either removing spent descent stages from permanent landing sites or selecting and preparing new sites. Three sites are needed for manned, cargo, and delivery of contingency ascent vehicle missions.
9. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle by plugging into base power system).

Year 2001

Mission 9 (4 crew, 8 day surface stay)

1. Checkout the powered-up safe haven systems (completely covered by teleoperated PM & hopper/conveyor system prior to arrival). Access shelter through pre-emplaced tunnels through the overburden.
2. Unload the Mission 8 lander.
3. Berth the module interface node to the tunnel connecting the solar flare shelter and the airlock to the node.
4. Connect utility interfaces to the modules (through an unused node berthing port and a redundant path through the alternative tunnel into the buried solar flare shelter).
5. Setup and checkout two more initial power systems.
6. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to Earth.
7. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
8. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 11 (4 crew, 24 day surface stay)

1. Unload the Mission 10 lander.
2. Berth the habitation module to the interface node emplaced in Mission 9. The habitat forms the core of the man-tended and permanently manned base. It contains the primary ECLSS system while other modules will contain safe haven consumables stored in the event of an emergency. After the module is emplaced, utilities connected, and systems checked out, the Lunar base can be declared a functioning man-tended base and crew stay times extended to a full Lunar day.
3. Conduct geological research studies and transport the geophysical station delivered in Mission 8 by unpressurized rover to a local site. The geophysical experiment package is designed to map density variations and the seismic, magnetic, and electrical properties of the subsurface. Portable seismometers and a number of explosive packages will be required, as well as portable magnetometers and gravimeters. A remotely controlled rover will be necessary to help emplace the explosive charges in the 10-100 km range from the seismic arrays to provide the active seismic sources for each deep profiling experiment.
4. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to Earth.
5. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
6. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 13 (4 crew, 24 day surface stay)

1. Unload the Mission 12 lander.
2. Berth the geochemistry materials laboratory to the other end of the module interface node emplaced in Mission 9.

3. Connect services/utilities interfaces and thoroughly checkout all on-board systems and scientific equipment.
4. Preventive maintenance, resupply, and logistics tasks.
5. Additional Lunar exploration and sample collection trips can be accomplished with the unpressurized rovers. The specific purpose of these geology trips will be to determine the optimum mining locations for excavating feedstock material for the lunar oxygen pilot plant.
6. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
7. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Year 2002

Mission 16 (4 crew, 24 day surface stay)

1. Unload the mission 15 lander.
2. Setup the pilot oxygen plant, checkout the system.
3. Monitor initial teleoperated operation: excavation of feedstock material with the Prime Mover, plant startup, correct system problems as required, allow pilot to remain up and teleoperated from Earth.
4. While the crew is on the surface, the geochemical laboratory can be used to support pilot plant startup and operation by analyzing samples retrieved from process flow streams to verify automatic analytical techniques and trouble shoot startup problems. The pilot plant should be located near the base, or attached to it, to allow easy access by the crew for correcting process difficulties.
5. Preventive maintenance, resupply, and logistics tasks.
6. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
7. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
8. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 18 (4 crew, 24 day surface stay)

1. Offload Mission 17 lander.
2. Berth an interface node to the habitation module.
3. Berth an airlock to the module interface node.
4. Emplace an additional radiator and interface into the thermal control system
5. Service the geochemical materials laboratory with fluids, experiment changeout, and return of any lunar manufactured materials.
6. Preventive maintenance, resupply, and logistics tasks.
7. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
8. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.

9. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 20 (4 crew, 24 day surface stay)

1. Offload the Mission 19 lander.
2. Emplace the first life science facility (berthed to the interface node emplaced on Mission 18). The plant and animal experiments begun during this mission will be remotely monitored from Earth after departure of this crew.
3. Preventive maintenance, resupply, and logistics tasks.
4. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
5. Continue research in geochemical and materials processing laboratory.
6. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
7. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 22 (4 crew, 24 day surface stay)

1. Offload the Mission 21 lander.
2. Berth the pressurized garage to the airlock landed in Mission 17, connect services/-utility interfaces to the pressurized garage.
3. Checkout pressurized rovers.
4. Checkout optical telescope components. Manned traverses are required to survey, select, and prepare locations for the 28 optical interferometry elements (27 scopes and central station). The optical interferometer telescope should be placed some distance (several km's) from the base to avoid contamination from base and landing pad operations. Contamination includes both physical (rocket exhaust, dust, etc.) and optical (lights, etc.) products. The optical interferometer is a Y-shaped array of 27 telescopes with each arm 6 km long and the maximum baseline being 10 km. Due to its size and distance from the base, the pressurized rovers are needed to facilitate emplacing the optical interferometer.
5. Preventive maintenance, resupply, and logistics tasks.
6. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
7. Continue research in geochemical and materials processing laboratory.
8. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
9. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

<u>Year 2003</u>

Mission 26 (4 crew, 24 day surface stay)

1. Offload the Mission 25 lander.

2. Berth the life science research node to the end of first life science module delivered on Mission 19.
3. Emphasis on this mission is Lunar planetary science. Using pressurized rovers, the crew will collect samples to allow accurate dating of a number of local craters. Longer traverses (up to 400 km round-trip will be required on this or later missions).
4. Activate the deep drilling experiment for drilling to approximately a kilometer in depth to acquire Lunar core samples and to collect volatile release data during the drilling.
5. Preventive maintenance, resupply, and logistics tasks.
6. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
7. Continue research in geochemical and materials processing laboratory.
8. Prepare landing site for next mission by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new site.
9. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 30 (4 crew, 24 day surface stay)

1. Continue science applications experiments in Lunar planetology, life sciences, material sciences, and Lunar resource development.
2. Additional effort required for crater dating and deep drilling.
3. Preventive maintenance, resupply, and logistics tasks.
4. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
5. Continue research in geochemical and materials processing laboratory.
6. Prepare landing site for next mission by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new site.
7. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 31 (4 crew, 24 day surface stay)

1. Continue science applications experiments in Lunar planetology, life sciences, material sciences, and Lunar resource development.
2. Additional effort required for crater dating and deep drilling.
3. Preventive maintenance, resupply, and logistics tasks.
4. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
5. Continue research in geochemical and materials processing laboratory.
6. Prepare landing site for next mission by either removing spent descent stage from permanent landing site (and transporting it to a discarded equipment storage area) or selecting and preparing new site.
7. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 32 (4 crew, 24 day surface stay)

1. Continue science applications experiments in Lunar planetology, life sciences, material sciences, and Lunar resource development.
2. Additional effort required for crater dating and deep drilling.
3. Preventive maintenance, resupply, and logistics tasks.
4. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
5. Continue research in geochemical and materials processing laboratory.
6. Prepare landing sites for next two missions by either removing spent descent stage from permanent landing site (and transporting it to a discarded equipment storage area) or selecting and preparing new sites.
7. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Year 2004

Mission 34 (4 crew, 24 day surface stay)

1. Offload the nuclear power plant from the previous unmanned lander.
2. Emplace reactor at a remote location from the base's pressurized modules, connect interfaces to the power distribution system, perform system checks, and startup the system. The high voltage power line from the reactor will require installation on poles or buried.
3. Preventive maintenance, resupply, and logistics tasks.
4. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
5. Continue research in geochemical and materials processing laboratory.
6. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
7. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 36 (4 crew, 24 day surface stay)

1. Unload oxygen mining equipment (primarily mining vehicles, loaders, and haulers) from the previous mission's unmanned lander.
2. Checkout the vehicle systems.
3. Begin preliminary mining operations to acquire a stockpile of feedstock material prior to the arrival of the primary oxygen extraction facility.
4. Service Geochemical Materials Lab.
5. Preventive maintenance, resupply, and logistics tasks.
6. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
7. Continue research in geochemical and materials processing laboratory.
8. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.

9. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 38 (4 crew, 24 day surface stay)

1. Unload the oxygen production plant from Mission 37 lander.
2. Emplace plant at location in protected area near the landing field.
3. Checkout systems prior to startup, startup the plant, and correct startup operational problems.
4. Service Life Science Facility.
5. Preventive maintenance, resupply, and logistics tasks.
6. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
7. Continue research in geochemical and materials processing laboratory.
8. Prepare landing site for next mission by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new site.
9. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 39 (4 crew, 24 day surface stay)

1. Continue previous manned efforts in developing the first full-scale Lunar resource utilization project, as well as science applications experiments in Lunar planetology, life sciences, and material sciences activities.
2. Preventive maintenance, resupply, and logistics tasks.
3. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
4. Continue research in geochemical and materials processing laboratory.
5. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
6. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

<u>Year 2005</u>

Mission 42 (4 crew, 180 day surface stay)

This mission represents the beginning of a permanently manned Lunar base. Crew stay times extend to a half year and the base population grows after the next manned mission to 8 personnel.

1. Unload the previous mission's unmanned lander.
2. Deploy a second communications relay station.
3. Berth a module interface node and a logistics module in the pressurized module complex.
4. Preventive maintenance, resupply, and logistics tasks.
5. Continue lunar science and field geology exploration using the unpressurized rovers,

collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.

6. Continue research and technology applications experiments in geochemical and materials processing laboratory.
7. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
8. Begin preparation of landing/launch site for Reusable Lander.
9. Recharge regenerative fuel cells on surface vehicles.

Mission 44 (4 crew, 180 day surface stay)

1. Offload the previous unmanned lander of a liquid oxygen tank truck and oxygen refueling facilities.
2. Install propellant depot/refueling facility in a location close to the landing pads near the full-scale oxygen production plant. This facility is needed to load liquid oxygen into the reusable Lunar lander that begins operation in 2006.
3. Continue startup operation of Oxygen production plant.
4. Service Geochemical Materials Lab.
5. Preventive maintenance, resupply, and logistics tasks.
6. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
7. Continue research and technology applications experiments in geochemical and materials processing laboratory.
8. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
9. Continue preparation of Reusable Lander landing/launch site.
10. Recharge regenerative fuel cells on surface vehicles.

Mission 46 (4 crew, 180 day surface stay)

1. Unload the second life science research facility, and the last module in the first quad of pressurized modules, from the Mission 45 unmanned lander.
2. Install to complete the race track pattern.
3. Continue startup activities on oxygen production plant.
4. Service Life Science Facility.
5. Preventive maintenance, resupply, and logistics tasks.
6. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
7. Continue research and technology applications experiments in geochemical and materials processing laboratory.
8. Prepare landing site for next mission by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new site.
9. Recharge regenerative fuel cells on surface vehicles.

Mission 47 (4 crew, 180 day surface stay)

1. Continue oxygen production plant operation.

2. Preventive maintenance, resupply, and logistics tasks.
3. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
4. Continue research and technology applications experiments in geochemical and materials processing laboratory.
5. Continue preparation of Reusable Lander landing/launch site.
6. Recharge regenerative fuel cells on surface vehicles.

5.2 Base Crew

The scenario described in Section 4 formed the basis of determining available crew time for surface operations. A crew size of 4 was used for all manned landings. As given in Table 4-3, the 4 earliest manned missions stay 8 days on the surface (1 in 1999, 2 in 2000, 1 in 2001), 14 missions are for a 24 day stay (2 in 2001, 4 each in 2002, 2003, and 2004), and 4 missions have a 180 day surface stay (all in 2005).

5.2.1 Character of Surface Stays

Operations are carried out from the Manned Module attached to the ascent stage during the period before a habitation module, solar flare shelter, and the necessary supporting equipment is emplaced. A baseline assumption constrains surface stays to 8 days for this mode of operation. These missions resemble Apollo Lunar Module operations and by similarity, ground support from Earth for systems monitoring and management is expected to be large. Extensive crew training will be required as operations will in many cases be new. Crew schedules will be full and tight with little room for real-time operations planning by the crew. Crew time, especially EVA, is the premium resource to be applied directly toward operations that will result in longer stay times.

After the habitation module and supporting systems are emplaced and operational, the base becomes the center of crew operations and stay times are initially extended through the complete lunar day/night cycle. Base operations will evolve into a mode resembling Space Station, with greater responsibility for systems monitoring/management placed on the lunar base, and a majority of crew efforts devoted to science objectives.

5.2.2 Scheduling Guidelines

Time allocations were made for crew work and non-work activities based on previously developed manned spaceflight crew scheduling constraint guidelines (22). Because the time allocations for sleep, personal hygiene, meals, rest/recreation, health maintenance and physical excercise directly effect the available work time, such allocations must be established early in operations planning/mission scheduling. Time allocated to non-work crew activities remains essentially independent of crew surface stay length. The following guidelines were established for this study from recognized spaceflight crew planning standards (22).

1. The <u>workday cycle</u> shall be limited to 22.5 to 26 hours.

The daily cycle is approximately 24 hours in duration. The wake up time is defined from Earth or space station awake time on the day of departure and adjusted for arrival to and departure from the lunar surface.

2. The <u>standard awake duration</u> is 16 hours.

For the nominal workday on the lunar surface, the standard awake time will be 16 hours duration. The minimum awake time is 14 hours duration. The maximum awake time is 18 hours duration.

3. The <u>sleep cycle</u> can be <u>shifted</u> a maximum of 1.5 hours per cycle or 6 hours per 8 days.

The workday cycle may be adjusted for lunar arrival or departure to occur at the beginning or middle of a crew workday cycle. To achieve this, the sleep start time can be shifted earlier 6 hours maximum for an 8 day lunar stay (14 day mission) and shifted later 8 hours maximum for an 8 day lunar stay (14 day mission). It can not shift earlier more than 1.5 hours or later more than 2 hours in one sleep cycle.

4. Pre-departure activities (inspection, power-up, systems checks, etc.) consume 3 hours the day before departure and 4 hours the day of departure.

All crew persons participate in configuring the module and ascent vehicle for departure. Three (3) hours are required the day before departure to configure equipment, verify systems and review procedures. Four (4) hours are required the day of departure.

5. EVA activities can be planned for 6 hours nominally and 8 hours maximum duration (exception: pressurized vehicle activity is counted as IVA).

All EVA's require 2 crewmen. No scheduled EVA's shall occur on landing or departure day. Scheduled and unscheduled EVA's at the end of the mission may only be performed if there are sufficient consumables and lunar launch opportunities to extend the mission to perform the EVA and preserve 2 wave-off days. Normal EVA's require 0.68 IVA hrs/EVA hr for maintenance and resupply. Additional EVA considerations are presented in Section 5.3.

The following major activities must by scheduled for all crew persons each day:

Activity	Duration	Comments
work	10 hrs	IVA and EVA vehicle maintenance, payload deployment, maintenance and operations, construction operations.
sleep	8 hrs	6 hours minimum when shifting sleep cycles
pre/post-sleep	2, 2 hrs	Includes personal grooming, 1 hour morning and evening meals, personal time, activity planning and team meetings, module configuration and housekeeping. Only minimal payload configuration activities may be scheduled during this time.
noon meal	1 hr	Perferable to schedule the whole shift together. Only minimal payload activities are allowed during the meal.
exercise	1 hr	1 hour per day unless EVA or strenuous payload activity of equivalent exercise rigor and duration

Based on these contraints, the total available crew time for strenuous payload and construction activities for missions having crew surface stay periods of 8, 24, and 180 days is given in Table 5-1. For 8 day surface stays (768 crew-hours for a 4 person crew), there are 320 heavy work hours available, out of which 92 hours are designated for IVA vehicle configuration activities after landing and prior to launch. Of the remaining hours, a maximum of 11 2-man, 6-hour duration EVA's are possible for a total of 132 EVA hours. Similarly for 24 and 180 day surface stays, a maximum number of 516 and 4,224 EVA hours are theoretically possible. However, other internal activities are planned, such as internal science experiments in the geochemical/materials and life sciences laboratories (delivered in 2001 and 2002, respectively), teleoperation of surface construction equipment and surface experiments, and internal systems monitoring checks and subsystem maintenance. Thus, a more conservative estimate of available EVA hours is given at the bottom of Table 5-1 (72, 144, and 936 hours for the 8, 24, and 180 day stays, respectively). And as explained in more detail in Section 5.3, these latter estimates may be more realistic of actual supportable EVA capability for these missions, after taking into account other factors.

Table 5-1. Available Crew EVA/IVA Time for 8, 24, and 180 Day Surface Stays

	Surface Stay Time (Days)		
	8	**24**	**180**
Surface Stay (hrs)	192	576	4,320
Number of Crew	4	4	4
Surface Stay (person-hrs)	**768**	**2,304**	**17,280**
On-Duty (hr/day)	10	10	10
Total On-Duty (hrs)	320	960	7,200
Arrival Day Checks (hrs) - (No EVA constraint)	40	40	40
Ascent Vehicle Prep. (hrs)	12	12	12
Departure Day Checks (hrs) - (No EVA constraint)	40	40	40
Available Time For Surface Ops (hrs)	228	868	7,108
IVA Support & Service Needed per EVA (hr/hr)	0.68	0.68	0.68
Number of Crew/EVA	2	2	2
EVA Duration (hrs)	6	6	6
Maximum Number of EVAs (given no other IVA activity than to Support/Service EVA Equipment)	11	43	352
Maximum Possible EVA (hrs)	132	516	4,224
IVA to Support EVA (hrs)	90	351	2,872
Available Time Margin (hrs)	6	1	12
For Planning Purposes: Select Maximum Number of Supportable EVAs (Necessary to allow time for other IVA activities)			
Number of Possible EVAs	6	12	78
Total EVA (hrs)	72	144	936
Necessary IVA to Support EVA (hrs)	49	98	636
Available Time Margin (hrs) For Other IVA Activities	107	626	5,536

5.2.3 Crew Shift Schedules

14 Day Missions. Single shift operation is defined for the short duration 14 day missions, 8 day surface stays. One shift operations provide quiet time for sleep in the confined lunar personnel module. In addition, 1/2 day of rest is planned for all crew during the middle of each 14 day mission. All other days are considered normal workdays. A schedule for a typical one-shift workday cycle is given in Figure 5-1.

Defining one-shift operations on the early missions requires that the time of all 4 crew be effectively utilized. This requires more tools, EVA equipment, and vehicles than for a two-shift operation which would be able to handover some equipment to the next shift.

30 and 180 Day Missions. Two shift operations are defined for the 180 day missions to maximize benefits of continuous activities such as production of lunar oxygen (which will be an around-the-clock operation). Two shifts are possible with the 30 day (24 day surface stays) missions because a habitation module has been emplaced on the surface. The habitation module and lunar bases shall be designed to provide quiet locations for sleep. Most 30 day missions will not require 2 shift coverage. But whenever two-shift operations are defined, crew time allocations include 1 day of rest in every 7 workday cycles. Handover between shifts should be scheduled for 30 minutes twice per 24 hours.

Many of the 24 day surface stay missions may not require continuous coverage based on requirements imposed by construction, science, or exploration objectives alone. If any of these missions require continuous monitoring/control, the lunar base will need to operate in a two or three shift mode. This is particularly true of lunar oxygen production (although this activity is not anticipated until crew stay times increase to 180 days. If primary monitoring and control responsiblility for the lunar oxygen production plant is assigned to the lunar base (versus primary control from Earth), then shift coverage will be required to ensure smooth operation. Shutting down and starting up the whole oxygen production plant every 24-hr cycle (required for one-shift lunar base operations) is not an option. However, many of the activities planned during the 2001-2004 period with 24 day stay times can be planned for a single shift, and some, such as emplacing modules and other construction activities, would probably benefit from larger single-shifts rather than double-shift coverage by half-size shifts. Most Earth construction projects are undertaken with a single shift. Continuous shift coverage is required principally for industrial scale production operations and monitoring of complex, long-term experiments.

The 28-day daylight/night cycle and the constraints imposed by limited pressurized space/-area impose other considerations that may affect shift operations. As on Earth, night operations on the Moon will be more difficult (taking longer to complete), more expensive (requiring lighting and heaters for equipment), and limits surface exporatory activities. Thus, there is an incentive to develop a schedule that fits more activities and work hours into the more productive day-light period (10-12 hr work/cycle), but backing off during the night (6-8 hr work/cycle).

Two-shift operation improves situations where resources, such as pressurized living space, are at a premium. The off-duty shift has the entire habitat module to themselves, while the on-duty shift has more laboratory resources available and faces fewer potential scheduling problems with supporting scientific equipment than one-shift operation. Enough pressurized living space is of particular concern when using Space Station hardware derivatives. One habitat module (and 3 lab modules) is sufficient for 6-8 crew in zero-g, where living volume is of concern. However, in the gravity field of the Moon, living area is of more importance. At the end of Phase II of the current lunar base scenario (2005), crew stay times extend to 180 days and the number of crew at the base grows to 8 with just one habitat module and from 2-3 laboratory modules. Thus, emphasis on designing the module interior for efficient use of space while still maintaining habitability and crew productivity may be even more important and challenging than on Space Station.

Figure 5-1. Typical One-Shift Workday Cycle

Post-Sleep (2 hrs)	Duty (5 hrs)	Meal Exer 2 hr	Duty (5 hrs)	Pre-sleep (2 hrs)	Sleep (8 hrs)

Post-Sleep <u>Activities</u>	**Workday <u>Activities</u>**	**Pre-Sleep <u>Activities</u>**	
Less Than 1 Hr. minimal PL Ops	10 Hrs. PL Ops or Construction	Less Than 1 Hr. minimal PL Ops	No PL Ops

---

Figure 5-2. Typical Two-Shift Workday Cycle

Shift

A	*HAND	Pre-Sleep (2 hr)	Sleep (8 hrs)	Post Sle-lep 2 hr	*HAND	Duty (5 hrs)	Meal Exer (2 hr	Duty (5 hrs)
B	OVER*	Duty (5 hrs)	Meal Exer (2 hr)	Duty (5 hrs)	OVER*	Pre-Sleep (2 hr)	Sleep (8 hrs)	Post Sle-lep 2 hr

* Handover = 15 minutes

5.2.4 Time Allocations for Operational Tasks

Table 5-2 lists 30 separate operations and the overall time estimated to complete each task. The estimate was derived by breaking each operation down into a set of discrete subtasks. Then rules were applied to calculate the time it took to do a certain subtask (i.e. hauling speed is 25 m/min, or the soil carrier holds 8 m^3 of regolith and is filled by a backhoe shovel holding 1 m^3 that takes 2 min/shovel, etc.). After determining how much time it took to complete a subtask, hours were assigned to Earth teleoperation, Lunar teleoperation, or Lunar EVA depending on the complexity of the subtask. For instance, from the results of a short study to determine typical operations which could be teleoperated (described in more detail in Section 5.5), most operations using the prime mover with bulldozer, front loader, or backhoe shovel attachments or involved in soil transferring operations (dragging a trailer), were considered teleoperable from Earth. Technology development will be needed to perform teleoperated tasks with a 5-6 second delay. Long but somewhat specialized tasks such as trenching for emplacing utility-ways, and tasks that required close coordination between teleoperator and EVA astronaut were assigned to Lunar teleoperations. Complex tasks such as making interface connections or critically important tasks such as offloading cargo were assigned to a 2-man EVA astronaut crew (although in some tasks they were assisted by lunar teleoperation of a crane or prime mover).

After assigning hours to Earth, Lunar IVA, or Lunar EVA, all subtasks were totaled to arrive at the time allocations for each operation given in Table 5-2. The detailed subtask set and calculation methodology are given in Appendix D. Of particular interest is the overall time estimate for emplacing a covered module which is 5 to 7 times more than the ~25 hours required to emplace an exposed module. Much of this time is expected to be assigned to Earth construction crew teleoperators, but EVA time is still doubled. More details of module emplacement will be given in Section 5.5. Note also that the time allocations for Lunar IVA include only the time required for a teleoperated task and do not include the support and servicing time required for each EVA. It was estimated that 0.68 hrs were required to support each hour of EVA as explained in Section 5.3. The estimates in Table 5-2 do not include contingency factors for problems/breakdowns (except where specifically indicated in Appendix D). A basic assumption is that the crews are well trained.

The time allocations for these operations were used to develop crew IVA and EVA allocations for each manned mission in the scenario described in Sections 4.2 and 5.1. These time estimates are summarized in Table 5-3. Support time for EVA and a 20 percent time contingency for module emplacement tasks have been included in the Table 5-3 allocations. The bar chart in Figure 5-3 compares total IVA and EVA time requirements versus available IVA and EVA manhours. As indicated by the IVA and EVA margins, sufficient time resources are available to accomplish recognized tasks for the first two manned missions. However, large negative margins (-63 IVA, -154 EVA, and -217 total hours) occured during the next mission to emplace a covered radiation shelter and the following mission to emplace the an module interface node and airlock (-12 IVA, -90 EVA, and -102 total hours). Margins improve after crew stay times increase to 24 days. One solution to negative margins for the short duration early missions is to delay completion of some early activities until a later mission; however, this would delay the transition to longer surface stay times (see Assumption #5 in Section 3.0). Surface activities should be chosen to allow the longer stay times to occur as scheduled. Another solution is to increase the surface stay times of the early missions, or to increase the number of crew, but this would place a greater design burden on the lunar lander since it serves as the operations center for the early missions. Still another solution would be to offload more activities onto Earth teleoperation. More study of these issues should be conducted.

Table 5-2. Summary of Surface Activities and Estimated IVA/EVA Time To Complete

(NOTE: Some IVA and EVA time takes place concurrently and is counted only once in overall time. Pressurized rover time counted as IVA. IVA time does not include support/servicing IVA required for EVA)

No.	Activity	Overall Time (hrs)	Earth Teleop (hrs)	Lunar Teleop (hr/person)	Lunar IVA Crew	Total IVA (hr)	EVA op	EVA Crew	Total EVA (hrs)
BASE CONSTRUCTION ACTIVITY									
1	Prepare Module Site. (includes leveling/grading site and installing utility-ways)								
		57.2	41.2	8.8	1	8.8	7.2	2	14.4
GENERIC OPERATION USED IN OTHER CALCULATIONS									
2	Prime Mover (PM) Attachment change-out. (time per single attachment change)								
	For Base Ops:	0.9	0.9	0.0	0	0.0	0.0	0	0.0
	For Landing Pad Ops:	1.3	1.3	0.0	0	0.0	0.0	0	0.0
LANDING/LAUNCH SITE OPERATIONS									
3	Prepare Landing Pads.								
	One Pad:	35.8	34.1	0.0	0	0.0	1.7	2	3.5
	Two Pads:	71.6	68.2	0.0	0	0.0	3.5	2	7.0
	Four Pads:	143.3	136.3	0.0	0	0.0	7.0	2	14.0
4	Emplace landing pad lights/navigation aids. (assume self-contained units requiring no power from base)								
	One Pad:	4.8	4.8	0.0	0	0.0	0.0	0	0.0
	Two Pads:	9.5	9.5	0.0	0	0.0	0.0	0	0.0
	Four Pads:	19.0	19.0	0.0	0	0.0	0.0	0	0.0
5	Prepare roads from pads to base.								
		125.9	118.4	0.0	0	0.0	7.5	2	14.9

Table 5-2 (Cont). Summary of Surface Activities and Estimated IVA/EVA Time To Complete

(NOTE: Some IVA and EVA time takes place concurrently and is counted only once in overall time. Pressurized rover time counted as IVA. IVA time does not include support/servicing IVA required for EVA)

No.	Activity	Overall Time (hrs)	Earth Teleop (hrs)	Lunar Teleop (hr/person)	Lunar IVA Crew	Total IVA (hr)	EVA op	EVA Crew	Total EVA (hrs)
6	Build blast walls at pads for protecting surrounding equipment and roads. (piled regolith)	52.4	52.4	0.0	0	0.0	0.0	0	0.0
7	Remove spent lander descent stage from pad	4.1	0.0	3.6	1	3.6	3.8	2	7.7
	CARGO HANDLING OPERATIONS								
8	Off-load generic cargo from lander onto trailer. (cargo: large individual payloads or pallet of smaller payloads)	2.6	0.8	0.5	1	0.5	1.8	2	3.5
9	Transport cargo to base area.	0.8	0.0	0.2	1	0.2	0.7	2	1.3
10	Off-load cargo at base.	1.4	0.1	0.5	1	0.5	1.3	2	2.5
	PRESSURIZED MODULE EMPLACEMENT (From Off-Loading Cargo at Pad to Operational Status)								
11	Emplace exposed hab/lab modules.	28.3	12.0	10.2	1	10.2	19.7	2	39.3
12	Emplace exposed node modules.	25.2	8.8	10.2	1	10.2	19.7	2	39.3

Table 5-2 (Cont). Summary of Surface Activities and Estimated IVA/EVA Time To Complete

(NOTE: Some IVA and EVA time takes place concurrently and is counted only once in overall time. Pressurized rover time counted as IVA. IVA time does not include support/servicing IVA required for EVA)

No.	Activity	Overall Time (hrs)	Earth Teleop (hrs)	Lunar Teleop (hr/person)	Lunar IVA Crew	Total IVA (hr)	EVA op	EVA Crew	Total EVA (hrs)
13	Emplace exposed airlock.								
		24.7	8.4	10.2	1	10.2	19.7	2	39.3
14	Emplace exposed logistics modules.								
		26.1	9.7	10.2	1	10.2	19.7	2	39.3
15	Emplace covered radiation shelter with bulkheads.								
		130.9	95.0	26.3	1	26.3	42.7	2	85.4
16	Emplace covered radiation shelter without bulkheads.								
		190.3	160.7	21.3	1	21.3	36.4	2	72.8
EMPLACE OTHER SURFACE SYSTEMS (From Off-Loading Cargo at Pad to Operational Status)									
17	Emplace initial power system (assume photovoltaic array).								
		26.9	9.4	10.9	1	10.9	19.5	2	39.0
18	Emplace radiator system.								
		17.5	7.6	7.2	1	7.2	15.7	2	31.3
19	Emplace communications station.								
		26.9	7.7	13.9	1	13.9	18.3	2	36.5

Table 5-2 (Cont). Summary of Surface Activities and Estimated IVA/EVA Time To Complete

(NOTE: Some IVA and EVA time takes place concurrently and is counted only once in overall time. Pressurized rover time counted as IVA. IVA time does not include support/servicing IVA required for EVA)

No.	Activity	Overall Time (hrs)	Earth Teleop (hrs)	Lunar Teleop (hr/person)	Lunar IVA Crew	Total IVA (hr)	EVA op	EVA Crew	Total EVA (hrs)
	RESOURCES OPERATIONS								
20	Emplace LO2 pilot plant.								
		32.1	9.8	18.9	1	18.9	18.9	2	37.7
21	Operate LO2 pilot plant. (on monthly basis, 720 hrs/month)								
		741.8	720.0	24.2	1	24.2	4.8	2	9.7
22	Emplace LO2 production plant.								
		97.4	33.4	64.3	1	64.3	65.6	2	131.3
23	Operate LO2 plant (on monthly basis).								
		956.6	0.0	720.0	1-2	956.6	1.4	2	2.9
24	Emplace reusable lander refueling facilities.								
		27.8	14.6	7.5	1	7.5	18.7	2	37.4
25	Refueling reusable lander (LOX only).								
		3.7	0.0	0.0	0	0.0	3.7	2	7.4
	SCIENCE ACTIVITIES								
26	Deploy/conduct lunar geophysical station experiment from lunar base.								
		59.5	1.0	54.8	1	54.8	4.7	2	9.3

Table 5-2 (Cont). Summary of Surface Activities and Estimated IVA/EVA Time To Complete

(NOTE: Some IVA and EVA time takes place concurrently and is counted only once in overall time. Pressurized rover time counted as IVA. IVA time does not include support/servicing IVA required for EVA)

No.	Activity	Overall Time (hrs)	Earth Teleop (hrs)	Lunar Teleop (hr/person)	Lunar IVA Crew	Total IVA (hr)	EVA op	EVA Crew	Total EVA (hrs)
27	Emplace optical interferometer.								
		660.1	609.6	18.8	1-2	36.3	32.7	2	65.3
28	Operate optical interferometer (monthly basis for earth - mission basis for lunar base).								
		751.2	720.0	29.2	1-2	35.0	2.0	2	4.0
29	Crater dating (50 craters >= 5 km diameter).								
		366.8	1.0	63.1	1-2	125.1	303.7	2	607.3
30	Deep drilling (1 core, 1 km deep).								
		217.8	1.0	210.5	1-4	810.5	7.3	2-4	18.0

Note: Overall Time = Earth Teleop Time + Lunar Teleop Time + EVA Ops Time (Overall time is the straight timeline time needed to complete a task. It does not include number of people used in each task nor does it include time to support EVA.)

Table 5-3. Manned Missions EVA/IVA Activity Budget

Activity Type	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA
Year	1999		2000				2001					
Mission	2		4		6		9		11		13	
Crew	4		4		4		4		4		4	
Surface	8		8		8		8		24		24	
Personal, Maintenance												
Sleep, Meals (13)	416		416		416		416		1248		1248	
Exercise (1)	32		32		32		32		96		96	
Maint. - Per.Mod (.5)	16		16		16		16					
Maint. - Hab Mod (1)									75	21	75	21
Act. Planning (.5)	16		16		16		16		48		48	
Rest & recreation +5	20		20		20		20		20		137	
Landing/dep config +10	40		40		40		40		40		60	
Subtotal Per./Maint.	540	0	540	0	540	0	540	0	1527	21	1664	21
Payloads, Construction												
Contingency Factor (20%) Added for Module Emplacement Activities												
Lunar sc & geology	38	38	11	10	11	10	11	10	11	10	11	10
Landing site/instru.	54	20	54	20	8	7	8	7	8	7	8	7
Prime mover/crane			31	16								
Surface comm station					39	37						
Site Preparation	10	14	19	14								
Rad storm shelter					95	102						
Therm control sys					28	31						
Personnel Trans.backup							11	2				
Crew logistics							11	2				
Module interface node							42	47				
Airlock							42	47				
Initial power plants					38	39	38	39	38	39		
Geophys station							6	8	4	6	57	3
Hab module									42	47		
Geochem materials lab											102	47
Liq ox pilot plant												
Rad/therm control sys												
Service geochem lab												
Life science lab												
Pressurized Garage												
Optical Interferometer												
Life sc research node												
Crater dating exp.												
Deep drilling												
Farside uv telescope												
Lunar based SETI												
Service life sc lab												
Adv power plant												
Ox mining equip												
Liq ox prod. plant												
Comm relay station												
Log module												
Propellant refuel stn												
Subtotal payloads	101	72	114	60	219	226	169	162	102	109	177	67
Total Time (hrs):												
Available = total,eva	768	72	768	72	768	72	768	72	2304	144	2304	144
Used = iva or eva	641	72	654	60	759	226	709	162	1629	130	1841	88
Used = iva + eva	713		714		985		870		1759		1929	
Margin = total,eva	55	0	54	12	-217	-154	-102	-90	545	14	375	56
Mass build up												
per Mission (lbm)	6,000		44,500		32,900		23,080		38,500		38,500	
Cumulative mass (lbm)	6,000		50,500		83,400		106,480		144,980		183,480	

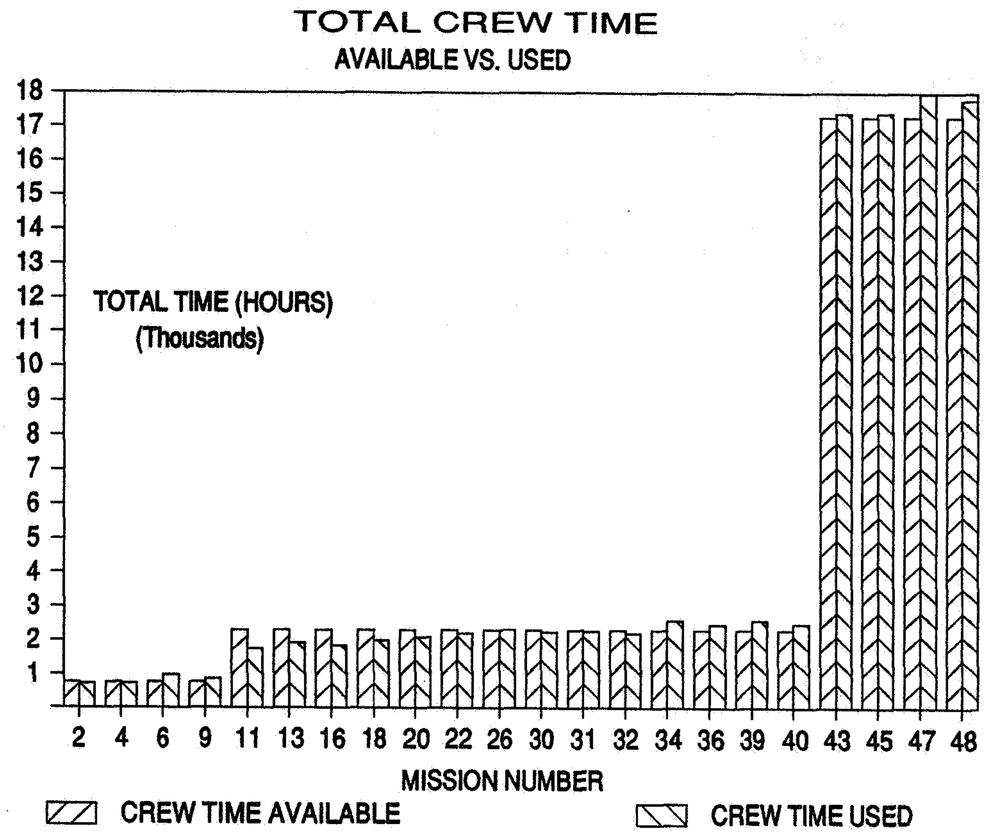
Table 5-3 (Cont). Manned Missions EVA/IVA Activity Budget

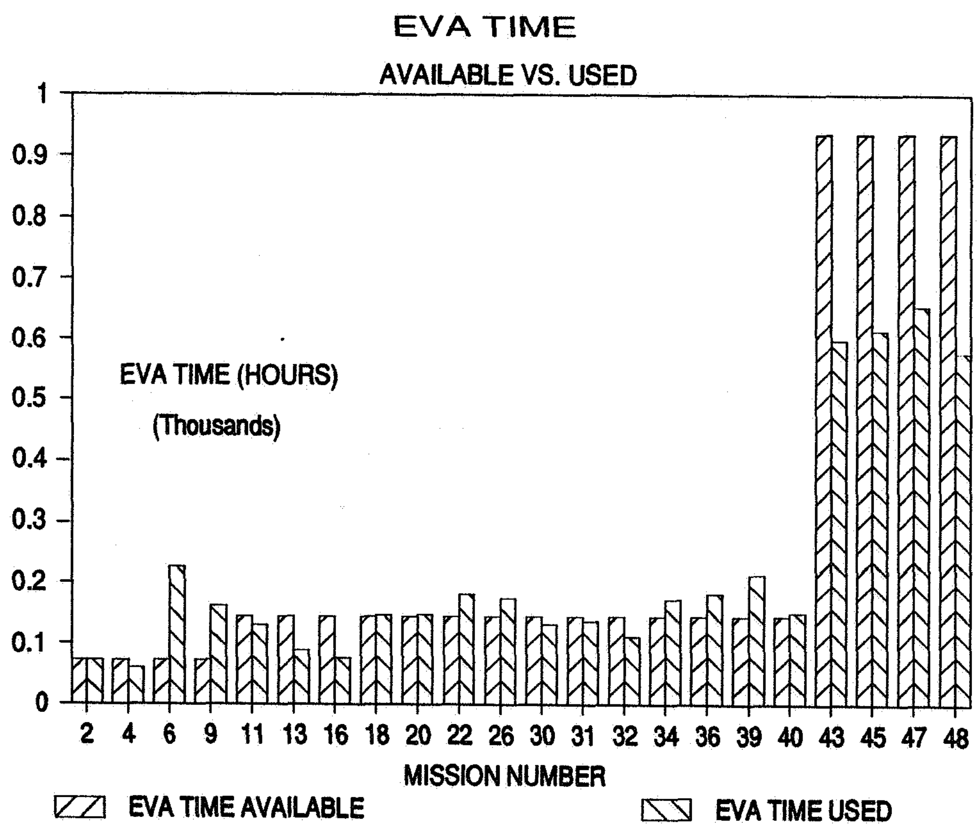
Activity Type	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA
Year	2002								2003							
Mission	16		18		20		22		26		30		31		32	
Crew	4		4		4		4		4		4		4		4	
Surface	24		24		24		24		24		24		24		24	
Personal, Maintenance																
Sleep, Meals (13)	1248		1248		1248		1248		1248		1248		1248		1248	
Exercise (1)	96		96		96		96		96		96		96		96	
Maintenance - PM (.5)																
Maintenance - HM (1)	75	21	75	21	75	21	150	42	150	42	150	42	150	42	150	42
Act. Planning (.5)	48		48		48		48		48		48		48		48	
Rest & recreation +5	137		137		137		137		137		137		137		137	
Landing/dep config +10	60		60		60		60		60		60		60		60	
Subtotal per/maint	1664	21	1664	21	1664	21	1739	42	1739	42	1739	42	1739	42	1739	42
payloads, construction																
Lunar sc & geology	11	10	11	10	11	10	11	10	11	10	11	10	11	10	11	10
Landing site/instru	8	7	8	7	8	7	8	7	8	7	8	7	8	7	8	7
Prime mover/crane																
Surface comm station																
Site Preparation																
Rad storm shelter																
Therm control sys																
Personnel Trans.backup																
Crew logistics																
Module interface node			21	23	21	23										
Airlock			21	23	21	23										
Initial power plants			13	5									13	5		
Geophys station																
Hab module																
Geochem materials lab	60		60		60		60		60		60		60		60	
Liq ox pilot plant	46	38	32	10	32	10	32	10	32	10	32	10	32	10	32	10
Rad/therm control sys			28	31												
Service geochem lab			24	20							24	20				
Life science lab					102	47	60		60		60		60		60	
Pressurized Garage							42	47								
Optical interferometer							80	65	38	4	38	4	38	4	38	4
Life sc research node									62	47	20		20		20	
Crater dating exp.									34	38	27	30	27	30	27	30
Deep drilling									112	16	106	8	106	8	106	8
Farside uv telescope																
Lunar based SETI																
Service life sc lab													24	20		
Adv power plant																
Ox mining equip																
Liq ox prod. plant																
Comm relay station																
Log module																
Propellant refuel stn																
Subtotal payloads	124	55	204	125	267	126	292	139	416	132	386	89	399	94	362	69
Total Time (hrs):																
Available = total,eva	2304	144	2304	144	2304	144	2304	144	2304	144	2304	144	2304	144	2304	144
Used = iva or eva	1788	76	1868	146	1931	147	2031	181	2155	174	2124	131	2138	136	2101	111
Used = iva + eva	1865		2014		2078		2212		2329		2256		2274		2212	
Margin = total,eva	439	68	290	-2	226	-3	92	-37	-25	-30	48	13	30	8	92	33
Mass build up																
per Mission (lbm)	38,500		18,400		40,000		38,300		13,200		0		0		0	
Cumulative mass (lbm)	221,980		240,380		280,380		318,680		331,880		331,880		331,880		331,880	

Table 5-3 (Cont). Manned Missions EVA/IVA Activity Budget

Activity Type	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA	IVA	EVA
Year	2004								2005							
Mission	34		36		39		40		43		45		47		48	
Crew	4		4		4		4		4		4		4		4	
Surface	24		24		24		24		180		180		180		180	
Personal, Maintenance																
Sleep, Meals (13)	1248		1248		1248		1248		9360		9360		9360		9360	
Exercise (1)	96		96		96		96		720		720		720		720	
Maintenance - PM (.5)																
Maintenance - HM (1)	150	42	150	42	150	42	150	42	562	158	562	158	562	158	562	158
Act. Planning (.5)	48		48		48		48		360		360		360		360	
Rest & recreation +5	137		137		137		137		1029		1029		1029		1029	
Landing/dep config +10	60		60		60		60		80		80		80		80	
Subtotal per/maint	1739	42	1739	42	1739	42	1739	42	12110	158	12110	158	12110	158	12110	158
payloads, construction																
Lunar sc & geology	11	10	11	10	11	10	11	10	42	40	42	40	42	40	42	40
Landing site/instru	8	7	8	7	8	7	8	7	8	7	8	7	8	7	8	7
Prime mover/crane																
Surface comm station																
Site Preparation																
Rad storm shelter																
Therm control sys																
Personnel Trans.backup																
Crew logistics																
Module interface node									42	47						
Airlock																
Initial power plants																
Geophys station																
Hab module																
Geochem materials lab	60		60		60		60		450		450		450		450	
Liq ox pilot plant	32	10	32	10												
Rad/therm control sys																
Service geochem lab			24	20												
Life science lab	60		60		60		60		450		450		942	47	900	
Pressurized Garage																
Optical interferometer	38	4	38	4	38	4	38	4	113	12	113	12	113	12	113	12
Life sc research node	20		20		20		20		310		310		310		310	
Crater dating exp.	27	30	27	30	27	30	27	30	83	91	83	91	83	91	83	91
Deep drilling	106	8	106	8	106	8	106	8								
Farside uv telescope																
Lunar based SETI																
Service life sc lab					35	30							60	30		
Adv power plant	341	60	40		40		40		120		120		120		120	
Ox mining equip			134	50	134	50	134	50	102	150	102	150	102	150	102	150
Liq ox prod. plant					85	31	100		2886	9	2886	9	2886	9	2886	9
Comm relay station									39	37						
Log module									52	47	10		10		10	
Propellant refuel stn											108	147	75	110	75	110
Subtotal payloads	703	129	560	139	625	170	604	109	4697	440	4682	456	5201	496	5099	419
Total Time (hrs):																
Available = total,eva	2304	144	2304	144	2304	144	2304	144	17280	936	17280	936	17280	936	17280	936
Used = iva or eva	2442	171	2298	181	2364	212	2343	151	16807	598	16792	614	17311	654	17209	577
Used = iva + eva	2613		2480		2576		2494		17405		17407		17966		17786	
Margin = total,eva	-309	-27	-176	-37	-272	-68	-190	-7	-125	338	-127	332	-686	282	-506	359
Mass build up																
per Mission (lbm)	38,500		38,500		33,333		0		10,700		38,500		40,000		0	
Cumulative mass (lbm)	370,380		408,880		442,213		442,213		452,913		491,413		531,413		531,413	

Figure 5-3. IVA/EVA Time Allocations for All Manned Missions In Phase II





5.3 Extravehicular Activities

This section summarizes key aspects of the EVA system and related parts of airlocks needed to support Lunar Surface operations by crewman in pressure suits. In particular, estimates are made of intravehicular time required to service and support each extravehicular mission.

5.3.1 EVA Operational Considerations

EVA is a hazardous activity. The extravehicular mobility unit (EMU) designs have had 20 years of evolution. Successive generations of suits have been developed for the U2 and SR-71, Mercury, Gemini, Apollo, Skylab, Shuttle and Space Station. Despite all this evolution, the EMU is still basically a single pressure wall separating the crew from vacuum. The single wall concept is the same whether the EMU is a hard suit such as the Ames AX-5, or a hybrid suit with a hard upper torso and soft extremities such as the Space Station baseline and the Zero Prebreath Suit. Because EVA is hazardous, it is not the preferred solution for operations. Teleoperation or robotic solutions should be identified.

The lunar EMU design may be selected as a non-venting one in order to either minimize water and gas usage or to minimize atmospheric contamination which might affect some experimenters. However, the penalty in size of the EMU will be significant. A Thermal electric-wax heat sink-radiator system will significantly increase the weight and volume of the EMU. It may not be possible to design a radiator based system which can operate throughout the day, with dust on the radiator, and with the high illumination of a lunar EVA with the sun at zenith.

If the Lunar base cabin atmosphere can operate at a lower pressure than terrestrial sea level, then the lunar Surface EMU could be designed at a pressure lower than 8.4 psia and still not require prebreathing to prevent bends. A lower pressure suit is preferred to enhance crew mobility.

Night EVA does not seem significantly more dangerous than day EVA. Falling down will not damage a properly designed EMU. In estimating the amount of EVA time available, it has been assumed that maintenance and repair activity can be performed at night since artificial lighting can be readily provided.

Heads up display technology will be well developed by the time of a Lunar Base. Procedures and checklists can be sent to the crewmen in real time or loaded into the EMU Data Processor (EDP) memory as part of the suit preparation.

Operation of construction equipment may not be possible at night because of thermal considerations. The hard alloys needed for teeth on excavators, or blade corners on bulldozers become brittle at temperatures below about -40°C. In fact, most operating mines in the U.S. and Canada shut down when the temperature drops below -40°C, because equipment failure becomes too common.

5.3.2 EVA Equipment

A list of EVA System and Airlock Element equipment is given in Table 5-4 and described in more detail below. The baseline assumption in developing this equipment list is that EVA activity will encompass a range of tasks including: 1) scientific research such as collections of lunar samples, installation of experiments on the lunar surface, and replacement of film canisters, 2) technical research in exploiting lunar materials including scooping and loading lunar material into pilot plant scale processing equipment, operating small excavating equipment or loading explosives into a shot hole, 3) routine maintenance activity such as inspection, lubrication, and cleaning windows, 4) repair activity involving replacement of subassemblies called Lunar Surface Replaceable Units (LSRUs) similar to Orbital Replaceable Units (ORUs) on the Space Station, 5) pressurized module maintenance and repair, 6) installation of modules at the lunar base including unloading from landers, transportation using powered equipment, positioning of modules using hand powered winches and pry bars, and make up of fluid and electrical connections.

EVA System

Extravehicular Mobility Unit (EMU)

Space Suit Assembly (SSA): The weight of the SSA listed is that for the Space Station which is a 8.4 psi fabric suit with a hard upper torso.

Portable Life Support System (PLSS): The size of the system defined here is a Space Station EMU which is a non-venting design. Compressed oxygen at about 5000 psi is provided with sufficient reserves to support suit purge for about 1/2 hour in the event of ventilation fan failure or a suit puncture. Carbon dioxide removal is provided by a regenerable absorption medium, possibly metal oxides of solid amine. LiOH is not considered to be regenerable under space conditions because of the high temperatures required (~1000°F). Cooling is provided by a non-venting radiator supported by a wax heat sink and thermo-electric devices.

EMU Spares and sizing elements: The Space Station SSA can accommodate astronauts from about the 50 percentile female up to the 95 percentile male with the use of two hard upper torso (HUT) sizes and sizing elements in the fabric portion of the SSA. The nominal load of spares is defined as two complete EMUs. One would probably be assembled and the second would consist of parts to replace LSRU's in the operating EMUs.

EVA Support Equipment and Tools (ESE&T)

A basic list of ESE&T is compiled from the general types of tools and equipment used on the lunar surface by Apollo, and by Space Shuttle, and Space Station lists modified for a lunar base. The Shuttle EVA Tool Catalogue (10) lists 155 individual tools and formed the basis for the list of small items. Many tools were specific to individual Shuttle missions. The list presented in Table 5-4 is based on the assumption that lunar surface equipment will be carefully designed for EVA use and repair with standardized fittings such as bolt heads, screws etc.

Tools, Hand: A hand tool list has been built from the STS list.

Tools, Power: A limited power tool list has been built from the STS list.

Tools, Scientific: A very limited set of mission specific scientific tools has been defined, based largely on the Apollo lunar surface tools.

Geology: The Apollo lunar sampling equipment serves as a baseline for this equipment set.

Table 5-4. EVA Equipment List

Name	Prime	Spares	Weight (lbs/ea)	Total Weight (lbs)
EMU				
Space Suit Assembly	4	2	160	960
PLSS	4	2	346	2076
EVA Support equipment and tools (ESE&T)				
Tools, Hand				
Wrist Tethers	2		0.57	1.14
Tool Caddy	2		1.88	3.76
Adjustable Wrench	2		0.99	1.98
Needle Nose Pliers	1		0.60	0.6
Diagonal Cutters	1		0.60	0.6
Bolt Puller	1		0.80	0.8
Vice Grips	1		1.20	1.2
Hammer	1		2.00	2
Probe	1		0.60	0.6
Lever Wrench	1		1.50	1.5
3/8 EVA Ratchet Drive	1		1.18	1.18
EVA Screwdriver	1		0.40	0.4
EVA Allen Wrench	1		0.40	0.4
7/16 socket & ratchet	1		1.00	1
1/2 open end Wrench	1		0.90	0.9
Snatch Block	1		1.66	1.66
1/2 ratchet box wrench	1		1.00	1
1/4 allen wrench	1		1.00	1
EVA Winch	1		24.00	24
Winch Rope Reel	1		8.10	8.1
Tube Cutter	1		1.70	1.7
3/8 ratchet drive	1		0.80	0.8
Loop Pin Extracter	1		0.80	0.8
Pry Bar	1		3.20	3.2
Forceps	1		0.20	0.2
Tape Set	1		0.83	0.83
Velco Strap Set	1		1.80	1.8
Trash Container	1		1.00	1
Bolt Cutter	1		2.50	2.5
Tools,Power				
EVA Power Ratchet	1		20.00	20
EVA Power Package	1		37.00	37
Circular Saw	1		12.50	12.5

Table 5-4 (Cont). EVA Equipment List

Name	Prime	Spares	Weight (lbs/ea)	Total Weight (lbs)
Tools Scientific				
Geology Tool Set	1	1	100	200
Camera, film	2	1	15	45
Camera, Video	1	1	29.5	59
Camera Battery	1	1	2.6	5.2
Inspection and Test Eq	1	1	200	400
Mobility Aides				
Ladders	1	1	30	60
Wheeled Tool Carrier	1	1	20	40
Balance Pole	1	1	8	16
Decontamination Equip	1	1	100	200
External Lighting				
Fixed	2	1	25	75
Portable,battery	2	1	35	105
Portable, cable	2	1	35	105
Navagation aides				
Laser Range Finder	1		35	35
Crew Rescue Equipment				
Mini-Rover, Gurney	1		50	50
Gas Pack	1		80	80
Pressure Bag	1		15	15
Airlock Elements				
CASE	2	1	1,015	3,045
Umbilicals	2	1	20	60
Don/Doff Station	4		15	60
External Equip Lockers	2		238	476
Internal Equip Lockers	2		40	80
PLSS	4		40	160
Pass through Airlock	1		650	650
Dust Removal Station	1		TBD	0
Hyperbaric Systems	1		TBD	0
EVA and Airlock Systems				**9188.15**

Cameras, film: Film cameras are necessary for data collection on the lunar surface. Video technology does not provide the required resolution. The Apollo lunar surface camera was a Hasselblad camera which took pictures 2 1/4 inches square on 70 mm wide rolls of film. Generally, the commander had a camera with color film and the lunar module pilot had a camera with black and white film. The camera was manually focused by estimating distances. Exposure settings were also estimated. The next generation of lunar surface camera should be an auto-focussing, auto-exposure camera. Because the Moon's colors are so limited, the black and white film camera had greater resolution and film speed. The reduced depth of field of a 2 1/4 inch negative relative to a 35 mm negative was not a problem on Apollo, however the factor of two better resolution was not an important factor in subsequent analyses of the photographs.

Cameras Video: The video camera defined is the Space Shuttle EMU Camera. Video is very useful in operations when an Earth support effort is involved. During Apollo, the video was used to monitor astronaut activity and to assist in locating lunar samples that were not fully documented photographically by the crew.

Inspection and Test (I&T) Equipment: I&T equipment will be required for inspection of the exterior of the pressurized modules and other equipment.

Mobility aids required for zero-g, such as tethers and foot restraints, are not required in lunar surface operations. However, ladders, tool carriers, mobile lighting, and other mobility systems will be needed.

Ladders: The most obvious piece of lunar surface mobility aid is a ladder to climb on top of modules.

Wheeled Tool Carrier: A wheeled tool carrier is proposed similar to the Mobile Equipment Transporter (Shepherd's golf cart) used on Apollo 14 to assist in activities within walking distance of the base.

Balance Pole: A balance pole is proposed to carry equipment on the lunar surface similar to that used to move the Apollo Lunar Surface Experiment Packages (ALSEP).

Decontamination Equipment: Contamination detection and removal equipment will be needed to detect and remove fuel, oxidizer, or coolants such as monomethyl hydrazine, nitrogen tetroxide, and ammonia. The unit would probably have a small heat lamp to volatilize some contaminant and quadrupole mass spectrometer for contamination detection. Bake off of the contaminants can be done by a set of infra-red lamps.

External Lighting, Fixed: Fixed lighting should be provided to illuminate the areas around the base.

External Lighting, Mobile: High power lights drawing current from the base electrical system via extension cords and which can be moved around the base. Such lights would be particularly useful for maintenance activity during the 14 day night-time period when EVA based exploration and traversing is not practical.

External Lighting, Mobile, battery powered: A less powerful set of lights which can be used for modest periods of time, for night time EVA.

Mobile, solar/battery powered, radio activated: Required for road and landing zone lights.

Crew Rescue and Retrieval: With the large amount of time being spent by the crew in EVA, it is anticipated that injuries may occur which prevent the injured party from moving by himself. These injuries may be associated with accidents which impair the operation or pressure integrity of the SSA.

Crew Rescue Equipment, Mini Rover: A manually powered cart is proposed that may be as simple as a two wheeled wheel barrow to move the injured crewman back to the airlock.

Crew Rescue Gas pack: Air or oxygen to pressurize the suit may be provided by the equivalent to the Apollo Buddy Life Support System, or it may consist of a tank of compressed oxygen which is plugged into one of the EMU's servicing ports.

Crew Rescue Pressure bag: A possible concept to take care of an astronaut with a leak is to place him in a thick walled bag which can take a differential pressure of at least 3.5 psi.

Navigation Aides and Surveying Equipment: Precision location of equipment on the lunar surface will be critical in assembling the base from components delivered on several flights. The proposed baseline solution to this requirement is a laser range finder system similar to the proposed Shuttle system.

Airlock Systems

EMU Checkout and Service Equipment (CASE): The weight estimate listed in Table 5-4 is based on a Space Station type device. The critical part of the servicing system is the service and checkout equipment. For the Space Station, a CASE to service two EMUs is a unit which fills up the equivalent of a single standard rack. Its dimensions are approximately 72x33x20 inches, conforming to a doubly curved surface of a spherical airlock. Total volume of the CASE is about 35 cubic feet and weighs about 1015 lbs. The airlock local controller supports CASE processing. The controller consists of a multichannel A/D converter, data processor (roughly equivalent to an IBM System 2 Model 80 PC with an INTEL 80386 CPU), displays, and a multiplexer-demultiplexer which interfaces with the rest of the Space Station data management system (DMS). During EMU servicing, the local controller interfaces with the EMU data processor (EDP) to perform the A/D conversion and multiplexing of the individual sensors in the EMU. The EMU processing is believed to require about 10,000 Standard lines of Ada Code (SLOCs). The EMU will have a caution and warning system. However, complete built in test, built in test equipment (BIT/BITE) may not be fully implemented. Instead, much of the processing will reside in the airlock's local controller.

Umbilicals will be necessary to support contingencies such as lengthy decontamination procedures or hatch failures. A set of two umbilicals would be placed at each airlock.

EMU Donning and Doffing Station: EMUs will be supported in the airlock by a rack that also supports the EMU during servicing.

Internal storage containers: Basically the requirement is for a storage area for EVA system spare parts and some tools as well as the sizing elements for adjusting the EMU to different astronauts.

External storage containers: Most EVA tools would not be stored in the pressurized volume, but rather in an external locker except with sufficient heating to keep equipment from failing or becoming too cold to be touched by an astronaut in an EMU.

Dust Removal Station: A provision will have to be made to remove dust from the EMUs. The system may consist of brushes to be used before entering the pressurized volume followed by a air shower system similar to that used at the entrance to many clean rooms.

Pass Through Airlock: It will be necessary to pass tools and equipment between the pressurized volume and the EVA astronauts. The concept employed here is derived from that used on the Japanese Experiment Module on Space Station.

Hyperbaric Systems: If a requirement is defined for hyperbaric treatment on the lunar surface as for Space Station, the facility is likely to be co-located with one of the airlocks.

5.3.3 IVA Time for Support of EVA

IVA servicing of EMU:

This is the routine EMU servicing after each EVA. The Space Station Requirement Document (8) allocates 470 crew hours per year for EVA operations. There are expected to be 156 2-man EVAs per year on Space Station. This works out to 1.5 hours of IVA time for servicing each EMU after use. The servicing process is automated to the largest degree possible, and the CASE is designed to reduce EMU checkout to an automated process insofar as possible. Space Station requires a 12 hour nominal servicing cycle, with a contingency cycle of 1 hour. The nominal post-EVA EMU servicing thus requires 1.5 hours manual labor and 10.5 hours of automatic servicing. EMU Servicing will involve the following steps:

a. Removing the urine collection device and any vomitus (manual)
b. Cleaning dust from the outside of the EMU (manual)
c. Drying out the inside of the EMU (manual wipedown)
d. Disinfecting the inside of the EMU (manual wipedown)
e. Cleaning the Liquid Cooling and Ventilation garment. This may involved essentially putting the garment in a washing machine.
f. Visual inspection of the interior and exterior (manual)
g. Connecting the EMU to the CASE (manual)
h. Removal of CO2 removing cartridge, depending on selected method for CO2 removal. If metal oxide system using high temperature decomposition of carbonates for re-furbishment is selected, then processing can not be done in PLSS.
i. Replacement of batteries (About every 20 EVAs)
h. Automatic checkout and servicing during which the following steps take place:
    - batteries are recharged
    - the interior of the suit is dried with forced air
    - air is flushed through the entire system
    - Oxygen tanks are refilled
j. About 2 hours before an EVA the cooling loop is turned on and the heat sink wax material is frozen at a temperature below 64°F. The process can be speeded up by using the thermo-electric devices embedded in the wax.

There is a 12 hour per year allocation of EVA time for maintenance of the external parts of the EVA system. This servicing would include inspection of the high pressure oxygen pump, inspection of the crew rescue device, inspection of external tool storage containers and any needed repairs.

EMU periodic maintenance:

The Space Station time allocation to the EVA system of 180 hours per year (8) should accommodate this function. If the lunar surface EMU is generally similar to the Space Station and previous EMUs, then it will consist of a large number of complex joints made of fabric and rubber like materials. However, the lifetime of these items is not currently established. A baseline assumption is that replacement of these items would be a four hour process performed on each EMU after 200 hours of use, or nominally after 33 6-hour EVAs. Periodic maintenance would consist of:

a. Replacement of worn or broken convolute joints in shoulder, elbow, wrist, knee, and ankle,
b. Lubrication of metal joints in brief,
c. Replacement of gaskets in "refrigerator door" seals,
d. Replacement of gaskets between helmet and HUT,
e. Replacement of wrist to glove gaskets.

EMU repair:

Within the 180 hour per year maintenance allocation, non-routine repair of the EMUs and CASE should be possible. For planning purposes, 0.5 hr for periodic maintenance and repair is allocated for each EMU after use.

Don/Doff time:

A period of two hours per EVA per crewman is allowed for activities including suit donning, egress, collecting and stowing tools, ingress, and doffing. The following timelines describe the sequence of these activities.

EGRESS TIME LINE

(HR:MIN) Time	Duration		
-2:	2:00	Cool-down Wax heat sink.	
0:00	0:10	a)	Don the EMU,
0:10	0:10	b)	Check out the EMU, enter airlock chamber, close service chamber to airlock hatch,
0:20	0:03	c)	Depress to 8 psia,
0:23	0:02	d)	Hold for pressure check,
0:25	0:08	e)	Depress to limit of pump,
0:33	0:05	f)	Vent remaining air, open outer hatch, egress,
0:38	0:30	g)	Gather up tools to begin the EVA.
0:68		Egress subtotal.	

INGRESS TIME LINE

0:00	0:30	h)	Stow tools,
0:30	0:10	i)	Check EMU for chemical contamination,

0:40	0:00	j)	Any contamination that is found must be removed (not a baseline activity),
0:40	0:10	k)	Brush off EMU to begin dust removal process,
0:50	0:05	l)	Enter the airlock, close hatch,
0:55	0:05	m)	Repressurize airlock,
1:00	0:05	n)	Remove remaining dust,
1:05	0:10	o)	Remove (doff) the EMU.
1:15			Ingress subtotal.
2:23			Egress/Ingress Total.

Table 5-5 shows the baseline EVA and IVA time allocations for surface stays of 8 through 180 days. In all cases, the total IVA time to service and maintain EVA systems is approximately 4 hours IVA for every 6 hour EVA (per crew member).

Table 5-5. Baseline EVA and IVA Support Time Allocation

Surface Stay (Days)	Number of 2-man, 6-hr EVAs	EVA Total (hrs)	IVA Servicing EVA (hrs)	IVA Maint of EVA (hrs)	Don/Doff Time (hrs)	Total IVA Support of EVA (hrs)	Ratio Time IVA/EVA (hr/hr)
8	6	72	18.1	6.9	24	49	0.68
14	8	96	24.1	9.2	32	65	0.68
24	12	144	36.2	13.8	48	98	0.68
30	14	168	42.2	16.2	56	114	0.68
90	36	432	108.5	41.5	144	294	0.68
120	50	600	150.6	57.7	200	408	0.68
180	78	936	235.0	90.0	312	637	0.68

5.4 Landing/Launch Operations

This section discusses operational considerations for the landing/launch sites including site preparation and cargo handling. Two areas in particular are addressed: 1) Whether permanent pads are required in either Phase II or Phase III base operations, and 2) Preparation requirements for the landing sites.

5.4.1 Considerations for Landing/Launch Site Preparation

Operations at a lunar landing/launch sites will differ markedly depending on lander type (reusable or expendable, single or two-stage) and lander propellant (cryogenic or storable). Throughout the Phase II man-tended lunar base scenario described in this report, a standard expendable lander is used for both manned and unmanned missions. An expendable ascent stage with attached crew module is landed on manned sorties while unmanned missions deliver cargo. During Phase II, preparations will need to be made to transition to reuseable single-stage landers early in Phase III. There is little reason why a permanent landing area could not be designated at the lunar base for the reusable lander (and several reasons why it should), but there are reasons why a permanent landing site might not be advantageous for the expendable landers used during Phase II. The most obvious, of course, is that a spent expendable descent stage is left at the landing site after all 39 lunar base missions (22 manned, 17 unmanned) scheduled in the 1999-2005 period (Table 4-4). Removing this spent stage from a permanent site might be difficult, not so much because of its mass (3.8 metric tons) but because of its size (8.2 m wide x 7 m high) which would require a wide trailer and road-ways cleared of at least objectionable boulders/-craters to transport it to a storage area. Obviously, this is not a concern for a reusable single-stage lander.

In addition, operational requirements for these two types of landers differ. Propellant for the reusable lander is assumed liquid oxygen produced from lunar resources and liquid hydrogen delivered from Earth. The reusable lander will require storage, refueling, and servicing/maintenance facilities at the lunar base. Since lander flights occur only approximately every two months, propellant may not be stored on-board. Separate propellant tank cars, tank car loading facilities, and storage tanks will be required for both LOX and LH_2. The Phase II expendable lander, on the other hand, uses storable propellants which can be stored on-board and will require minimal (if any) refueling capability to recover from contingencies such as an inadvertent fuel spill. Thus, it appears that the support infrastructure for the reusable lander will be significant in comparison to that required for the expendable lander. The actual support facilities required for each type lander and the location of these facilities in relation to the landing pad is being studied by a parallel study (Landing/Launch Site Study). However, it can be said that reusable lander's support facilities (and the base) should be located as close as to the reusable landers landing/launch site as range safety and blast considerations allows, since time and risks for propellant refueling, lander maintenance, cargo and crew transfers can be minimized by a shorter distance. This, and the fact that a landing site will require lights and navigation aids, argues for a permanent reusable lander launch/landing pad.

The question of whether permanent landing pads will be required for the expendable landers as well comes down to two questions: 1) Can landing take place safely or at minimum risk on unprepared sites, and 2) Can cargo be transported successfully across unprepared lunar surface. Preliminary indications from the parallel landing site study indicate that both these questions can be answered in the affirmative. The initial landing will require a lander capable of landing on unprepared surfaces using visual guidance (first landing with an expendable lander is manned) as well as a reliable combination of automatic hazard avoidance systems and robust landing gear. Risks in later landings should be lower since they will utilize the same systems and will benefit from navigation beacons and lighting emplaced on the surface. Two or more radar transponders could be used to allow precise landings at designated target sites. Surface lighting will be required to support manned landings and to assist cargo handling and other surface operations at night. Since the lighting and navigation beacons only need operate ~10 minutes every 2 months, they can be battery powered, perhaps solar charged, and radio activated.

Off-loading cargo will require a crane or some other equivalent system to get it off the expendable lander stage and place it on a trailer for transport to the base. If a prepared road has to be constructed (by removing boulders and leveling craters) for transporting cargo from every expendable landing site to the base, it would be so time consuming (see time estimates for road grading/leveling in Table 5-2 and Appendix D) that it would be easier to build it only once, and remove the expended descent stage from a permanent landing site after every mission. Fortunately, it appears that the lunar soil properties have enough load bearing capability that prepared road surfaces are not necessary (15). Certainly, a cargo transporter trailer can be constructed with wheels in numbers and sizes that it can carry any load without penetrating so deeply into the surface that it gets stuck. A 500 kg trailer loaded to capacity (17.5 metric tons) having 6 wheels, each 2.4 m diameter x 0.6 m wide (8'x 2'), would penetrate approximately 10 cm (4") into the soil, based on an average modulus of subgrade reaction for the lunar regolith of 1000 $KN/m^2/m$ (11). Table 5-6 lists the number of wheels, diameter, and width needed for a similarly loaded trailer given other allowable surface penetration depths.

The crane used to offload the cargo lander represents a significant design challenge. It should not be difficult to set up and it must be able to lift cargo heavier than itself. It will be landed on the first unmanned mission along with a cargo transport trailer and other construction equipment (including a prime mover as described in Section 5.5). Some method must be developed to offload the crane from the lander, possibly using a ramp or rails and driving it off, pushing it with the prime mover, or pulling it off with a specialized winch. If an unloading system has to be developed for the crane, it could possibly be applied in unloading other cargo as well, either to provide a contingency in case of crane failure or possibly to surplant the need for a crane in this capacity. However, because a crane is needed at the base site to position modules for berthing as well as other tasks, it remains a key payload in the baseline scenario.

5.4.2 Scenario for Landing/Launch Site Preparation Activities

Given the above considerations, the following scenario for landing/launch site preparation acitivities in Phase II was derived:

1. Landings during the Phase II lunar base will be at essentially unprepared surface sites.

2. Two (typically) 50 m diameter sites will be selected by each manned mission for subsequent manned and unmanned missions (sometimes only 1 is needed and at most 3). The sites selected will be relatively flat and free of large boulders or craters (detailed selection criteria are being developed by the parallel landing/launch site study) and separated by 200m - 1000m from each other to minimize effects caused by soil and dust kicked up by descent engine. The lunar base will be located in a

direction normal to the vehicle groundtrack to minimize the probability of an accident that might impact base elements.

3. The crew will survey the selected site to ascertain percise surface coordinates that will be used by the landers guidance system in conjunction with position fixes derived by radar transponders or other surface navigation aids. Navigation aids will be need to be emplaced by the first manned crew.

4. The selected manned landing site will be marked and lights will be placed for visually identifying the site during the terminal descent phase. The lights should be portable (hitched to an unpressurized rover), rugged to withstand any blast/dust from the lander's exhaust, and powered by an on-board storage system. Additional portable floodlights will be needed to unload the unmanned cargo lander at night.

5. A track for the cargo transport/trailer will be marked from the designated cargo landing site to the base.

6. The above activities will be performed by suited astronauts on unpressurized rovers (until pressurized rovers are delivered). At the completion of a mission, the crew should recharge the rovers' batteries and leave the rovers near (in a protected area or far enough away not to be damaged by soil/rocks raised by the descent engine) the designated landing site for the crew of the next mission.

7. A site will be designated and prepared for the reusable lander and support facilities. This site could be worked to provide one or more smooth, leveled surfaces (pads) and thereby reduce design margin requirements for the reusable lander's landing gear/-structure. An estimated 36 hours is necessary to survey, clear boulders, grade, compact the surface, and perform final leveling of one 50 m circular pad as given in Appendix D. The vehicle used for many of these tasks could potentially be tele-operated as described in Section 5.5. It was assumed in this estimate that the pad was located 1 km from the base. Power from the base distribution system would be extended to the pad area to recharge lander fuel cells, and power lights and maintenance equipment. Installing buried utility trays from the base site to this permanent pad site is estimated (from Appendix D) to require 40 hours: 25 hours by lunar base IVA crewman teleoperating a prime mover with trencher to dig the utility-way and prime mover with grader to backfill the trench after the utility trays have been deployed, and 15 hours of EVA by a 2-man EVA crew (30 hours total EVA) to install the utility trays. Other construction tasks associated with the reusable lander pads may involve preparing a road from the pad area to the base, building blast walls from local materials to protect nearby equipment/structures, and setting up a liquid oxygen tank car loading spot, all of which are defined in Appendix D.

8. The reusable lander will utilize this pad during Phase III. More than one reusable lander may be needed but has not been designated in the baseline scenario.

Table 5-6. Tire Size and Number for a Cargo Carrying Trailer

Cargo Mass = 17.5 metric tons
Trailer Mass = 0.5 metric tons

Modulus of Subgrade Reaction = 1000 $KN/m^2/m$

Depth Wheels Sink into Soil (cm)	Number of Tires	Tire Diameter (cm)	Tire Width (cm)	Tire Diameter (ft)	Tire Width (ft)
2.5	4	1196	299	39.2	9.8
10	4	316	79	10.4	2.6
15.2	4	225	56	7.4	1.8
2.5	6	914	228	30.0	7.5
10	6	245	61	8.0	2.0
15.2	6	179	45	5.9	1.5
2.5	8	755	189	24.8	6.2
10	8	206	51	6.8	1.7
15.2	8	154	39	5.1	1.3

5.5 Construction and Assembly Operations

A key surface operation will be the emplacement of pressurized surface modules. As given by the baseline assumptions in Section 3.0, four modules are required at the lunar base before crew stay times are significantly increased from the constraints imposed by the lander's Manned Module; they include three exposed modules (habitation, module interface node, and airlock) and one protected from solar flare radiation. This section will describe 1) options for emplacing buried modules, 2) the potential role for tele-operated/robotic construction operations, and 3) the methodology used to estimate the exposed and buried module emplacement times as presented in Appendix D.

5.5.1 Requirements for Radiation Protection

Lunar base crew members will require more protection than provided by a standard module from high energy particle radiation (19). The amount of protection depends on on the maximum dose limits and crew stay times. Allowable radiation dose limits for previous lunar and long duration missions were (21):

Mission	Dose Limit (rem)	Exposure Duration (days)
Apollo	50	14
Skylab	35	56

Space Station ionizing radiation exposure limits (rem) are (35):

Exposure Interval	Skin (.1 mm)	Eye (3 mm)	Bone (5 cm)
30 days	150	100	25
Annual	300	200	50
Career	600	400	100-400

Protection from charged particle radiation is a major issue to be addressed in lunar base habitation studies. Ionizing radiation can affect not only biochemical systems, such as the crew, but also electronics, especially integrated circuits, by producing soft upsets and permanent damage (31,32). Radiation threats can occur from both natural and man-made sources. Typical man-made radiation sources include leaking or inadequately shielded radioactive equipment such as RTG's, particle accelerators, and liquid metal heat exchangers. Even radio frequency radiation and electromagnetic radiation produced by RF generators can inadvertently trigger ordnance devices or interfere with the operation of critical equipment. Adequate design accommodation must be made to ensure that the lunar base crew and equipment are protected from all radiation sources; however, this study will treat protection from natural sources as the primary concern.

Penetrating charged particles can have sufficient energy to penetrate several centimeters of metal and still produce significant levels of ionization (radiation dose rate) on the other side (31). There are two primary sources of these particles on the lunar surface: energetic particles from solar particle events (SPE) and the galactic cosmic ray (GCR) flux. Both the GCR and SPE (on average yearly basis) fluxes on the lunar surface will be approximately half that of free space because of the 2-pi shielding by the planetary mass (33).

Galactic cosmic rays (GCR) are an omnidirectional flux of protons (82-85 percent), alpha particles (12-14 percent), and heavier nuclei (1-2 percent) arriving from interstellar sources such as supernova (32). The magnitude of the GCR flux varies inversely with the solar activity cycle, because the screening effect of the interplanetary magnetic field lessens with solar activity. GCR particles in the 100-1000 MeV/nucleon energy range increase 3-5 times when solar activity changes from maximum to minimum. Although the overall contribution from GCR to the total dose in rads is typically less than 15 percent, these particles (particularly the heavier nuclei) are considered responsible for unique effects in microelectronics including soft errors such as bit flips (31). GCR exposure is essentially inevitable in lunar surface operations, and constitutes a minimum baseline dose equivalent at the surface of approximately 18 rem/year (35).

Energetic particles from anomalously large SPE (ALSPE) are the primary risk of dangerously higher dose rates for the crew. The most significant component of these particles are high energy protons (few to several hundred MeV) ejected during solar flares, which are the bright eruptions from the Sun's chromosphere that tend to occur between sunspots or over their penumbrae (31). Thus, the frequency of solar flares corresponds roughly with the sunspot cycle, which averages 11.1 years but varies from 7 to 17 years. Although approximately 100 SPEs occur during a 11 year solar cycle (concentrated in 4-6 years of high sunspot activity), only a few SPEs are sufficiently large to be considered dangerous (36). The largest SPEs normally occur during the ascending or declining portion of the solar cycle (32) with perhaps a greater tendency for them to occur after the sunspot peak (37). Major SPEs are usually absent during solar maxima or minima. The last solar maximum occured in 1980 and the next will likely occur near 1991 and 2002.

Flares events require only minutes to develop (37). Solar particles will reach the vicinity of Earth within minutes, reach peak intensity in a few hours, then decay over the 36-48 hours (31, 37). In part because flares last for only a couple days, during which the Sun has rotated ~30° on its axis (given a 25-day solar rotational period), the effects of a SPE are concentrated in solar longitudes near where the parent solar flare occured. Thus, the intensity of the radiation reaching the lunar surface will depend not only on the intensity of the flare (which is notoriously variable from flare-to-flare) but its direction relative to Earth. During the first phases of the SPE, particles arrive from the direction of the Sun; however, they are rapidly scattered by the interplanetary field until they appear to come from all directions (36). Thus, a shield placed in the direction of the Sun is not expected to reduce the total radiation dose greatly (36). If this phenomenom applied to a shield the size of the Moon, solar flares might effect even night lunar operations. Based on solar particles released in one of the largest flare recorded (August 4-7, 1972), the expected equivalent doses major body organs would be exposed to in a spacecraft are (doses on the lunar surface would be approximately half as much due to 2-pi shielding by the planetary body):

Radiation Source	Skin Dose	Deep Dose (5 cm)
Chronic Exposure to GCR		
in Free Space	36 rem/year	27 rem/year
(with 4 g/cm^2 Al or 1.5 cm thick shielding)		
Acute Exposure to ALSPE		
in Free Space	1106 rem	105 rem
(with 2 g/cm^2 Al or .7 cm thick shielding)		
in Free Space	27 rem	7 rem

(with 15 g/cm^2 Al or 5.5 cm thick shielding)

Comparing this expected exposure with the allowable dosages given before, it appears obvious that the lunar base crew will require radiation protection from major solar flares. Also, it appears the exposure from galatic cosmic rays is well within Space Station allowable limits, especially for the short duration missions (14 and 30 days) planned for the majority of Phase II. (Note that the total dosage of ionizing radiation the crew will receive on a mission also includes exposure to particle radiation in the Van Allen Belts which are traversed twice, and the equivalent dosage of secondary neutron radiation.) The above radiation dosages should not be construed as maximums. It has been reported that the August 1972 flare would have resulted in 10 times more radiation than actually recorded if the flare had occured 4 days later when the flare zone on the Sun was in more damaging position relative to the Earth (33, p.635).

The required quantity of protection varies depending on assumptions concerning the radiation threat, allowable radiation dose, and effectiveness of shielding. In this study, it was assumed that 700 g/cm^2 of lunar regolith shielding is required to provide adequate (<5 rem) protection from the worst ALSPE (19). This corresponds to ~4 m of regolith, given a bulk lunar soil density of 1.66 g/cc (11).

5.5.2 Options for Providing Radiation Protection

With a solar maximum expected around 2002, it was assumed that emplacing a solar flare radiation shelter would be a high priority objective for the crew in 2000, and one of the requirements before risking longer stay times. An estimate was made of the time required to emplace an exposed and a buried shelter as given in Tables 5-2 and 5-4. Far more time is required to place a buried shelter. Because over 160 hours of Earth teleoperation, 20 hours of Lunar teleop, and 70 EVA hours were estimated for emplacing a buried module (4.45 m dia. x 7.23 m long) while an exposed module might only require 10 hours Earth teleop, 10 hours Lunar teleop, and 40 hours EVA, there was a major incentive to bury only what was required during Phase II to meet radiation dose limits.

Thus, the scenario in this study required that only one module be buried initially for radiation protection. This module was covered by ~4 m of regolith all around and was connected by a 5 m long tunnel to the other exposed modules. All other modules remain unburied until Phase III. This allows limited human resources to be directed to other base construction and science activities. The exposed modules also allow easier growth. Buried shelter utilities are brought in through the tunnel; therefore, a standoff between the shelter and surrounding regolith to provide maintenance access to the exterior of the shelter is not considered required. As in Space Station, the utility connections between modules are located around the outside of the berthing ring (203 cm diameter). A rounded-corner square hatch opening is located at the centerline of the frame inboard of the utility feedthroughs and is 127 cm x 127 cm in size with a 30.5 cm radius in each corner. Utilities are also fed through the radiation shelter/tunnel and tunnel/module berthing assembly. Cables and fluids lines from the power, thermal control, and communications systems interface at unoccupied berthing ports on the module interface nodes and are subsequently routed to the rest of the modules.

The scenario used in this study for emplacing the core pressurized modules of the base involved the following sequence of steps spread over several manned missions: prepare a site large enough for all pressurized modules; excavate and lay a buried utility distribution system; place the radiation shelter; berth access tunnels to either end of the radiation shelter; provide power and other utilities via the access tunnel at one end of the shelter; cover the radiation shelter (illustrated in Figure 5-4); berth a 5-port module interface node (No. 1) to the other end of the shelter; provide redundant utility connections into this node; berth an airlock, habitation module, and geochemical laboratory to the other ports of node 1; place node 2 at the end of the habitation module; provide redundant utility connections to node 2; berth airlock 2 to this node; berth a pressurized garage to airlock 2; attach the first life sciences module to node 2; berth a life sciences interface node to the life science 1 laboratory; provide redundant utility connections to the life sciences interface node; berth a logistics module to node 2; attach a module interface node 3 to the geochemical laboratory, and provide redundant utility connections to it; and emplace the final Phase II module, a second life sciences laboratory, between node 3 and the life sciences node. Power, thermal control, and communication systems are set up during early missions and connected to the utility distribution system. Details of early missions in this scenario are:

1. A base site is selected, surveyed, and marked by the first manned crew (Mission 2).

2. A crane & trailer, prime mover (PM), and PM attachments are unloaded, checked out, and transported to the base site by the second manned crew (Mission 4).

3. A 50 m x 50 m base site was prepared by over 40 hours of PM operation using bulldozer blade, grader, and backhoe attachments in the Earth teleoperation mode. (The Mission 4 crew monitors this operation as an IVA activity or while conducting surface exploration, lunar science and geology experiments in the intervening time). The crew will conduct final leveling operation using a PM/Bulldozer blade in the manual mode.

4. The Mission 4 crew also begins to prepare 300 m of utility-ways around the 50 m x 50 m site by using the PM/trencher or PM/backhoe in the Lunar IVA teleoperated mode.

5. The Mission 6 crew unloads utility-ways from the cargo lander, transports them back to the base, installs them into the utility-ways prepared by the previous mission, and backfills the trench (teleoperated by the crew from the Manned Module).

6. Using the PM/front loader/cart, a 1 m deep x 6.5 m wide x 7.3 m long trench is excavated (Earth teleoperated) where the shelter will be placed. The 1 m deep soil is assumed to be reasonably easy to move, although it is recognized that the soil becomes more packed, and contains larger stones with depth (11, 15). This trench depth also allows a 3 m high x 2 m wide tunnel to have its floor meet at the same level as the lower edge of the berthing ring. This allows easier movement of crew from the tunnel into the shelter as well as connection of utilities at the berthing ring interface.

7. The Mission 6 crew than unloads cargo from the unmanned lander including the radiation shelter with attached mounting cradles (& movable leveling legs), bulkheads, and conveyor/hopper system, and the cargo is transported to the base.

8. The conveyor/hopper system is unloaded from the transporter and checked out. The bulkhead sides and ends are laid out and restraining straps are positioned. The shelter is unloaded from the transporter, positioned, placed in the trench, and leveled. These activities are carried out by a 2 or 3 man EVA team assisted by a

IVA crewman assisting on crane positioning/control via teleoperation. Figure 5-4 illustrates steps in the shelter installation.

9. The tunnels are unloaded from the transporter, each is positioned and mated to either end of the module. Interface connections are made between the tunnels and shelter for power/communications/data management/thermal/and ECLSS.

10. The initial power system, thermal control system, and communications station is unloaded from the cargo lander, transported to the base, individually unloaded from the transporter, checked-out, and positioned. Utility-ways and/or power cables are installed in trenches excavated from each system to the utility grid emplaced around the base module site, and connections are made at both ends.

11. The shelter system is powered up and thoroughly checked out.

12. The bulkhead is set up by lifting the sides and retained by using compression rods installed between the module and bulkhead.

13. The hopper/conveyor system is positioned to fill the bulkhead, powered up and performance checked after loading the hopper with regolith (using the prime mover/-front loader).

14. The bulkhead is filled (~1400 m^3 soil required) by teleoperation from Earth of the prime mover using a 1 m^3 front loader (or back loader if the soil is not soft enough) to fill a 8 m^3 cart (1 m high x 2 m wide x 4 m long), transport it back to the base, and dump it into the hopper (cart is similar to the bed of a dump truck). The hopper feeds regolith onto a conveyor belt (with vertical risers to contain the soil) that carries soil to the top of the bulkhead. The conveyor belt must be 16 m long to reach 4 m over the top of the bulkhead, and to remain directly over the center of the module. The conveyor/hopper system is not self-propelled, but it is on wheels to enable the prime mover to push or pull it into a new position after filling the bulkhead in front of it.

15. The radiation shelter's systems are function checked again through a test and verification sequence from Earth and the Mission 9's crew (IVA remote and EVA).

16. Prior to Mission 9, Earth teleoperation has controlled prime mover/front loader excavation of 1 m deep trenches for all exposed modules (4 nodes, 4 full-length modules, 2 airlocks, pressurized garage, and logistics module). Each trench is dug 1 m wider on either side to allow access for leveling the module after placing it with its cradle in the designated locations.

17. The crew of Mission 9 will unload a module interface node landed on Mission 8, and to the shelter's access tunnel.

18. Redundant power, thermal control, and communications connections are made from the utility distribution system to this interface node. Redundant utility connections are made to each interface node to provide multiple utility feeds in case a node is lost from fire or other contingency.

19. The Mission 9 crew will unload, transport, position, place, berth, and level a airlock. The node/airlock power, communications, data management, thermal, and ECLSS

interface connections will be made. The node/airlock systems will be powered up and checked out.

20. The Mission 11 crew will unload and transport a habitation module to the base site. The module will be positioned and berthed with the module interface node. After leveling the habitation module, the crew will connect power, electrical and fluids interfaces between it and the interface node. The Habitat will be powered up, systems tested, and verified. Habitat internals will be destowed. If the module becomes operational before the usual 8-day crew stay time limit has expired, the crew will remain on the surface for 24 days. Emplacing the habitation module is the last step to achieving the man-tended base program milestone.

There are, of course, many options other than the buried module scheme picked in this study. To provide ~4 m deep lunar soil protection from solar flares, the following techniques could be used:

<u>Bury Module</u>

1. Excavate hole deep enough to completely cover module with 4 m soil (~9 m deep for 4.5 m diameter module). The hole can be dug (a) without bulkheads, allowing soil to settle into its natural angle of repose, or (b) with bulkheads pushed down around the hole as it is excavated to limit the amount of soil to be removed (and thus reducing excavation time).

   Completely buried module options were not considered viable because of the uncertainty of the subsurface structure to 9 m, especially in maria regions. As explained in Section 4.3, loose soils in maria regions such Lacus Veris may only extend 3-5 m before transitioning into a region of large, broken boulders and bedrock. Excavating deep holes in maria areas, therefore, appears likely to take more time and be more difficult than collecting soil from shallow excavations to cover modules. Also, excavating a hole that would be backfilled later is inefficient since it means that the soil is handled twice: once when digging the hole and transporting the excavated soil to a pile, then a second time to backfill the excavation after placing a module. This is much less efficient than collecting soil once to cover a module.

<u>Partially Bury/Partially Cover Module</u>

2. A combination of excavating a hole and covering the module could be employed to provide the required protection. Options for this technique include (a) excavating and covering without bulkheads, (b) using subsurface bulkheads to minimize the volume of the excavation, (c) using surface bulkheads around the module to minimize the amount of soil needed for covering, or (d) both surface and subsurface bulkheads. Minimizing the amount of soil that is moved while emplacing a protected module was studied as a method of reducing the amount of time needed for this operation. Using no bulkheads, and assuming a 35° angle of repose for soil in surface piles and subsurface excavations, the total volume of soil (excavated hole volume plus above surface cover soil volume) used to protect a radiation shelter with 4 m soil was determined for different ratios of hole to above surface cover depth. As given in Table 5-7, the minimum volume of soil moved (once) occurs when half the total height of module and overburden is above the lunar surface and half is below (a hole 4.5 m deep needed to bury a 4.5 m diameter module with 0.5 m cradle and cover with 4 m soil).

Cover Module

3. Completely cover module with regolith without bulkheads as shown in Figure 5-5.

4. Completely cover module without bulkheads but after constructing an envelope structure around the sides of the module to allow direct access by the crew to the exterior of the module for maintenance/inspection. This option is described elsewhere (20).

5. Use bulkheads surrounding the module to minimize the amount of soil necessary to completely cover module. Constructing bulkheads will of course take some time. However, as given in Table 5-2, covering a radiation shelter without bulkheads consumed 190 hours, 60 hours more than estimated using bulkheads. Raising bulkheads was assigned as an EVA activity, resulting in more EVA time required for covering with a bulkhead. However, the connecting tunnels will be shorter and easier to manage with the bulkhead scheme. Also, a structural envelope to allow direct EVA access to the exterior of the module was not considered necessary with the bulkhead scheme. Given that utilities enter the module complex at the nodes, and are routed to the radiation shelter through an access tunnel, access to the module's exterior skin was not considered likely. If access is required on a very infrequent (contingency) basis, the straps stretched between opposite sides of the bulkhead can be detached, allowing the soil to spill out. After removing the remaining soil with a prime mover equipped with bulldozer blade, the required maintenance could be performed, bulkhead reconstructed, and soil conveyed back in.

6. Sandbags could be filled (automatically) and placed completely around the module (38).

7. Bricks made by hot pressing lunar soil could be made (automatically) and placed completely around the module.

8. Soil could be loaded on blankets stretched on the surface on either side of the module. Cables would be attached to the far end of one blanket and routed over the module to a power winch which would pull the loaded blanket over the module. The operation would be repeated for the blanket on the other side of the module. The blankets would need to be specially constructed so that sections of the blanket would draw close to keep the soil in place as it is pulled over the module. The finished product of this technique is illustrated in Figure 5-5.

9. The modules could be covered with the assistance of carefully placed explosive charges as suggested in the CNDB (2).

Table 5-7. Required Volume of Soil Moved to Bury/Cover Radiation Shelter

Module Dimensions (for radiation shelter)	
Diameter (m)	4.5
Length (m)	7.23
Approx. Volume of Shelter (m^3)	115.0
Angle of Repose (deg)	35

(Note: Soil required for covering compensated for volume of module)

Depth of Excavation (m)	Height of Soil Cover (m)	Volume Covered (m^3)	Soil Req. for cover (m^3)	Volume Excavated (m^3)	Volume Total (m^3)
0	9	3,632	3,517	0	3,517
1	8	2,725	2,610	52	2,662
2	7	1,981	1,866	154	2,020
3	6	1,386	1,271	322	1,593
4	5	921	806	572	1,379
4.5*	4.5	734	619	734	1,352
5	4	572	457	921	1,379
6	3	322	207	1,386	1,593
7	2	154	39	1,981	2,020
8	1	52	0	2,725	2,725
9	0	0	0	3,632	3,632

* Minimum total volume of soil moved in covering and burying (i.e., Excavation) module occurs when excavation equals half of overall height distance = (diameter of module + depth of required overburden + 0.5 m for module support cradle).

Figure 5-4. Assembly Sequence for Covering Radiation Shelter using Bulkheads

Buried Shelter Construction

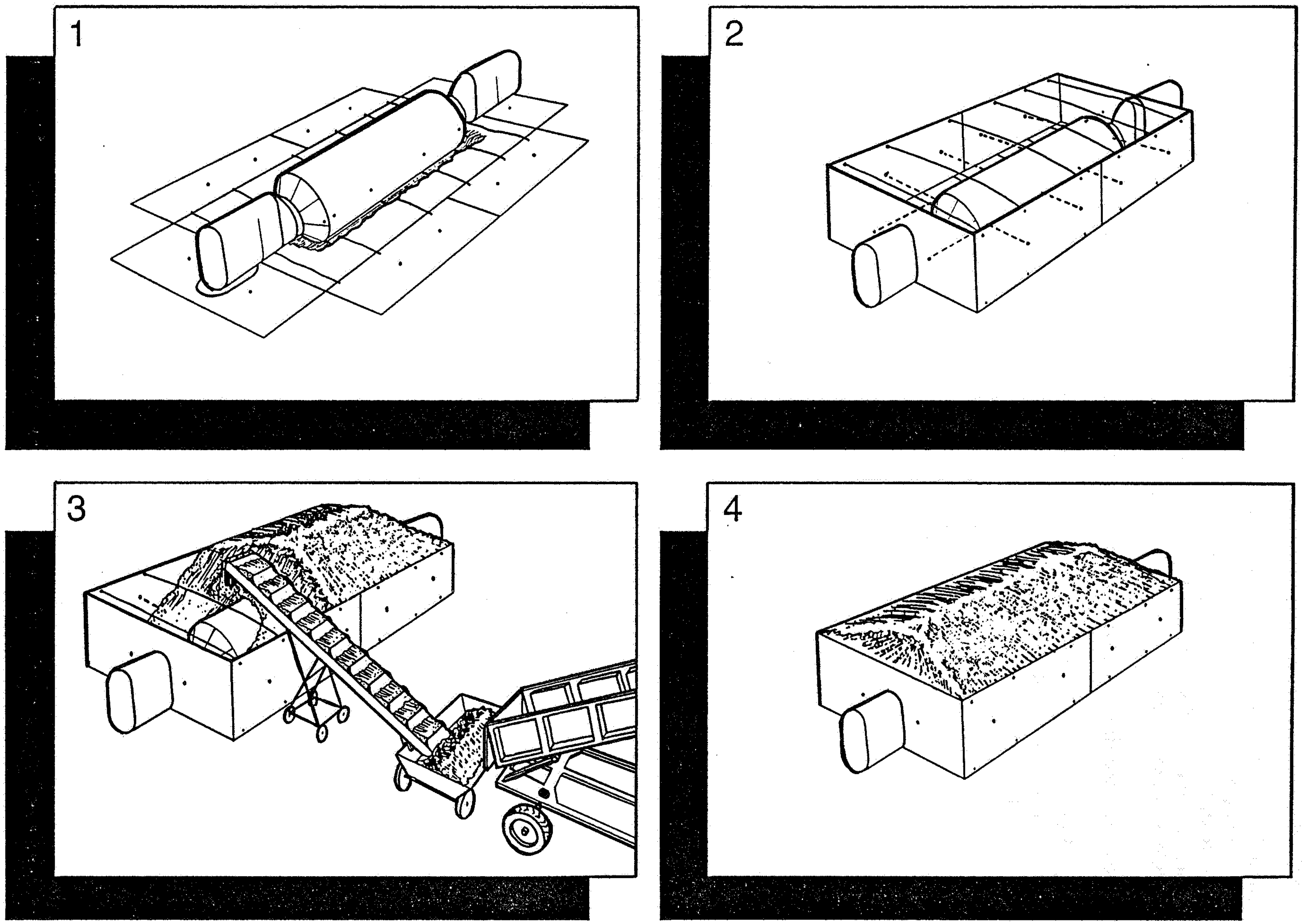
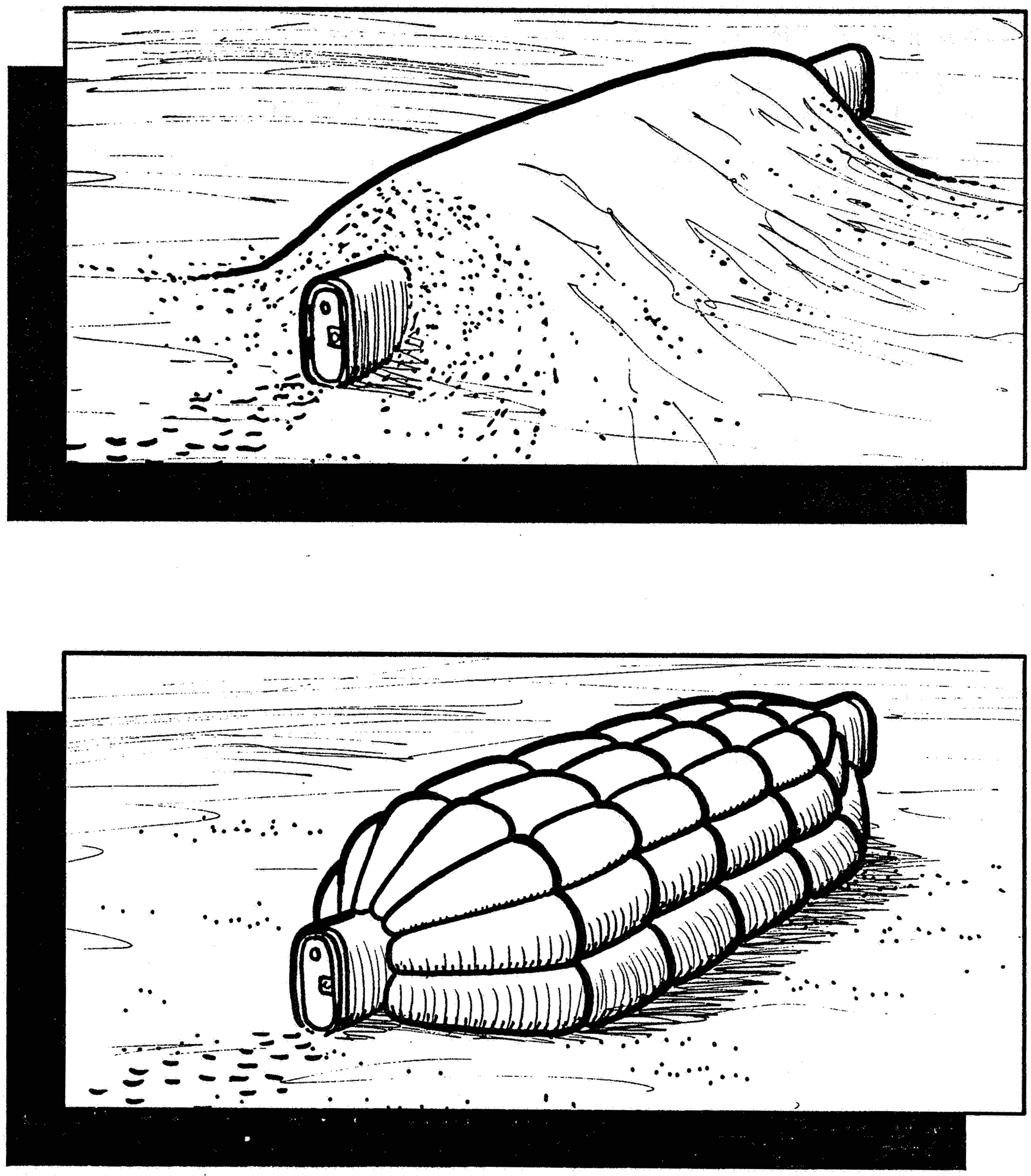


Figure 5-5. Buried Module Alternatives: Covered without Bulkheads and Covered with Filled "Blankets"



5.5.3 Lunar Construction Equipment Considerations

The ability to move quantities of lunar soil and rocks will be required during an early phase of the lunar base to cover a module for radiation protection. Although soil moving operations are similar to those encountered during Earth construction, the equipment will be different due to several constraints imposed by the lunar environment.

Hydraulic systems should not be used on the Moon due to the high maintenance requirements anticipated resulting from the vacuum, high radiation, and regolith dust environment.

All regolith moving equipment motions will be electrically operated since powerful diesel engines cannot be practically employed. This is true not only for vehicle forward and reverse motions, but all linear and rotary motions.

Technology exists to design "smart" regolith moving equipment which would be telerobotically controlled, rather than carry life supporting enclosures for crew operation. Teleoperated vehicles should be designed to have growth potential for supervised autonomous operation. Such vehicles would eventually be capable of performing some tasks totally autonomously after confidence has been well established.

Telerobotic vehicles for lunar operations will require technology development, particularily in adapting automation and robotic (A&R) systems to the lunar environment. Continued support of A&R research in areas such as software architecture, sensors, rugged mechanisms, and fault detection and recovery, is required (42). Solutions to problems imposed by the 3-5 second communications delay in Earth-controlled lunar teleoperation applications deserves particular study. A high degree of on-board computation capability for nearly autonomous operation with human supervisory control is indicated. Extension of the state-of-the-art and integration of this technology with other systems (software, sensors, processor, mechanisms, and external navigation systems) will be required for Earth teleoperations.

5.5.4 Baseline Construction Equipment

Construction equipment required by the scenario described in this study includes the following:

1. Crane and cargo carrying trailer: The crane must be capable of lifting 17.5 metric tons. The ability to operate the crane in both manual and teleoperated modes could be advantageous.
2. Prime mover and soil carrying trailer: The prime mover (PM) is described in more detail later in this section. It must be capable of pulling a fully loaded cargo carrying trailer (18 metric tons) or soil trailer (14 metric tons).. The PM would have various attachments: bulldozer blade (3 m wide x 1 m high), front loader shovel (1 m^3 capacity), backhoe (1 m^3 capacity), power winch and cable system, surveying system, grader blade (3 m wide x 1 m high), and it must be equipped with a hitch to pull a trailer. The soil carrying trailer measures 1 m high x 2 m wide x 4 m long and its must be able to dump soil into the hopper/conveyor system used to cover the radiation shelter.
3. Hopper/conveyor system: This equipment would be used to cover a module for radiation protection. The hopper would have the capacity to hold 16 m^3 of regolith (2 trailer loads) and a screening system to remove large rocks. A 16 m long conveyor belt would be attached to the hopper, conveying soil out of the hopper onto the top of a module. Some assembly of this system will be necessary. The hopper/conveyor

would not be self-propelled but would need to be mobile. The structure supporting the conveyor would also require wheels. The PM would pull or push the hopper/-conveyor the short distance required to place it in a new position to continue filling the bulkhead surrounding a module.

4. Storage Shed: An unpressurized, light-weight storage shed may be required to provide a thermally controlled area for the construction equipment. It could be made from graphite/epoxy truss covered by flexible thermal blanket/micrometeoroid shield. Although this equipment must be capable of operating during the long cold lunar night, keeping sensitive subsystems within allowable temperature ranges will be easier when the equipment is stored in a temperature controlled shed. The shed would be located near the base because the crane and prime mover is required there or at the landing field, and because it is convient to the power distribution system. Power outlets in the shed would allow all vehicles to recharge fuel cells while they were stored. The prime mover will require a designated area to store and change-out attachments. The crane, prime mover, and other construction equipment will require a spare parts storage area as well. Storing this equipment in a covered shed may be required to reduce dust contamination and to protect against micrometeoroids and UV degradation. Maintenance would be easier in a dust controlled area. A representation of the storage shed is given in Figure 5-8.

Details of the construction equipment follows.

Cargo Handling Equipment. Construction activities on the Moon will require capability to offload heavy (18 metric ton) payloads, transportation to a construction site, offload them a second time, position and emplace them. A crane with trailer is described in Section 5.4.

Earth Moving Operations. The typical types of Lunar Surface construction can be broken down into the following operations with regolith:

1. Leveling
2. Trenching
3. Digging - Ripping - Scarfing (Loosening)
4. Filling
5. Transporting Regolith & other equipment.
6. Covering Shelters
7. Lifting & Repositioning Regolith & equipment
8. Pulling/Pushing equipment
9. Compacting
10. Drilling
11. Drag Lining

Examination of these operations suggest that a standard electrically powered prime mover can be designed to provide all construction operations anticipated for the lunar surface (Figure 5-6). Special purpose attachment implements can be designed to fit the prime mover to perform construction operations. The lunar prime mover (PM) will be equipped with a linear motion drive and a Power Take Off (PTO) rotary drive for the family of implements.

Multiple prime movers can be employed when excavation, hauling, etc., requirements grow to justify it. Heavier duty operations can then be accomplished by operating two or more prime movers in tandem (like train engines) to pull heavy loads, or pushing together against heavy loads beyond the capacity of a single prime mover. Figure 5-7 illustrates a standard prime mover conducting various types of construction work on the lunar surface.

A general purpose utility trailer will also be required for hauling equipment, ore, etc. This trailer will also be modular in design so that a variety of trailer beds and fixtures can be attached for a variety of applications. Figure 5-7 shows the general purpose utility trailer being filled with soil and Figure 5-4 shows the trailer dumping its load into the hopper for covering a radiation shelter.

Implement Requirements:

Given that a standard prime mover can be designed, a family of special purpose implements that can be easily attached and removed (possibly by robots or possibly by using a specially constructed fixture) must be developed. The motion requirements for each implement must be defined and electrically powered drive mechanisms must be designed to provide the necessary motion to operate the implements. The following suggests the type of detailed analysis that must be performed:

	IMPLEMENT:	MOTION REQUIRED:
1	Blade	UP / DOWN
2	Mechanized Trencher	UP / DOWN - ROTARY
3	Bucket with scarfing teeth	UP / DOWN
4	Bucket and/or Blade	UP / DOWN BUCKET - CLOSE/RELEASE
5	Trailer / Bed	UP / DOWN TO UNLOAD BED
6	Bucket and/or Blade	UP / DOWN BUCKET - CLOSE/RELEASE
7	Boom	UP / DOWN (EXTEND?)
8	Bumper / Hitch	N/A
9	Compacting Tracks on Prime Mover	N/A
10	Drill	UP / DOWN - ROTARY
11	Winch	ROTARY
12	Power Take Off (PTO)	ROTARY

Reference should be made to Figure 5-7 for an illustration of typical implements in use. Several implement drive mechanisms will be required to complement the lunar standard prime mover. All drive mechanisms will employ high gain mechanical techniques like worm gearing, jack screws, and planetary gearing to convert low torque, reversible DC motor drives to linear and rotary motions with sufficient force (and torque) to operate the family of implements.

Control Requirements:

The capability of operating the prime mover in either manual or teleoperated mode would help to reduce required EVA. A remote tele-robotic control station for the prime mover is no small consideration. Such a station must be comfortable and give the operator the sense that he has the "feel" of operating the prime mover as if he were sitting on it (Figure 5-9). Employment of stereo vision television for depth perception vision, and bi-lateral force feed back for motion controls can be developed (and Earth tested) to closely simulate this sensation.

The general controls required for prime mover(s) and attached implements are:

1. Start/Park
2. Initiate Diagnostic Check/out
3. Remain stationary
4. Accelerate Forward to variable set speed
5. Decelerate to Stop (Brake)
6. Accelerate Reverse to variable set speed
7. Turn Right
8. Turn Left
9. Raise Implement
10. Lower Implement
11. Turn PTO on Clock-wise
12. Turn PTO on Counter Clock-wise
13. Turn PTO off
14. Bucket Open
15. Bucket Release
16. Vision System On/Off
17. Lights On/Off
18. Vision & Lights Pan Right/Left
19. Vision & Lights Tilt Up/Down
20. Vision Zoom In/Out

The control station will be supported with a caution/warning console to alert the operator to contingent operation requirements.

General Monitoring Measurement (Caution/Warning) Requirements are:

1. Diagnostic warnings
2. Loads on Implements
3. Temperatures
4. Radiation
5. Time until Service Due

Prime Mover Power Considerations:

Regenerative $H_2/O_2/H_2O$ Fuel Cell packs with electrical and mechanical quick disconnects will be employed. These packs will be modularly connected to deliver the power level required for the application. The basic power pack could also be used for a generic lunar telerobotic servicer (described in Section 5.9). Several of these packs will be combined to provide power to the heavy duty prime movers.

While prime movers are operating, extra packs will be readied for quick change-out. Replaced fuel cell packs will be serviced and added to the set of available packs.

Operations:

All prime movers and implements will be stored and serviced in an unpressurized shelter. For those operations that will routinely result in the prime mover being near the service shelter, EVA crewmen or teleoperated robots in the shelter will remove the prime mover regenerative fuel cell for service. The crewman/robot will then attach a replacement modular regenerative fuel cell, perform a diagnostic check-out operation on the installed fuel cell pack, and authorize the prime mover to return to operational status. This quick change out operation will probably require only about thirty (30) minutes once the prime mover is in the service shelter.

For those operations that do not routinely result in operations in close proximity to the service shelter, it may be practical to have a Generic Lunar Telerobotic Servicer (see Section 5.9) deliver replacement regenerative fuel cell packs to the operations site and perform the exchange and check-out.

A drag line (winch/cable) may be established at the equipment shelter for retrieving failed equipment. A winch pack will be developed for attachment to prime movers for relatively low energy applications (ie. climb steep inclines) or in combination with a short boom, to lift payloads too large for the crew but too small to take the time to position the large crane.

Cleaning the equipment of regolith dust build up is anticipated to be a major servicing requirement for reliable operations. Dust build up will have to be periodically removed from TV camera lenses, lights, antenna, electrical diagnostic ports, mechanisms, etc. for reliable operation. An equipment static electricity "shower" may have to be provided for both electro-statically attracted and settled regolith films and deposits. Portable regolith removal fixtures may have to be developed to be robotically taken to prime movers excavating in the lunar mining area.

Constraints and Limitations:

The approach to remotely controlling the prime mover and its attached implements will require line-of-sight transmission from the control station to the antenna on the prime mover. If the prime mover is to operate inside a crater or excavation or behind a lunar obstacle, a communications relay tower will have to be set up on the rim or on top of the obstacle to maintain line-of-sight communications.

Heat rejection for the concentrated electronics and drive motors in the prime mover(s) will present a major environmental control problem for the prime mover(s) especially if dust collects on the radiators. The radiation direction will be limited to the up direction.

Buildup of static electric charge on the prime mover(s) will result in attraction of regolith dust. A static discharge scheme for the prime mover will be more complex than dragging a ground strap since the body of the prime mover(s) will be of non-conducting carbon composite to save weight. Control of the prime mover(s) will be reduced or inhibited if the TV lens are obscured with dust.

Earth tests to support lunar regolith moving equipment:

Comprehensive tests will be conducted on Earth with simulated lunar soil to verify the concepts postulated in this study. The following major lunar tasks should be Earth tested:

- Remote Controls
- Robotics
- Diagnostics / Service / Maintenance / Repair
- Power Profiles verified
- Heat Dissipation system verified
- Implement effectiveness
- Regolith dust removal

Construction around a Lunar Base can be supported with existing and improved technology. Considerable testing should be performed on Earth however, several years in advance of final equipment design.

Figure 5-6. Lunar Prime Mover (Shown Without Attachments)

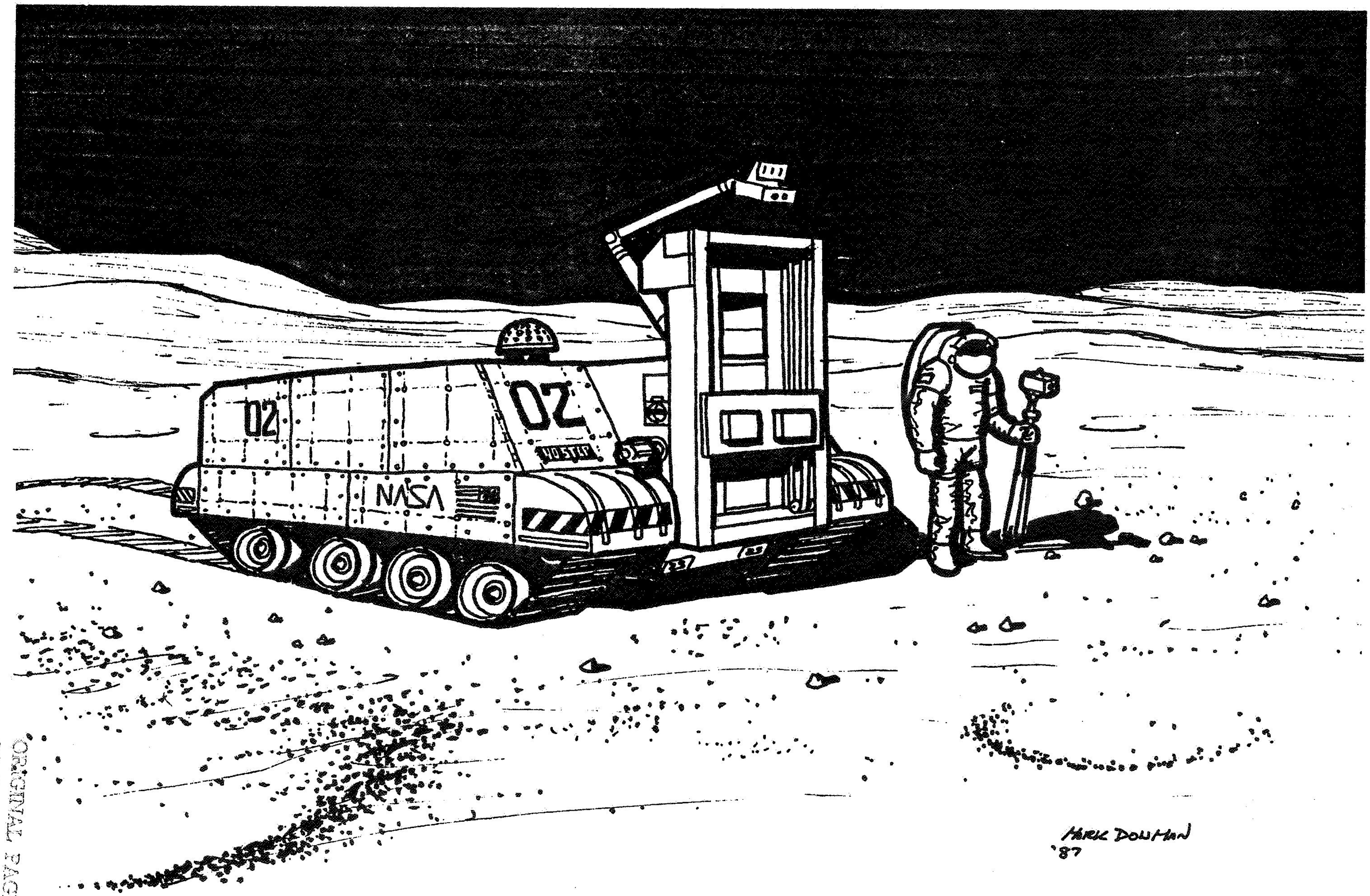


Figure 5-7. Typical Prime Mover Operations: Filling Trailer, Bulldozing, Drilling

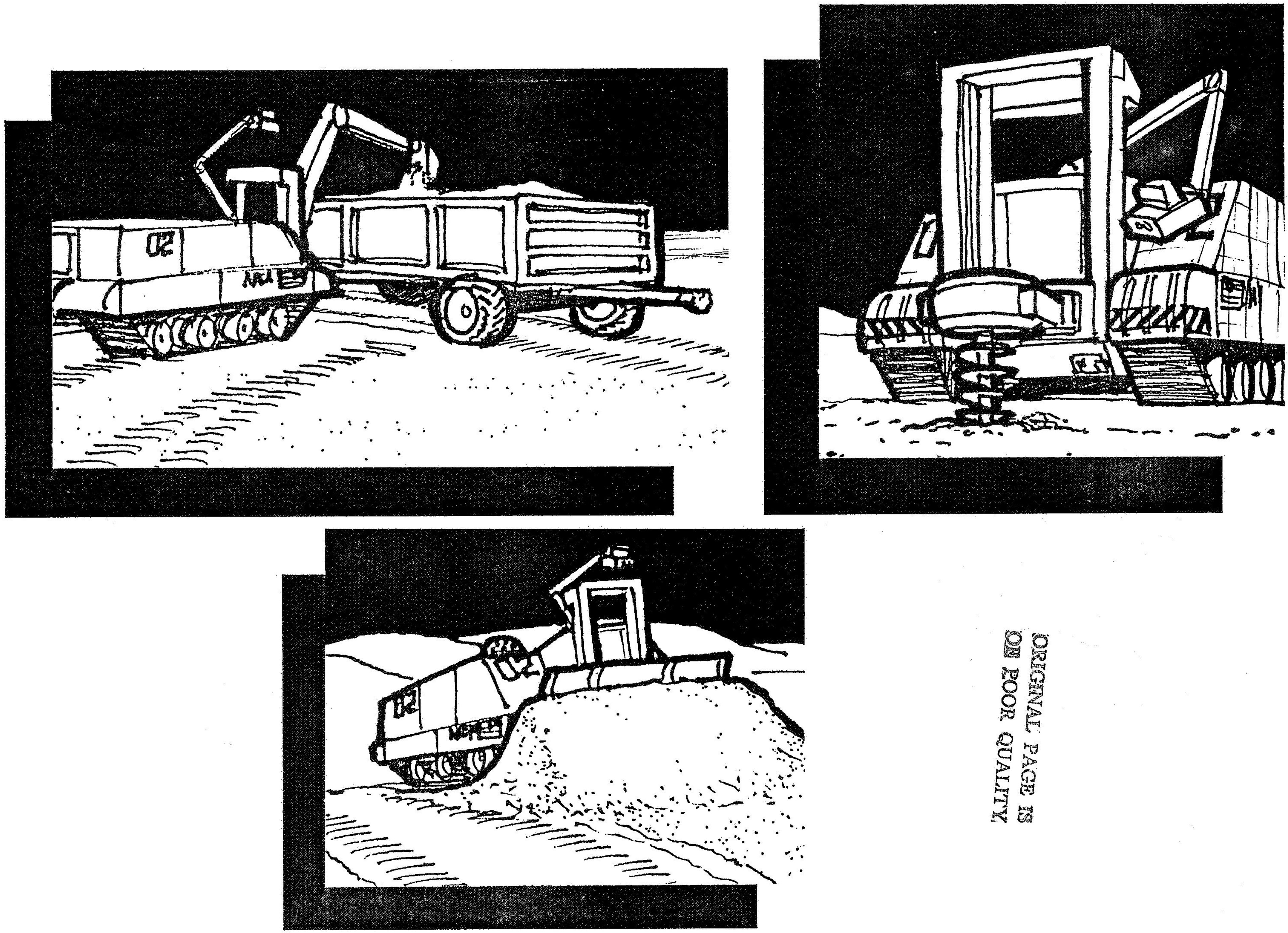
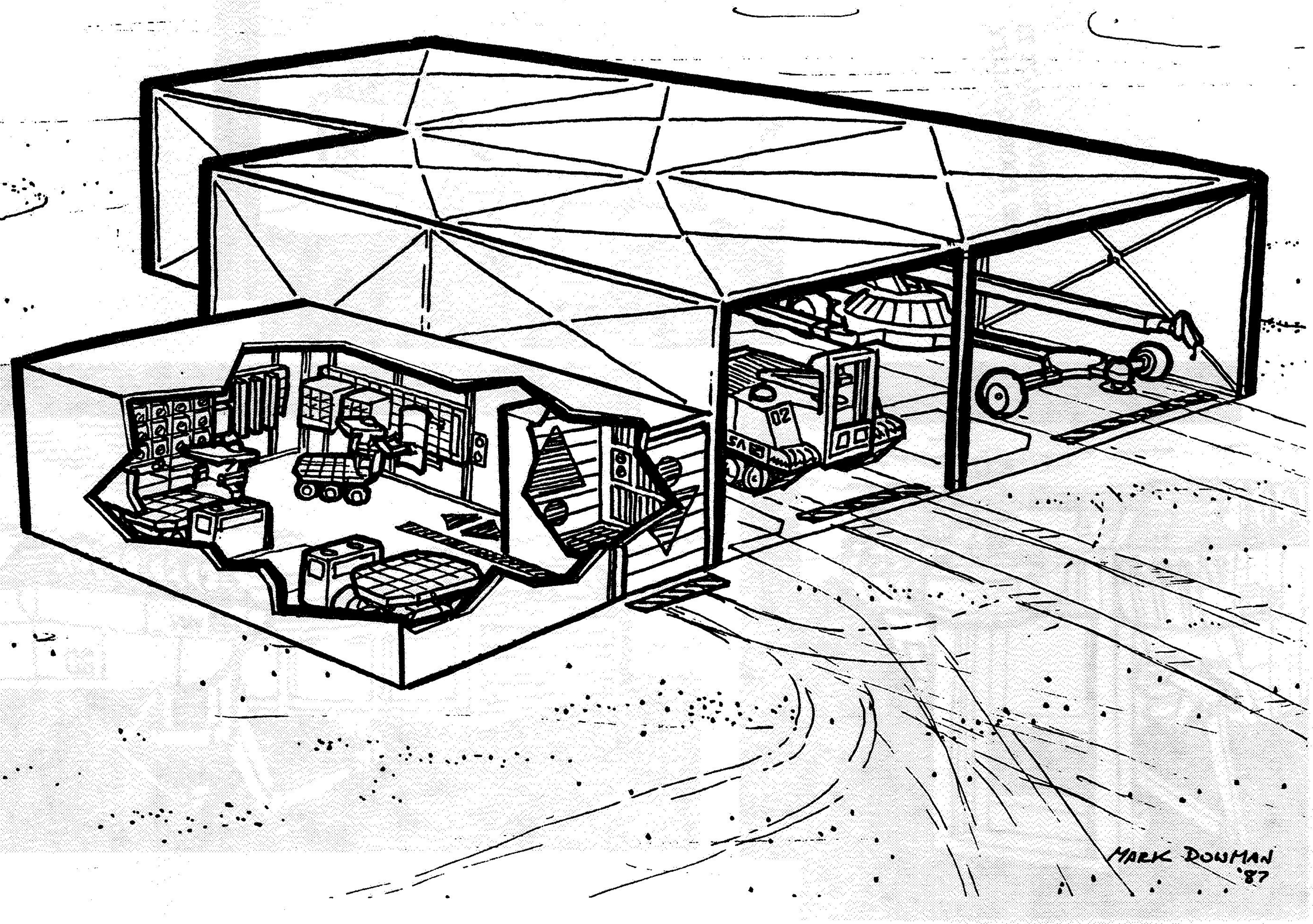


Figure 5-8. Unpressurized Storage Shed



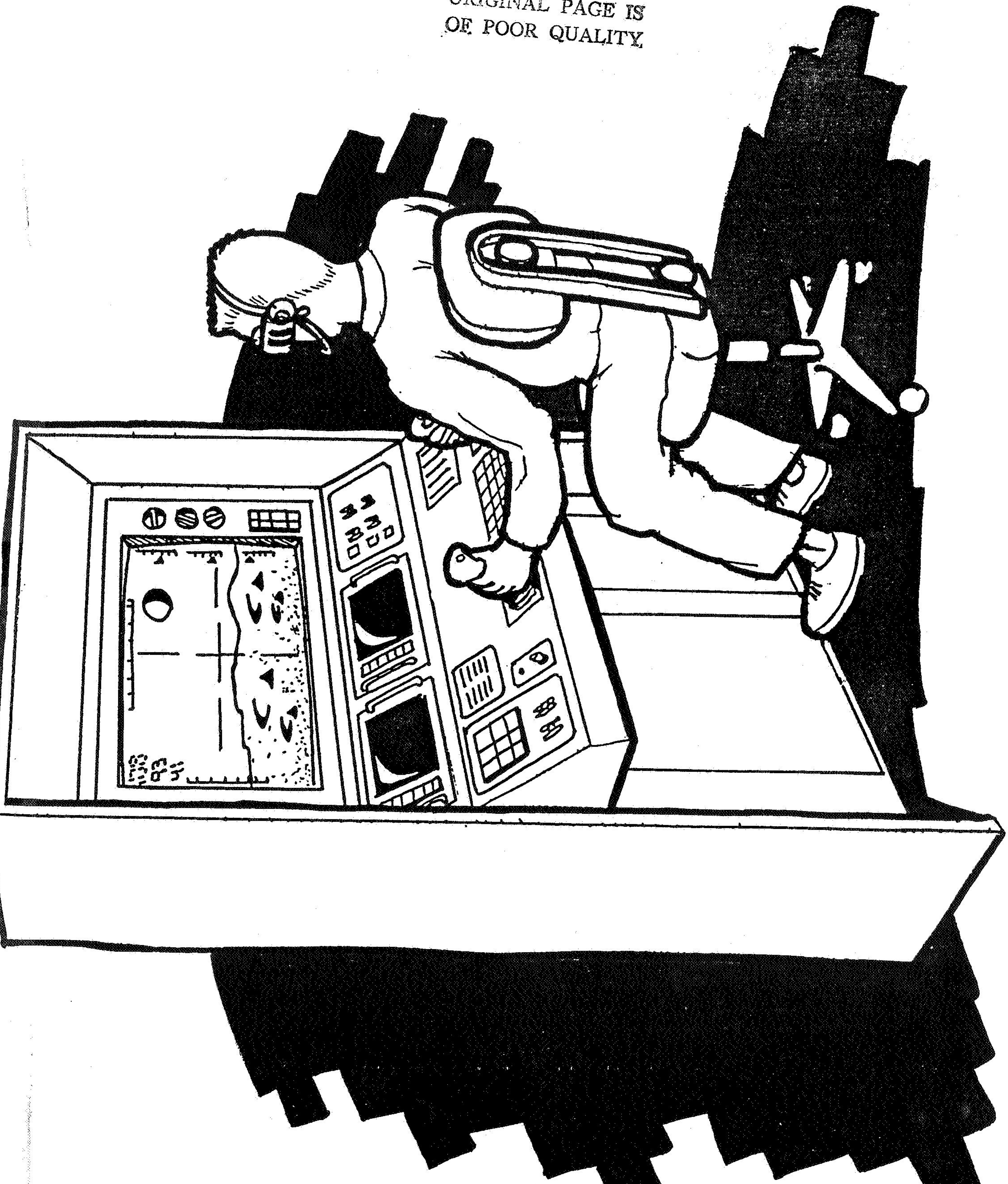


Figure 5-9. Prime Mover Teleoperated Workstation

5.6 Science Operations

Lunar base science evolves with progressively more complex science missions during Phase II. However, many missions are deployed and/or operated independently of the base. This decoupling of on-going science missions from base operation allows allocation of more crew time to base building. The major science missions are listed below; also shown are those that are deployed automatically or by lunar base personnel, managed/-controlled by Earth or the lunar base, and the year they are deployed in the Phase II period. Active operation periods for all science experiments are expected to continue throughout Phase II.

Mission	Year Deployed	Deployment Mode	Operation Mode
Lunar Science/Field Geology	1999-2005	LB Crew	Lunar Base
NS,FS,Polar Geophy. Stations	2001-2003	Automatic	Earth
LB Geophysical Station	2001	LB Crew	Earth
Geochemistry/Materials Lab.	2001	LB Crew	Lunar Base
Life Sciences Lab. No.1	2001	LB Crew	Lunar Base
Optical Interferometer	2002	Automatic (LB support)	Earth
Farside UV Telescope	2003	Automatic	Earth
Farside SETI	2003	Automatic	Earth
Crater Dating	2003	LB Crew	LB Crew
Deep Drilling	2003	LB Crew	LB Crew
Life Sciences Lab. No.2	2005	LB Crew	LB Crew

Lunar Science/Field Geology (LS&FG)

As defined in the CNDB (2), LS & FG experiments are similar to the Apollo Lunar Scienctific Experiments Package (ALSEP) which includes seismometers, magnetometer, instruments to measure heatflow, a radioisotope thermoelectric nuclear generator (RTG) power source, and central junction station that distributes power and transmits experimental data to Earth. Sampling equipment will be provided, including sample bags & boxes, rakes, tongs, hammers, corers, drive tubes, and other tools to collect surface and subsurface samples. EVA personnel will use a rover to deploy the experiments and collect samples. The range of the field geology and exploration traverses will increase after delivery of pressurized rovers in 2002. As given in the crew time allocation plan presented in Table 5-3, 10 hours EVA and 11 hours IVA support (for EVA equipment refurbishment/maintenance and for sample handling/stowage) are budgeted for each mission.

Geophysical Network Station

These missions, not carried in the CNDB, are essentially independent unmanned science missions to a variety of locations on the near and far sides. They contain instrumentation similar to ALSEP; an unmanned, remotely operated rover to deploy active seismic sources and collect samples; and a Earth sample return capsule. Three missions, completely independent of lunar base operations, are proposed to a remote nearside site, a polar region site, and to the lunar farside. The first experimental package (not including a sample return vehicle) is delivered to the lunar base, checked out by the crew, and deployed by the unmanned rover teleoperated from the lunar base (or alternatively, from Earth). The rover will install the experiments several hundred kilometers from the base, collect samples, and return the samples to the base for repackaging and return to Earth. As given in Appendix D, the lunar base (LB) mission is estimated to involve 55 hours for teleoperation of the rover and 9 hours total EVA to unload and checkout the system prior to deployment (Table 5-3 budget includes additional IVA required to support EVA and time to repackage and return samples).

Laboratory Operations

The geochemical and life science laboratories and operations are described in Appendix B and elsewhere (39). The geochemical and materials processing laboratory will support on-site analysis of lunar science, selecting some to be sent to Earth for more detailed analysis. It will contain equipment to conduct materials processing experiments in a stable 1/6 gravity field and should also be capable of supporting oxygen pilot plant/-production plant analytical/chemical laboratory support. Equipment such as a X-ray fluorescence spectrometer, X-ray diffractometer, thin section facility, petrographic microscope, gas chromatograph, mass spectrometer, and other instruments will be needed. The life science laboratory would conduct studies and experiments in human physiological adaptation to lunar environment (allowing longer staytimes), improved ways to grow food, systems to recycle essential elements, and other experiments which would lead to enhanced long-term habitability on the Moon. After emplacing these modules, 60 IVA hours per 24-day mission and 450 hours per 180-day mission is budgeted for operations in each laboratory as given in Table 5-3.

Optical Interferometer Telescope

The optical interferometer consists of 27 one meter telescopes operating as an optical analog to the Very Large Array (VLA) radio atronomy observatory in New Mexico. The optical telescopes are arranged in a Y-shaped array measuring 6 km along each arm giving a 10 km baseline (16). A central aperture synthesis station correlates the received light from the telescopes, determines the exact position of each telescope by laser interferometers, and transmits data to Earth. The individual telescopes need to be easily manueverable to allow the capability of array reconfiguring (17).

An estimate of 660 hours was made for deploying this system (Table 5-2 and Appendix D). A portion of the total estimate, site preparation, consisted of identifying an area (10 km equilateral triangular area) for the interferometer generally free of high obstacles that would present more difficulties for tracking each telescope's location and that has unobstructed views of relevant celestial observation targets, then surveying, selecting, and marking sites for the individual elements. Over 350 hours was estimated for this task (Appendix D), which was allocated primarily to Earth teleoperated surveying rovers, supported by on-site inspection of the selected areas by lunar base crew. Pressurized rovers were considered essential for the on-site inspection task, since over 16 hours per inspection trip was necessary due to the size of the general area and time required for inspections of all 28 element sites. Crew time was allocated to unload and checkout all telescope elements prior to deployment by individual, remotely controlled (from Earth) rovers, each carrying a telescope, optical image transmitting equipment, and thermal/light shield. A cable connecting the separate rovers is also laid (without burying) to provide power and to allow transmitting data concerning the condition of each separate element back to the lunar base for maintenance support during the operational phase of the observatory. Two pressurized rover traverses with EVAs from the rovers are budgeted after deployment to resolve problems uncovered during the test and verification. Alternative deployment schemes are possible. Instead of using individual self-propelled rover/telescopes, rails could be laid for one or two special telescope transporters as in the VLA in New Mexico. This plan may be more EVA labor intensive. However, it is clear that establishing an optical interferometry observatory early in an overall lunar base plane is a very ambitious undertaking, quite possibly involving far more EVA and IVA support from the lunar base for construction than allocated in the resource budget. Management and control of the optical interferometer is assumed from Earth with system maintenance support from the lunar base. Table 5-3 lists a time allocation of 38 hour/24-day mission to supporting the optical interferometer from the base based on inspection by teleoperated robots, and 1-2 pressurized rover traverses with EVAs each mission to correct problems as defined in Appendix D. This allocation may also be low based on an estimate from one source (17) for up to 6 lunar base support crew being required for the telescopes operational phase. It should be noted that the best Earth analog, the VLA, has a staff of over 60 to support its maintenance operation (17).

Crater Dating

The purpose of the crater dating mission is to determine if there is correlation between the impact cratering record and periodic extinctions on Earth. The objective of this experiment is to collect a selection of appropriate samples to accurately date a number of lunar impact craters. Based on data given in one reference (18), 50 craters in the 5 km diameter class should be considered a minimum sample set. To sample this set of craters, traverses throughout an area measuring 90 km across will be required (based on data in Ref.19 - calculations in Appendix D). Manned, pressurized rovers were considered essential for this mission. A total roundtrip traverse of nearly 400 km was used in the estimate of required EVA/IVA time given in Table 5-2 and Appendix D. Each traverse uses two pressurized rovers to transport 2 crew persons (2 rovers needed for safety redundancy) to collect surface melt and relatively shallow core samples (<10 m). If longer cores are needed, greater time allocations will be required. Pressurized rover time is counted as IVA time. EVA from the rovers was also considered required. 300 hours of 2-person EVAs was estimated to collect samples from the 50 craters. A total estimate of over 725 hours IVA and EVA time was made (Appendix D) for the mission, not including support and maintenance that required for EVA and pressurized rover systems. Crater dating allocations are shown in Table 5-3 as continuing over a number of missions and years, stretching out into Phase III permanent base period.

Deep Drilling

Acquiring core samples from over 1 km deep drill holes will be a difficult task in the lunar environment. A suitable drill rig has not been defined but it was assumed that the drilling operation will require manned operation from a pressurized rig. Based on counting hours in the pressurized rig as IVA hours, over 800 IVA hours and 20 EVA hours may be required to drill one 1 km core (Table 5-2 and Appendix D).

Farside UV Telescope

The large UV/X-ray telescope will be used for imaging, spectroscopy, and polarimetry of nearby UV/X-ray sources and the interstellar medium. This mission is assumed to require no lunar base support for deployment and operational support consisting of a servicing mission every 5 years using pressurized rovers from the base or a manned landing from Earth. Earth command and control of the telescope is assumed.

Farside SETI

This radio astronomy observatory is designed to search for intelligent life elsewhere in the galaxy. Like the farside UV telescope, deployment and day-to-day operation is assumed to require no lunar base support. Servicing from the lunar base may be possible depending on distance from the base and base mobility capabilities.

5.7 Resource Utilization Operations

5.7.1 Ilmenite Mine Site Selection

Production of oxygen from ilmenite is the baselined resource utilization objective. Lunar oxygen will be used in the base's life support system and propellant for the reusable lander. Selecting a base site near a concentrated ilmenite supply will be important. Methodologies for evaluating and selecting a resource site are defined elsewhere (40). In this study, precursor unmanned missions were assumed to provide much of the required information to select a base site near an ilmenite source, while manned geological surveys will further refine the mining area location before pilot plant operations begin.

5.7.2 Pilot Plant Operations

An estimate of the EVA/IVA time required to emplace a oxygen pilot plant was developed in this study. Appendix D breaks down pilot plant emplacement into subtasks included site surveying, utility installation, cargo offloading, cargo transportation, element emplacement, interface connections, power up and verification testing. As given in Table 5-2, a total of 40 hrs EVA, 20 hrs IVA teleops, 10 hrs Earth teleop was estimated with no allowance for IVA support of EVA. Operation of the pilot plant was assumed to be an around the clock activity carried out by Earth teleoperation. Lunar base support was limited in the operation phase to loading feedstock (assumed regolith concentrated in ilmenite) into the pilot plant feed hopper via lunar base teleoperation of construction equipment (prime mover with front-loader or backhoe attachment and trailer), and to IVA and EVA assistance in responding to pilot plant operation problems (alarms) and maintenance.

5.7.3 Production Plant Operations

A commercial scale process plant to produce liquid oxygen is delivered in 2004. Emplacing this plant is estimated (Appendix D) to require approximately 130 hrs total EVA, 65 hrs lunar IVA teleops, and 35 hrs Earth teleop. It is assumed that operation of this plant will require full time lunar base coverage and therefore commences in 2005 with the transition to permanent occupancy of the base. As given in Appendix D, a production rate of 26 metric tons liquid oxygen per month will require the mining of about 2500 metric tons feedstock assuming 10 percent ilmenite in the feedstock material. This requires over 180 loads/month using a 8 m^3 trailer and prime mover defined in Section 5.5. All excavation is assumed to be performed in a lunar base teleoperated mode. Along with system monitoring, response to alarms/plant problems, and maintenance, operations will require 4 full time IVA crew working in shifts. During some short-term plant problem situations, more lunar base personnel may be required to provide a 2-man EVA team to resolve the problem while the normal plant operator monitors the situation and assists via lunar base teleoperation.

5.7.4 Oxygen Refueling Operations

The Phase II base scenario includes the delivery of facilities to refuel liquid oxygen to a reusable lander. The refueling facilities will be emplaced during Phase II and verified in a realistic LOX transfer demonstration test (Appendix D). Refueling facilities were assumed to consist of an insulated tank truck to carry 26 metric tons of LOX and loading facilities for the tank truck (structure, overhead loading pipe/boom, pumps, loading pad for turning tank trucks around). A pipeline from the oxygen production plant's storage tanks could be installed underground (for insulation) to the loading facility. The tank truck would be filled at the loading station by turning on pumps to pull LOX out of the production plants storage tanks, then transporting the LOX to the reusable lander, and then into the lander's oxygen tanks (using pumps on-board the tank truck). An alternative would be to install the underground pipe all the way to the reusable lander landing pad and provide a loading facility there. However, a loading facility at the pad would have to be designed to withstand or be protected from the engine exhaust load encountered during the reusable lander's launch and landing.

Because the reusable lander will be used only once every month or two, separate storage and refueling facilities for liquid hydrogen may be required.

5.8 Logistics and Maintenance Support Activities

Since the Lunar Base will be developed after the Space Station has been operational for several years, the maintenance and logistics concepts for the Lunar Base will be compatible with the Space Station system. A parallel study is developing methods to apply these concepts to the Phase II Lunar Base and to define required logistics and maintenance operations, equipment, and resources necessary to practically develop a Lunar Base.

The preliminary viewpoint of this parallel study is that maintenance and logistics functions divide into three periods corresponding to the crew staytimes of 8, 24, and 180 day visits. The maintenance and logistics approach must consider these three phases and maximize the capabilities at each period.

However, certain maintenance and logistics functions are common throughout Phase II Lunar Base development:

Lunar Base

- Perform resupply support for ECLSS and consumed materials during lunar base construction and for lunar science and geochemical experiments.
- Monitor critical subsystem status.
- Perform maintenance and replacement of failed Lunar Replacement Units (LRU). This increases in complexity and includes less critical systems as the lunar support system expands.

Earth Control

- Monitor subsystem status, maintain trend analysis, and identify spare required for following mission.
- Develop component life reliability and failure mode data base.
- Command and control of Lunar Base equipment during unmanned periods

Advanced Space Transportation System

- Increase replacement of consumables and spares as capabilities and complexity of lunar station increases.
- Build up spares supply on lunar surface.
- Return Lunar science and geology samples.
- Return failed LRU modules for analysis on earth.

Logistics and maintenance for each period is given in Table 5-8. Two fundamental guidelines have been assumed:

1. All failed equipment which can not be repaired on the moon or at LEO will returned to the Earth for failure analysis.

2. All logistics materials not used on a mission will be stored on the moon, not returned to LEO or Earth. Therefore, shielding or storage facilities will be needed at a very early in the Lunar Base buildup stage, as well as a logging and tracking system.

5.8.1 Maintenance and Logistics Operations Plan for 8-day Surface Stays

During the initial period when lunar surface stay time is 8 Earth-days, the mode of operation is similar to that used for the Apollo lunar surface missions. In this period, essentially everything necessary to support crew and equipment is carried on-board the vehicle for each mission. The base of operation is the Personnel Module which also has to serve as the vehicle for travel to and from Earth. No other provisions are available for habitation on the lunar surface during this period. Planned maintenance during this period is minimal and subsystem fault recovery is primarily dependent upon hardware redundancy.

For manned missions, the basic approach is to transport only those consumables, supplies, and spare required to support the crew and equipment for each mission. Unused consumables, supplies and spares will be stored on the lunar surface when practical. Failed equipment will be returned to the Earth for failure analysis.

For unmanned missions, supplies will be delivered to the lunar surface for storage on a space and weight available basis.

A list of expected maintenance and logistics operations is given in Table 5-9.

5.8.2 Maintenance and Logistics Operations Plan for 24-day Surface Stays

This period is characterized by the availability of the habitable module on the lunar surface which allows the surface stay time to be extended to 24 earth-days. The base of operations will now be centered in the Habitable Module (HM) with improved crew habitation accommodations and the availability of an Operations Management System (OMS) which is controlled from a workstation. Continual buildup of the lunar base occurs with the delivery of major elements to the lunar surface by expendable unmanned landers. Scheduled maintenance of equipment is now a minor part of the crew tasks and unscheduled repairs are accommodated by the availability of spares and crew time. A list of required operations in this period is given in Table 5-9.

The manned mission approach is to transport only those consumables, supplies, and spare required to support the crew for each mission. Unused consumables, supplies, and spares will be left stored on the lunar surface when practical. Failed equipment will be returned to the Earth for failure analysis.

For unmanned missions supplies will be delivered to the lunar surface for storage on a space and weight available basis.

5.8.3 Maintenance and Logistics Operations Plan for 180-day Surface Stays

With the completion of the lunar oxygen production plant and refueling facilities for a reusable lander, the third period of lunar base operations begins. In this period, the

C-2

crew will extend their Lunar surface stay time to 180 earth-days which allows permanent occupation of the lunar base with crew complements of up to eight crewpersons for the major duration of time. In this period, the lunar base will still be dependent on Earth for consumables such as food, water, nitrogen, crew equipment, and spare parts. Operation of the lunar base is now essentially a continual activity with regular scheduled maintenance of equipment on the lunar surface and limited repair capability of LRUs below the modular level. Operations are now focused outwards with emphasis on lunar science and surface exploration which requires longer duration excursions aboard the rovers which in turn requires more maintenance. Logistics to support the needs of the lunar base have now outgrown the capability to bring all of the logistics items along with the manned landers and now requires dedicated unmanned delivery of logistics items to the lunar surface. Operations are listed in Table 5-9.

For manned missions, adequate consumables, supplies, and spares are transported to supplement the lunar reserve which provides adequate supplies required to support the crew for each mission. Unused consumables, supplies, and spares will be left stored on the lunar surface. Failed equipment will be returned to the Earth for failure analysis.

Unmanned and manned missions will deliver consumables, supplies and spares to the lunar surface for storage in an organized modular logistics system.

Table 5-8. Lunar and Earth Logistics and Maintenance Functions During Phase II

Lunar Based Functions	Earth Based Functions
For 8-Day Surface Stays:	
-Lunar Base Subsystem Monitoring	-Subsystem Data Collection
-Operations Overview	-Reliability and Failure Analysis
-Unmanned Lander Equipment Unloading	-Maintenance and Repair Scheduling
-Equipment Assembly and Checkout	-Logistics Planning and Support
	-Returned LRU Failure Analysis
	-Communications Network Management
	-Remote Site Equipment Command and Control
	-Unmanned Lunar Base Command and Control
For 24-Day Surface Stays:	
-Operations Overview	-Lunar Base Subsystem Monitoring
-Subsystem Management by the OMS	-Subsystem Data Collection
-Unmanned Lander Equipment Unloading	-Reliability and Failure Analysis
-Equipment Assembly and Checkout	-Maintenance and Repair Scheduling
-Lunar Base Construction	-Logistics Planning and support
-Lunar Base Maintenance Management System Operation	-Returned LRU Failure Analysis
-Equipment Maintenance and Service	-Communications Network Management
-Equipment Troubleshooting and Repair	-Teleoperation of Rover
-Lunar Surface Communication Network Management	-Remote Site Equipment Command and Control
	-Unmanned Lunar Base Command and Control
For 180-Day Surface Stays:	
-Operations Overview	-Lunar Base Subsystem Monitoring
-Lunar Base OMS Subsystem Monitoring	-Subsystem Data Collection
-Unmanned Lander Equipment Unloading	-Data Base Management
-Equipment Assembly and Checkout	-Reliability and Failure Analysis
-Lunar Base Construction and Expansion	-Returned LRU Repair
-Near-term Maintenance Scheduling	-Long-term Maintenance Scheduling
-Equipment Service and Maintenance	-Logistics Planning and Support
-Equipment Troubleshooting and Repair	-Communications Network Management
-LRU Testing and Repair	-Remote Site Equipment Command and Control
-Lunar Surface Exploration	-Teleoperation of Equipment
-Remote Site Equipment Servicing	
-Oxygen Production Plant Operations	
-Lunar Propellant Logistics	
-Lunar Base Support Logistics	
-Lunar Surface Science and Geology	

Table 5-9. Phase II Maintenance and Logistics Operations

Lunar Based Operations

For 8-Day Surface Stays:

-Operate from the Personnel Module

-Store consumables and spares inside the Personnel Module or on the lander
-Monitor critical subsystem status. Depend on system redundancy in the event of component failure.
-Replace failed LRU available spares only for critical subsystems.
-Perform critical scheduled maintenance (very little in 14 days: replace equipment, run post-maintenance test checks, check system status)

Earth Based Operations

-Monitor subsystem status and identify spare required for following mission
-Develop component life reliability and failure mode data base.

Advanced Space Transportation System

-Carry consumables replacements and planned spares
-Deliver critical spares identified from previous mission
-Leave new spares for base in expended lander bay
-Return Lunar Science and Geology samples
-Return failed modules for analysis on earth

Lunar Based Actions

For 24-Day Surface Stays:

-Monitor top level subsystems from the Habitable Module with the OMS
-Initiate operation of the Lunar Base Maintenance Management System
-Depend on system redundancy in the event of component failure
-Transfer consumables and spares from manned lander to Habitable Module
-Retrieve consumables and spares from unmanned lander
-Replace failed LRU with available spare for subsystems
-Perform critical repairs and unscheduled maintenance (replace equipment, run test checks, check system status)
-Perform scheduled maintenance and repairs on limited life equipment.

Earth Based Actions

-Monitor subsystem status in detail and identify by performance trend analysis preventative maintenance required at subsystem level
-Monitor subsystem status and identify spares required for following mission.
-Develop component life reliability and failure mode data base.
-Perform long term logistics planning

Table 5-9 (Cont). Phase II Maintenance and Logistics Operations

Advanced Space Transportation System

For 24-Day Surface Stays:

-Carry consumables replacements and spares for mission critical items.
-Carry consumable and scheduled maintenance parts and predicted spares developed from earlier missions.
-Leave spare for bases and equipment in expended lander bays and habitable modules.
-Deliver large spares on unmanned delivery missions.
-Return Lunar Science and Geology samples.
-Return failed modules to Earth for analysis.

Lunar Based Operations	Earth Based Operations
For 180-Day Surface Stays:	
-Monitor critical subsystem status with the OMS. -Schedule near term maintenance and repairs with the MMS. -Transfer Logistics Module from lander to Lunar Base. -Deliver consumables and experiment modules to remote site experiments. -Replace failed LRU with available spares for all subsystems. -Perform scheduled maintenance on equipment and repairs on failed equipment. Provide shirt sleeve volume for equipment repairs and spares storage. -Provide all maintenance procedures on Lunar Surface data base for real time display to maintenance crew.	-Monitor subsystem status and scheduling repairs and maintenance on LRU based on trend data. -Monitor subsystem status and identify spares required for following mission. -Further develop component life reliability and failure mode data base.

Advanced Space Transportation System

-Carry consumables, normal servicing spares, and predicted failure spares on each manned mission.
-Augment spares on unmanned mission where excess down payload capacity exists.
-Retain repaired components in spares inventory.
-Leave new spares for base in expended launcher bay.
-Provide dedicated modules for spares delivery on unmanned missions.
-Return non-repairable modules for analysis on earth.
-Return Lunar Science and Geology samples.

5.9 Man/Machine Division of Labor

It is expected that crew time will be carefully scheduled for productive tasks inside the lunar base in a similar way that it will be scheduled within the Space Station. Thus, reduction of time consuming, mundane crew tasks external to the lunar base is highly desirable. Elimination of crew tasks in hazardous areas such as high radiation, extreme temperatures, etc. will also need to be accomplished where practical.

5.9.1 Generic Lunar Surface Telerobotic Servicer

A Generic Lunar Telerobotic Servicer (LTS) can be designed to perform any lunar surface task that a suited crew-person plans to perform. This requires that the design of the lunar base and its supporting equipment is "robot friendly", that is, that standardization be invoked for all access doors, latches, fasteners, etc. and that they be physically located within reach of the robot whose mobility will be restricted to the plane of the lunar surface or to ramps designed to raise the robot to the work area. To illustrate, a LTS can operate a lunar crane if the crane controls are located so that the LTS can reach them from the lunar surface or if a suitable ramp is provided for the LTS to climb to within reach of the controls. This concept should be used on all lunar base equipment and facilities (even if lunar teleoperated servicers or true autonomous robots are not eventually developed) since it makes the job of the crew much more efficient and significantly reduces training requirements. The major gain to be realized with the employment of a generic LTS will be the productivity leverage that it will provide the crew.

The telerobotic servicer assembly will be made up of two basic units, the torso and the mobility base (Figure 5-10). Whereas the torsos are alike, the mobility bases will differ for a wide variety of task assignments. A LTS mobility base may employ tracks designed to increase the bearing area and traction between the lunar surface and the LTS for pushing and pulling operations such as light soil removal, soil leveling, or towing a lightly loaded trailer. Wheels may be employed on a LTS mobility base designed for more rapid travel over rough terrain.

With the flexibility afforded by various mobility bases, the LTS will be able to perform certain tasks not planned for crew-persons. For example, if the LTS is equipped with a track type mobility unit and a blade, it can be used to perform light lunar soil leveling, soil relocation, back-fill around buried habitation modules, etc. With this mobility base, the LTS can also serve as a lunar "Donkey" for pulling or pushing other equipment about the site. Additional weights (made form lunar materials) may need to be added to the mobility unit to increase traction during this type of operation. Figure 5-10 illustrates a lunar telerobotic servicer concept configured with a track type mobility unit.

The LTS can be treated as an "expendable" piece of equipment that can be replaced with a back-up unit. Therefore, the LTS can be employed to perform tasks in highly hazardous environments rather than risk a suited crew-person for that task (Figure 5-11).

5.9.2 Telerobotic Servicer Operations

The telerobotic servicer could be designed with enough capability to eventually perform certain tasks autonomously. However, control of a lunar robot will initially be tele-presence. In this application, tele-presence means that a crew-person can operate the robot remotely in a shirtsleeve environment with controls that gives the sensation that the operator is physically at the telerobotic work site. Stereo television cameras will provide on-the-scene visual depth perception for the operator. Lights will be provided if shaded work areas require illumination. Bi-lateral force feed-back will be incorporated into the position controllers to provide feel for the amount of force being exerted by the manipulator arms.

With experience and crew confidence build-up, the LTS will be "trained" to perform routine tasks autonomously. Supervised autonomy can be controlled from earth by issuing an initiating command for a sequence of operations. Initially, the LTS will serve as a crew "helper". With application of artificial intelligence, the LTS will be capable of performing certain tasks without constant human oversight in a truely robotic operating mode. Suited crew will be able to over-ride the robot via voice command if the individual observes that the robot is initiating a hazardous operation.

If a family of LTS's are permanently delivered to the lunar surface, they could diagnose one another for electronic malfunctions by inserting an electronics diagnostic probe into the "sick" LTS. The LTS electronics should be modularized in such a manner that it will be practical for one LTS to extract any module, and replace it with a spare. This modular packaging approach should be employed for all equipment designed for lunar surface operation to facilitate exchange by both humans and telerobotic servicers.

The torque and force delivery capacity of the manipulator arms will be at least equivalent to a suited crew-person as follows:

- Arm Reach: 36 inches
- Arm Tip Speed: >20 inches/second
- Arm Tip Position: <= 0.004 inches with respect to the robotic coordinate system
- Arm tip torque: 30-35 inch-pounds
- Arm Tip Force: 20-25 pounds
- Two manipulator arms and two stabilization arms
- Each of the four arms will have six (6) degrees of freedom

Operation of the LTS's will be from Earth stations, the Space Station, or locally from inside the lunar base. Earth based and Space Station operation pre-supposes the existence of line-of-sight RF transmission between the operations base and the LTS. Due to the approximately three second delay between command and response, Earth based operations via relay satellite will become more practical as the LTS is taught to perform routine tasks (ie. inspection of lunar power system, etc.) in response to an initiating command. Application of these telerobotic servicers will effectively establish manned presence (remotely) much earlier in the lunar base plan than is practical without them.

Control software development will be performed on Earth and up-linked to the lunar base processors. Control programs will be modularized such that software modules required to perform the various application assignments will be down-loaded from the lunar base processing center to the LTS.

The LTS could be sheltered in a structure like the shelter discussed in Section 5.5, along with all special end-effectors, tools, and parts required to perform all anticipated surface tasks. The shelter could also support heavy duty soil moving equipment. The LTS shelter should also be equipped with a regenerative fuel cell servicing facility for the LTS. All robotic spare parts (manipulator/stabilizer arms, electronic modules, radiators, fuel cells, etc) and external base facility and equipment spare parts could be stored in the shelter. All parts and modules will be stowed along the walls of the shelter such that the LTS can reach them. The LTS will select end-effectors, tools, and spare parts required to perform any assigned task while in the shelter prior to being dispatched to execute the assignment. These selected end-effectors, tools, and parts will be carried in the LTS tool box/carrying case. The LTS should also be able to automatically reconfigure itself with a different mobility base in its shelter without assistance from the crew. Figure 5-8 illustrates LTS's in the unpressurized shed.

A special remote power station network will need to be provided for the lunar tele-robotic servicers. Power outlets should be provided at known robotic work locations such as the landing pads, inspection sites, etc. The LTS will traverse to the work site under it's own fuel cell power. Upon arrival at the work site, the LTS will connect itself to the power utility outlet energized by the base power system. This approach will extend the robotic work cycle indefinitely around the base.

Each LTS will weigh approximately 2000 pounds without tools and end-effectors. The main structural materials will be carbon composite selected for rigidity and light weight. Each will house its own electronics and processors with considerable growth potential for incorporation of artificial intelligence software. Communication with each LTS will be via RF communication links for command, stereo TV return, and data return.

Larger scale remotely controlled vehicles will be required to support heavy duty tasks like excavation, ore transportation, etc.

SPECIFIC LUNAR SURFACE APPLICATIONS:

Surface Systems Assembly

Surface systems such as communication towers/antenna, utility distribution feeds, landing/-launch pads, roadways, heat rejection radiators, solar screens, habitable modules/nodes/air-locks, etc., could have to be assembled/disassembled on the surface. Operations such as lifting, re-orienting, relocating, torquing, securing, mechanical alignment, leveling, etc. will have to be performed. Since surface systems assembly is not a highly repetitive operation, it is anticipated that the LTS will serve as an assistant to suited crew rather than be depended upon to perform the complete assembly autonomously. Since the assembly/disassembly sequence will be well known in advance, the LTS could be programmed to fetch tools, rigidize components, hand materials to the crew-person in the proper sequence, etc.

Equipment Setup

The LTS could be "taught" to set-up and take-down equipment that needs to be placed inside protective shelters when not in use. Thus, a set of highly repetitive steps will be taught to the LTS to transport equipment components between the storage shelter and equipment use site. Once on site, the equipment will be assembled, activated, and diagnosed for proper operation. If improper operation is diagnosed, then the LTS will communicate recommended corrective actions to the crew. If approved, the LTS will extract faulty equipment components, retrieve proper spares, insert the spares, and re-diagnose the equipment for proper operation.

Reusable Lander Landing Site Setup

The LTS will initially serve as an assistant to suited crew during the initial landing site preparation and setup operation. It will be used to fetch tools, place landing site equipment in place, check-out the landing site equipment, perform light soil leveling operations, and perform later repetitive inspections/maintenance.

Landing Site Preparation

Landing site preparation for landing is highly repetitive once the landing procedures are established. Landing site preparation for landings in Phase II will require more preparation than when operations transition to the reusable lander at a permanent field. Preparations may include the relocation of terminal landing aids such as lighting from either other landing pads or from storage shelters. The LTS could be used to survey the landing site for obstructions and make recommendations to the crew if obstructions are identified. All required terminal landing aids will be set up and diagnosed for proper operation. The LTS could be responsible for restoring any faulty landing aids to full operational status and informing the crew of the landing aid operational status.

Equipment sheltered during base non-crew occupancy periods can be removed from the shelters, relocated, and initialized to support Lander arrival via remote command of an LTS from Earth. Appropriate crew support equipment (crew transporter, medical support, ECLSS consumables, etc.) will be properly located and activated to support arriving crews.

Cargo handling/transport equipment will be properly located and activated to unload cargo delivered via unmanned landers (landed a month or more in some cases before arrival by crew). Light cargo unloading activity such as for equipment pallets delivered by the crane/trailer could be automatically or remotely accomplished with the LTS (if the robotic friendly standardization strategy has been invoked). The unloaded cargo will be properly transported to its sheltered storage location near or in the base to minimize the time required by a suited crew to unload, locate and assemble the cargo. Heavy duty equipment will also be required to unload the lander of modules, pallets containing heavy cargo, etc.

Post-Arrival Activities and Preparation for Ascent Stage Departure

The LTS could perform portions of pre-flight ascent stage check-out on the lander shortly after landing. This procedure will be invoked to provide the maximum time to restore the ascent vehicle to operational readiness if a failure is detected.

All landing equipment not needed for ascent launch will be disassembled and stored in its protective shelter, or relocated to another pad scheduled for a near-term landing.

Connecting the reusable lander's fuel cells to the base power system will be performed by the crew with robotic assistance.

Launch support equipment used to prepare and service the launch vehicle could be de-activated by the LTS and stored in shelters designed for protection during non-use periods.

Later in the base plan, the LTS could perform LO_2 transfer and refueling operation from the oxygen production plants loading facility to the reusable lander vehicle. Special liquid consumable transfer fixtures and fittings developed to service satellites could be employed by the LTS to transfer the LO_2.

EVA Operation

All EVA operations could be assisted by the LTS and some replaced by the LTS. The LTS would "fetch" tools, hold materials, hand off materials to a crew-person in the proper sequence (thus minimizing excessive bending, stooping, and reaching by the suited crew-person). The most important application of robots (teleoperated or autonomous), though, is to reduce the need for human EVA.

Science Operations Installation

Since installation of special scientific devices like telescopes, portable seismometers, explosive packages, etc. are not highly repetitive, the LTS will serve as an assistant for transporting, holding, and checking out the equipment in support to suited astronauts.

Science Operations

If the science operation requires periodic maintenance or initialization cycles, or routine data collection, the LTS could be trained to autonomously travel to the sensor site, replace data recording cassettes with unused cassettes, power the sensory system up/down as required, perform routine calibrations and return data cassettes to the Lunar base for analysis.

Science Operations Deactivation, Disposal, or Return

The LTS could be taught to serve as an assistant to suited crew for the deactivation of scientific data collection stations, or to remove them via remote control. The LTS's can hold components and transport those components back to the base or disposal site.

Logistics Module Exchange

Logistic module change-out is planned later in the Phase II base plan. Thus, procedures and control software for the LTS fleet could have matured considerably if used from the beginning of base operation. Since module change-out is a repetitive operation for each mission (once started), it is reasonable to expect that the LTS could be taught to perform this exchange with limited crew supervision. Heavy cargo handling equipment in manual or teleoperated mode will also be employed to directly handle the heavy modules. The LTS could perform operations such as final guiding and berthing where the risk to suited crew would be greatest.

ECLSS Replenishment

Employment of the LTS for replenishing life support systems may be restricted to ECLSS units on the pressurized surface rover and expendable Lunar ascent vehicle since they both require exposure to the Lunar surface environment. The LTS could be "taught" to autonomously diagnose the performance of these ECLSS units and make simple modular replacements like filter canisters when required.

Preventive (Scheduled) Maintenance

The LTS could be "taught" to autonomously perform most preventive maintenance tasks for all facilities and equipment external to the habitation modules. Initiation of the preventive maintenance operation will be accomplished remotely by crew from Earth, Space Station, or inside the base.

Unscheduled Maintenance

Unscheduled maintenance will be special maintenance on a failed piece of equipment or facility. The LTS will be programmed to perform diagnostic checks on all Lunar based equipment and facilities. Following the diagnostic operation, the LTS will transmit its recommendation for repair to the crew. Upon approval, the LTS would fetch a spare LRU (lunar replacement unit), extract the faulty unit and place it in the LTS's tool box/carrying case, insert the substitute LRU, and rediagnose the failed equipment for proper operation. The faulty part will be returned to the base for repair, disposal, or sent to Earth.

Repairs like minor welding, drilling, cutting, coating, cleaning, decontamination, etc. will likely be required over the base lifetime. Special tools will be required to support these and other operations. Careful selection or design of such tools for suited crew use should result in their usefulness by an LTS.

Systems Monitoring

An LTS could execute this task as part of its routine inspection task. In preparation for an inspection (monitoring) task assignment, the LTS will select the necessary end-effectors and non-destructive test sensors from their storage shelter, and start the inspection sequence. Sensors employing non-destructive techniques (X-ray, ultrasonic, leak detection, radiation particle monitoring) will be required to perform the extensive monitoring and inspection tasks.

Lunar site inspection is anticipated to be a continuous requirement since the facilities and equipment will be exposed to harsh environment cycles. Deterioration of materials in such an environment is of concern until a confidence base is established for the materials. This inspection requirement would consume inordinate crew time unless it can be performed robotically or by teleoperation. The LTS will be equipped with appropriate sensors for inspecting all facilities and equipment exposed to the external environment. Data collected from the inspection surveys will be transmitted to the base, Space Station, or Earth based processing facilities to assess the state of health of Lunar facilities and equipment. The LTS could be "trained" to perform all inspection tasks under a supervised autonomy mode of operation.

Rescue - Retrieval

Over the life of the Lunar base, there is considerable risk to crew safety associated with equipment failure. In anticipation of such an event, one LTS could always be in a stand-by mode. In this mode, the LTS could be rapidly dispatched to carry pressurized oxygen (or other anticipated life supporting equipment) to the stranded person, or in the case of an incapacitated astronaut, bring the person back to the habitation module at base.

Hazardous Lunar Surface Tasks

Over the life of the base, it is likely that it will be necessary to dispatch suited crew (or a telerobotic servicer) to perform a known hazardous task. Use of a LTS as an expendable resource is a definite crew safety contingency. Figure 5-11 shows a LTS performing a critical repair to a nuclear power plant in a known high radiation area.

CONSTRAINTS AND LIMITATIONS:

Thermal control is expected to be a major concern for lunar teleoperated servicers. Heat generated by drive motors and electronics will have to dissipated during direct sunlit daytime operations. Heat conservation will have to be employed during night or extended shadow operations.

Regolith soil and dust can become a serious problem if it becomes electrostatically attracted to the vision system lens, covers the thermal radiators, or enters manipulator arm joints or other mechanisms.

Line of sight communications will have to be continually maintained for remote control of the LTS's. This will likely require the installation of an omni antenna on a mast at the base and/or work site. This will be a limitation if work is planned inside a crater or excavation or on the far side of an obstacle.

Today's technology can be used to design and build a prototype lunar telerobotic servicer to test solutions to these problems. Modularity should be included to incorporate growth and advancements in hardware/software technologies for increased robotic performance. As mentioned in Section 5.5.3, technology development is required in areas such as automation and robotics software and sensors, supervisory control algorithms to allow Earth teleoperation, ruggedized and reliable mechanisms and processors, and fault detection and recovery systems, all of which need to be adapted to lunar environmental and task conditions. Such technology development is a prerequisite to an Earth test program that will be needed to verify robotic related technologies and procedures several years in advance of the production of LTS's.

Figure 5-10. Teleoperated/Robotic Astronaut Assistant

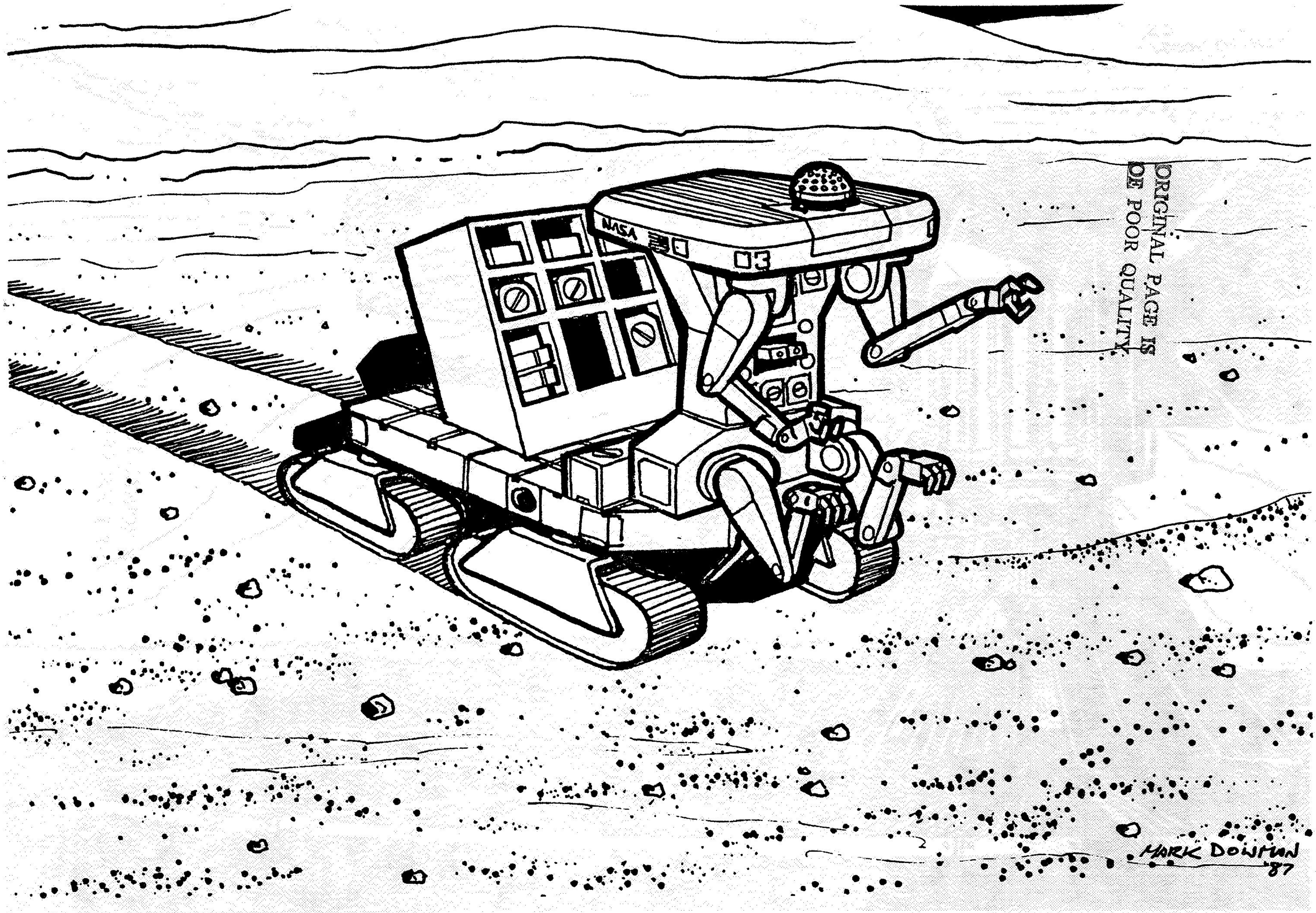
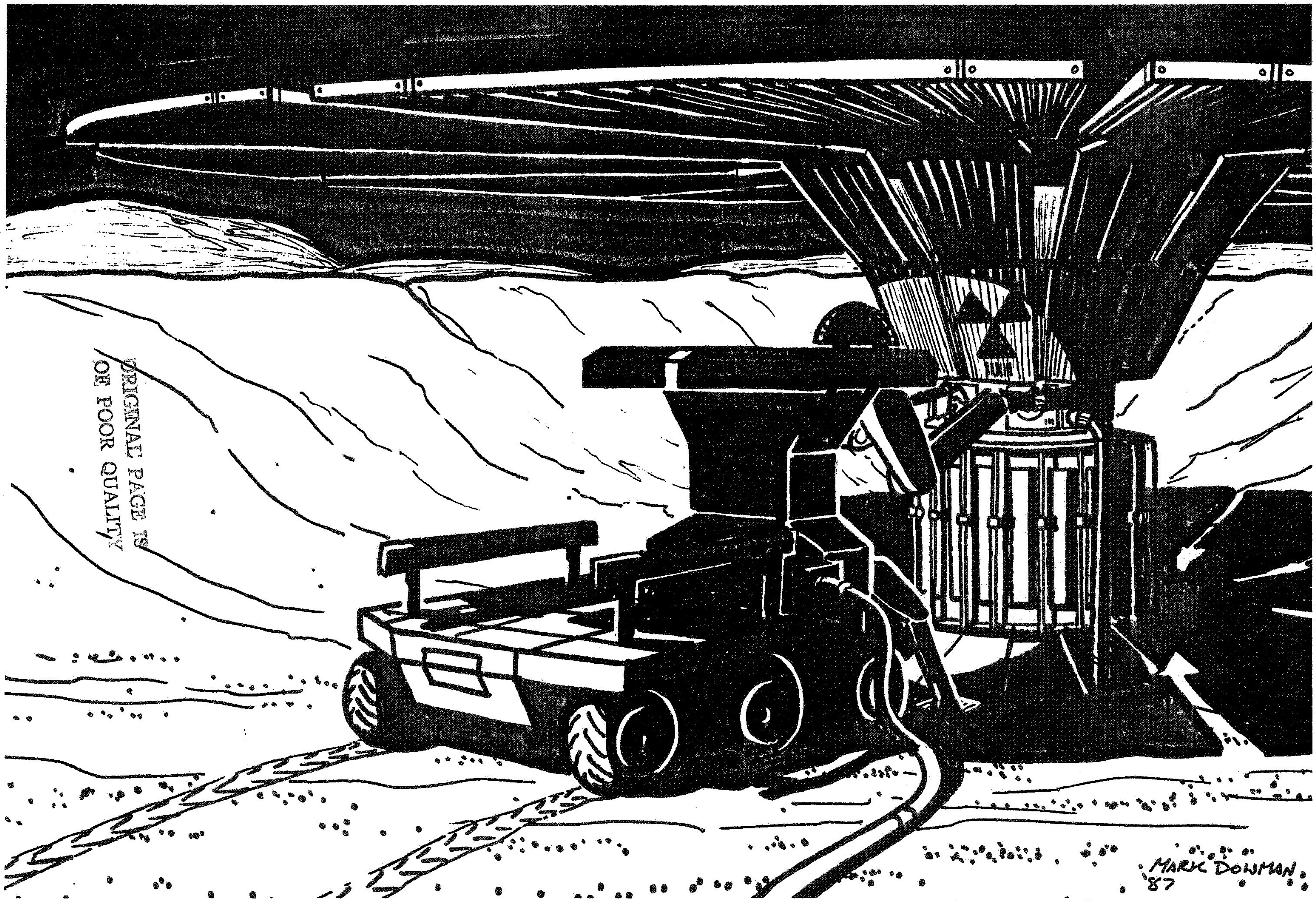


Figure 5-11. Teleoperated Performance of Potentially Hazardous Servicing Operation



5.10 Contingency Operations

Contingency operations planning should be started early because it usually has significant impacts on program weights and costs. Because by its very nature it requires recognition of real world problems and solutions, contingency planning lends credence to advanced mission planning. Contingency planning should develop fallback solutions and operational strategies to compensate for failures in equipment or other problems. One contingency situation not previously discussed in this report is planning for the operational problems that are inevitable in any complex endeavor, but that require more time than allocated to correct. One approach to this is to multiply all estimates of task completion times by some fudge factor (maybe 2). In this study, we have assumed that all tasks have been thoroughly studied, planned, demonstrated, and trained for on Earth. Our mission budgets (Table 5-3) only contain an IVA and EVA margin that can be applied as a contingency to problem resolutions.

Other contingency operations should be planned for situations which could result in compromising mission success. This requires an indepth study to identify potential threats to mission success, a systematic assessment of the effects of these threats, and then planning a realistic response usually by adding new mission elements, redundant backups, or strategies to improvise using available equipment. The following areas of the scenario defined in this study are responses to identified mission threats.

Solar Flare/Radiation Shelter

During a serious solar flare, the crew will evacuate the exposed pressurized modules and retreat to a protected shelter. To alert the crew of the arrival of potentially dangerous levels of solar particles, provision should be made to equip the habitation module and lander personnel module with alarmed dosimeters (set at suitable level) and to provide a warning to EVA crew members. Special plans would be needed if a large solar flare occurs during a long manned traverse. The pressurized rovers may need to be equipped with a shelter or have the capability to quickly bury themselves (and to dig themselves out later) using explosives (Ref.41) or heavy duty manipulators. To avoid unnecessary alarms and loss of productive time, there is a need to develop the ability to quickly distinguish between the few large, serious solar flare events from the many smaller ones occuring during a solar cycle (36). Flare prediction is possible (31) but they are more of a forecast based on observations of active regions up to 10 days before an event (36).

Contingencies have not been developed for the crew during Earth/Moon transit. This is a potential problem, especially for a crew just starting a transit since a flare is over in less than 2 days.

Landing Vehicle/Launch Pad Emergency

An extra ascent vehicle was landed in this scenario as a contingency escape vehicle in the event of loss of the primary ascent vehicle or other crew emergency. However, this contingency solution will not provide fast transfer of injuried crewman back to Earth for medical attention. This is because window considerations (studied in parallel transportation study) may constrain launch opportunities to Earth every 9 days, with another wait for phasing with Space Station. The optimum contingency vehicle location may be somewhere else (L1/L2, LLO, Earth orbit).

Other possible concerns involve unmanned/manned lander accuracy and the possiblity of damage resulting to key base installations from an inaccurate landing/crash, fuel spills, range safety, and launch vehicle scrubs. Many of these concerns are being reviewed in a parallel study on launch/landing facilities.

EVA Emergencies

As discussed in Section 5.3, 30 minutes contingency oxygen is included in the EMU consummable budget for EVA emergencies. The EVA equipment list includes a cart to transport an injuried crew member. A teleoperated lunar rover or robotic servicer was discussed in both Sections 5.3 and 5.9 as a useful way to provide assistance or to retrieve a helpless crew member.

Module Contingency Equipment

A medical support center similar to Space Station's should be included in the habitation module manifest. And as on Space Station, all modules should contain safe haven supplies of all crew consummables (air, water, food) in the event of the loss or isolation of a module.

Meteoroid protection is not believed to be an issue for the lunar base modules, especially if Space Station module inheritance is used, since the double-wall station modules are designed to protect against both meteoroids and orbital debris. Orbital debris will not be a factor for lunar surface installations. However, it may become a problem in lunar orbit unless procedures are established early to minimize the amount of material expended in lunar orbit.

6.0 Conclusions

SUMMARY

1. Crew schedules are particularly tight for the earliest missions with an 8-day surface stay constraint. Although the first 2 manned missions have positive margins for EVA and IVA time, it is mainly because only 1 cargo mission is landed. However, by the third and fourth manned missions, significant negative margins are forecast (Table 5-3) due primarily to emplacement of a buried module for radiation protection, although other installation requirements for additional surface infrastructure assumed required to allow increased surface stays also contributed. With the fifth manned mission planned for a surface stay of 24 days, the available time margin improved. Possible solutions to the early negative margins are: (1) land two unmanned cargo missions after the first manned site certification mission, and thus offload some manned effort allocated to the third mission, (2) make more use of teleoperations/robotics to leverage crew time, although the current scenario already calls for aggressive use of this technology, (3) find ways to increase surface stay times and EVA hours during early missions, or to reduce the amount of equipment assumed necessary to transition to longer stay times, or (4) increase the number of manned short duration flights, or (5) increase the number of crew per flight.

2. EVA is a hazardous operation, and is not a particularly efficient use of human surface time resources either. Approximately 4 hours is consumed in IVA support and maintenance activities, and in non-productive ingress/egress time, for each 6 hour EVA. This study assumed some EVA tasks can be done at least as efficiently by teleoperated control from the lunar base (or personnel transfer module on a lunar lander). Teleoperated tasks include: site surveying; surface preparation, grading,-leveling; trenching utility ways and backfilling trenches after utility trays are installed; excavating for module emplacement and oxygen plant feedstock; transporting soil; and standardized inspection/maintenance chores. To achieve scenario objectives, teleoperation from Earth of certain site preparation and soil transportation tasks was necessary to leverage EVA time. A lunar surface telerobotic servicer device was proposed, which should have capability to eventually perform some tasks autonomously. Construction equipment, especially a prime mover but possibly a crane as well, should be capable of dual-mode control: either manual or by teleoperation from a lunar base or Earth workstation. Advances in automation and robotics technology is crucial to this scenario.

3. The role of Earth ground support in managing and controlling surface operations is significant, perhaps greater than might initially be expected or desired for future manned programs. In this scenario, to achieve early mission objectives, real-time mission support via Earth teleoperation of key construction activities (such as soil transporation for covering a radiation shelter) was required. Also, because nearly all crew resources are dedicated to surface activities during the short (8-day) duration surface stays, continuous Earth ground support for mission management/-control and systems monitoring duties is assumed necessary, similar to Apollo. This mode of operations continues until the lunar base functions like Space Station later in Phase II. In addition, limited surface stays during most of Phase II requires a well trained crew. Thus, pre-mission training activities will remain extremely important to mission success.

4. Burying or covering modules with regolith is far more time consuming than emplacing exposed modules (although many of the tasks to cover a module could probably be teleoperated from Earth given A&R technology development and proper engineering design). Because of this, and the probability that the crew in short duration (8-24 day) surface stays will not need additional radiation protection except from solar flares, this scenario emplaces only one covered module and leaves the rest of the modules exposed on the surface until Phase III, when crew time is available to bury them. This approach simplifies construction/assembly and allows for easier growth. The solar flare/radiation shelter will be buried or covered with 700 g/cm^2 of regolith (approximately 4 m).

5. All complex, external science missions are controlled from Earth during the experiment's operation phase. The assumed lunar base interaction is to deploy the experiment and to provide limited servicing. Crew science activities are mainly focused on conducting experiments in the geochemistry and life sciences modules. Other science missions are landed independently at farside and remote nearside locations. Phase III will have more time and resources for scientists at the lunar base to analyze data and control experiments.

6. Science objectives drive base mobility requirements. For instance, deploying an optical interferometer and conducting wide-ranging crater dating experiments are beyond the capabilities of unpressurized rovers. Pressurized rovers and support equipment are required. Base mobility is still low even with manned pressurized rovers, compared to direct manned landings from Earth or from a manned low lunar orbiting space station.

RECOMMENDATIONS

1. Develop a widely shared consensus for lunar base science objectives (specific missions, sequence, number). Develop more complete understanding of each science mission's needs for lunar base support in construction requirements, operations support for systems maintenance, base support for operations/mission management, and control. Develop rationale for lunar base location and mobility requirements based on science objectives.

2. Develop a consensus for what is really required in terms of specific surface elements, capabilities, or experience base to allow extending crew stay times. Mission requirements allowing transition from short (8 day) to intermediate stay times (24 days) and then to long duration (180 days) are needed.

3. Analyze required habitation size requirements for 4, 8, and 12 person crews and 180 stay times. The current scenario has only one Space Station type habitation module for an eventual crew of 8 (although 3 full size laboratory modules are attached). This may not be adequate.

4. Carefully consider the allowable radiation dosage and required radiation protection. Develop an optimum technique for emplacing modules with the required protection.

5. This operations study should be updated at the end of the current lunar base study effort using all revisions to the scenario and the latest element configurations.

7.0 References

1. Alred, J.W.: "Lunar Base Activities: An Overview," NASA JSC Advanced Programs Office, September 21, 1987.

2. Reese, T.G., Hemmerly, R.A., and Taylor, D.A.: "Civil Needs Data Base, Version 3.0," General Research Corporation, NASA Contract Number NASW-3921, July 16, 1987.

3. "Impact of Lunar and Planetary Missions on the Space Station," Eagle Engineering Report No. 84-85D, Contract No. NAS9-17176, November 21, 1984.

4. "Lunar Surface Return," NASA JSC Lunar Base Study, March 1984.

5. Lunar Base - Space Station Accomodation Study, NASA Langley.

6. "Baseline Configuration Document," JSC 30255, Space Station Program Office, January 15, 1987.

7. "Space Station Operations Plan," JSC 30201, Space Station Program Office, January 15, 1987.

8. "Space Station Projects Requirements Document," JSC 31000, Rev.C, Space Station Projects Office, March 6, 1987.

9. Critical Evaluation Task Force: "Final Presentation to the NASA Executive Technical Committee," September 15, 1986.

10. "EVA Catalog Tools and Equipment," JSC 20466, Mission Operations Directorate, NASA, November 4, 1985.

11. "Handbook of Lunar Materials," Lunar and Planetary Sciences Division, NASA JSC, May, 1978.

12. "Apollo 17 Mission Report," JSC 07904, NASA JSC, March, 1973.

13. Baker, D.: The History of Manned Space Flight, Crown Publishers, 1981.

14. Simonds, C.H.: "Analysis of Scientific Objectives for a Lunar Base," Eagle Memorandum, October 1987.

15. Simonds, C.H.: "Topographic Effects and Soil Mechanics at Candidate Landing Sites for Lunar Base," Eagle Memorandum, Draft, November 19, 1987.

16. Burke, B.F.: "Astronomical Interferometry on the Moon," pp. 281-292, Lunar Bases and Space Activities of the 21st Century, Mendell, W.W.,ed., Lunar and Planetary Institute, Houston, 1985.

17. Burke, B.F.: Personal Communication, November 27, 1987.

18. Horz, F.: "Mass Extinctions and Cosmic Collisions: A Lunar Test," pp. 349-360, Lunar Bases and Space Activities of the 21st Century, Mendell, W.W.,ed., Lunar and Planetary Institute, Houston, 1985.

19. Silberberg, R., Tsao, C.H., Adams, J.H., and Letaw, J.R.: "Radiation Transport of Cosmic Ray Nuclei in Lunar Material and Radiation Doses," pp. 663-670, Lunar Bases and Space Activities of the 21st Century, Mendell, W.W.,ed., Lunar and Planetary Institute, Houston, 1985.

20. Kaplicky, J. and Nixon, D.: "A Surface-Assembled Superstructure Envelope System to Support Regolith Mass Shielding for an Initial-Operational-Capability Lunar Base," pp. 375-380, Lunar Bases and Space Activities of the 21st Century, Mendell, W.W.,ed., Lunar and Planetary Institute, Houston, 1985.

21. Guerra, L.A.: "A Commonality Assessment of Lunar Surface Habitation," Master Thesis, University of Texas, August 1987.

22. "Crew Scheduling Constraints, Appendix K, Space Shuttle Crew Procedures Management Plan," JSC 22359, March 1987.

23. "Lunar Oxygen Impact Upon STS Effectiveness," Eagle Report No. 83-63, May 1983.

24. "Analysis of Lunar Propellant Production," Eagle Report No. 85-103B, December 9, 1985.

25. "Manned Mars Systems Study, First Quarterly Report," Martin Marietta Astronautics, NAS8-3712, August 20, 1987.

26. "Space Station Definition and Preliminary Design, WP-01, Book 2, Common Module Data Requirements No. DR-02, Rev.A," Martin Marietta Astronautics, Denver, Colorado, NAS8-36525, SSP-MMC-00031, June 30, 1986.

27. "Space Station Definition and Preliminary Design, WP-02, Book 1, Overall Configuration," McDonnell Douglas Astronautics Company, MDC-H2792, December, 1986.

28. Bate, R.R., Mueller, D.D., and White, J.E.: Fundamentals of Astrodynamics, Dover Publications, 1971.

29. The Astonomical Almanac for 1987, United States Naval Observatory, U.S. Government Printing Office.

30. Burke, J.D.: "Merits of a Lunar Polar Base Location," pp. 77-84, Lunar Bases and Space Activities of the 21st Century, Mendell, W.W.,ed., Lunar and Planetary Institute, Houston, 1985.

31. Space Station Definition and Requirements, Section 3, Space Station Systems Requirements, Appendix 3.1, Natural Environment Definition for Design, JSC 31000.

32. Reasch, R.F., Peercy, R.L., Rockoff, L.A.: "Space Station Crew Safety Alternatives Study," Final Report, Vol. II, Threat Development, NASA CR 3855, Contract No. NAS1-17242, June 1985.

33. Nachtwey, D.S.: "Manned Mars Mission Radiation Environment and Radiobiology," Manned Mars Missions Working Group Papers, pp.634-641, NASA M002, June 1986.

34. Letaw, J.R., Silberberg, R., and Tsao, C.H.: "Natural Radiation Hazards on the Manned Mars Missions," Manned Mars Missions Working Group Papers, pp.642-655, NASA M002, June 1986.

35. Space Station Program Definition and Requirements, Section 3, Space Station Systems Requirements, JSC 30000, Rev. D, Space Station Program Office, January 15, 1987.

36. Heckman, G.: "Solar Particle Event Predictions for Manned Mars Missions," Manned Mars Missions Working Group Papers, pp.674-683, NASA M002, June 1986.

37. Hall, S.B. and McCann, M.E.: "Radiation Environment and Shielding for Early Manned Mars Missions," Manned Mars Missions Working Group Papers, pp.686-705, NASA M002, June 1986.

38. SICSA Outreach, Sasakawa International Center for Space Architecture, The University of Houston, Vol.1, No.2, August 1987.

39. "Advanced Space Transportation System Mission Analysis," Final Report, Battelle Columbus Division, NASA Contract No. NAS9-17356, March 13, 1987.

40. Williams, R.J., and Hubbard, N.: "Report of the Workshop on Methodology for Evaluating Potential Lunar Resource Sites," NASA TM 58235, 1981.

41. Dick, R.D., Blacic, J.D, and Pettit, D.R.: "Use of Chemical Explosives for Emergency Solar Flare Shelter Construction and Other Excavations on the Martian Surface," Manned Mars Missions Working Group Papers, pp.478-493, NASA M002, June 1986.

42. Sliwa, N.E., Harrison, F.W., Soloway, D.I., McKinney, W.S., Cornils, K., Doggett, W.R., Cooper, E.G., and Alberts, T.E.: "Automation and Robotics Considerations for a Lunar Base," Paper No. LBS-88-184, presented at the second Lunar Bases and Space Activities in the 21st Century symposium, April 5-7, 1988, Houston, Texas.

Appendix A - CNDB Mission Manifest

CNDB Mission Manifest
Note: Mission manifests are not defined in CNDB
(This list reflects CNDB payloads without any changes)

Pre-1999

Earth/Moon L2 Libration Point:
1. Communication Relay Satellite in 1994

Lunar Orbit:
1. Lunar Geoscience Orbiter in 1993
2. (2) Lunar Polar Penetrator Network in 1996 & 1997
3. Advanced Lunar Geoscience Orbiter in 1997

Surface:
1. (2) Lunar Polar Sample Returns in 1996 & 1997
2. (2) Surface Surveying Rovers in 1997 & 1998

Year 1999

Surface: (117 K lbs)

Mission 1 (Unmanned to Lunar base site)
1. Surface Surveying Rover (2,200 lbs)
2. Expendable Lunar Lander (41,660 lbs)

Payload = 2,200 lbs   Total = 43,860 lbs

Mission 2 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs)
2. Expendable Lunar Ascent Vehicle (16,275 lbs)
3. Crew Logistics - 04/14 (300 lbs)
4. Crew Rotation - 04/14 (1,800 lbs)
5. Expendable Lunar Landers (41,660 lbs)
6. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 32,075 lbs   Total = 73,735 lbs

Year 2000

Surface: (315 K lbs)

Mission 3 (Unmanned)
1. Soil Mover/Crane/Constructor - Phase 2 (38,500 lbs)
2. Expendable Lunar Lander (41,660 lbs)

Payload = 38,500 lbs   Total = 80,160 lbs

Mission 4 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs)
2. Expendable Lunar Ascent Vehicle (16,275 lbs)
3. Crew Logistics - 04/14 (300 lbs)
4. Crew Rotation - 04/14 (1,800 lbs)

5. Expendable Lunar Lander (41,660 lbs)
6. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 32,075 lbs   Total = 73,735 lbs

Mission 5 (Unmanned)
1. Communications Relay Station - Phase 2 (2,500 lbs)
2. Initial Power Plant (7,000 lbs)
3. Unpressurized Rover (4,000 lbs)
4. Expendable Lunar Lander (41,660 lbs)

Payload = 13,500 lbs   Total = 55,160 lbs

Mission 6 (Manned)
1. Expendable Lunar Ascent Vehicle (16,275 lbs)
2. Crew Logistics - 04/14 (300 lbs)
3. Crew Rotation - 04/14 (1,800 lbs)
4. Expendable Lunar Lander (41,660 lbs)
5. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 31,575 lbs   Total = 73,235 lbs

Mission 7 (Unmanned to Farside - CNDB did not specify lander type or enough expendable landers)
1. Lunar Farside UV Telescope (10,000 lbs)
2. Lunar Based SETI (20,000 lbs)

<u>Year 2001</u>

Surface: (422 K lbs)

Mission 8 (Unmanned)
1. Module Interface Node (8,200 lbs)
2. (2) Initial Power Plants (7,000 lbs/each)
3. Expendable Lunar Lander (41,660 lbs)

Payload = 22,200 lbs   Total = 63,860 lbs

Mission 9 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs)
2. Expendable Lunar Ascent Vehicle (16,275 lbs)
3. Crew Logistics - 04/14 (300 lbs)
4. Crew Rotation - 04/14 (1,800 lbs)
5. Expendable Lunar Lander (41,660 lbs)
6. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 32,075 lbs   Total = 73,735 lbs

Mission 10 (Unmanned)
1. Liquid Oxygen Pilot Plant (38,500 lbs)
2. Expendable Lunar Lander (41,660 lbs)

Payload = 38,500 lbs   Total = 80,160 lbs

Mission 11 (Manned)
1. Expendable Lunar Ascent Vehicle (16,275 lbs)
2. Crew Logistics - 04/14 (300 lbs)

3. Crew Rotation - 04/14 (1,800 lbs)
4. Expendable Lunar Lander (41,660 lbs)
5. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 31,575 lbs Total = 73,235 lbs

Mission 12 (Unmanned)
1. Optical Interferometer Telescope (15,000 lbs)
2. Expendable Lunar Lander (41,660 lbs)

Payload = 15,000 lbs Total = 56,660 lbs

Mission 13 (Manned)
1. Expendable Lunar Ascent Vehicle (16,275 lbs)
2. Crew Logistics - 04/14 (300 lbs)
3. Crew Rotation - 04/14 (1,800 lbs)
4. Expendable Lunar Lander (41,660 lbs)
5. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 31,575 lbs Total = 73,235 lbs

<u>Year 2002</u>

Surface: (458 K lbs)

Mission 14 (Unmanned)
1. Habitat Module - Phase 2 (38,500 lbs)
2. Expendable Lunar Lander (41,660 lbs)

Payload = 38,500 lbs Total = 80,160 lbs

Mission 15 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs)
2. Expendable Lunar Ascent Vehicle (16,275 lbs)
3. Crew Logistics - 04/30 (900 lbs)
4. Crew Rotation - 04/30 (1,800 lbs)
5. Expendable Lunar Lander (41,660 lbs)
6. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 32,675 lbs Total = 74,335 lbs

Mission 16 (Unmanned)
1. Oxygen Mining Equipment (38,500 lbs)
2. Expendable Lunar Lander (41,660 lbs)

Payload = 38,500 lbs Total = 80,160 lbs

Mission 17 (Manned)
1. Expendable Lunar Ascent Vehicle (16,275 lbs)
2. Crew Logistics - 04/30 (900 lbs)
3. Crew Rotation - 04/30 (1,800 lbs)
4. Expendable Lunar Lander (41,660 lbs)
5. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 32,175 lbs Total = 73,835 lbs

Mission 18 (Manned)
1. Expendable Lunar Ascent Vehicle (16,275 lbs)

2. Crew Logistics - 04/30 (900 lbs)
3. Crew Rotation - 04/30 (1,800 lbs)
4. Expendable Lunar Lander (41,660 lbs)
5. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 32,175 lbs Total = 73,835 lbs

Mission 19 (Manned)
1. Expendable Lunar Ascent Vehicle (16,275 lbs)
2. Crew Logistics - 04/30 (900 lbs)
3. Crew Rotation - 04/30 (1,800 lbs)
4. Expendable Lunar Lander (41,660 lbs)
5. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 32,175 lbs Total = 73,835 lbs

Year 2003

Surface: (541 K lbs)

Mission 20 (Unmanned)
1. Geochemical Materials Laboratory (38,500 lbs)
2. Expendable Lunar Lander (41,660 lbs)

Payload = 38,500 lbs Total = 80,160 lbs

Mission 21 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs)
2. Expendable Lunar Ascent Vehicle (16,275 lbs)
3. Crew Logistics - 04/30 (900 lbs)
4. Crew Rotation - 04/30 (1,800 lbs)
5. Expendable Lunar Lander (41,660 lbs)
6. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 32,675 lbs Total = 74,335 lbs

Mission 22 (Unmanned - overweight)
1. Module Interface Node (8,200 lbs)
2. Liquid Oxygen Production Plant Mission (33,333 lbs)
3. Expendable Lunar Lander (41,660 lbs)

Payload = 41,533 lbs Total = 83,193 lbs

Mission 23 (Manned)
1. Expendable Lunar Ascent Vehicle (16,275 lbs)
2. Crew Logistics - 04/30 (900 lbs)
3. Crew Rotation - 04/30 (1,800 lbs)
4. Expendable Lunar Lander (41,660 lbs)
5. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 32,175 lbs Total = 73,835 lbs

Mission 24 (Unmanned)
1. Advanced Power Plant (38,500 lbs)
2. Expendable Lunar Lander (41,660 lbs)

Payload = 38,500 lbs Total = 80,160 lbs

Mission 25 (Manned)
1. Expendable Lunar Ascent Vehicle (16,275 lbs)
2. Crew Logistics - 04/30 (900 lbs)
3. Crew Rotation - 04/30 (1,800 lbs)
4. Expendable Lunar Lander (41,660 lbs)
5. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 32,175 lbs Total = 73,835 lbs

Mission 26 (Manned)
1. Expendable Lunar Ascent Vehicle (16,275 lbs)
2. Crew Logistics - 04/30 (900 lbs)
3. Crew Rotation - 04/30 (1,800 lbs)
4. Expendable Lunar Lander (41,660 lbs)
5. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 32,175 lbs Total = 73,835 lbs

<u>Year 2004</u>

Surface: (454 K lbs)

Mission 27 (Unmanned)
1. (1) Liquid Oxygen Production Plant Missions (33,333 lbs/each)
2. Unpressurized Rover (4,000 lbs)
3. Expendable Lunar Lander (41,660 lbs)

Payload = 37,333 lbs Total = 78,993 lbs

Mission 28 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs)
2. Expendable Lunar Ascent Vehicle (16,275 lbs)
3. Crew Logistics - 04/30 (900 lbs)
4. Crew Rotation - 04/30 (1,800 lbs)
5. Expendable Lunar Lander (41,660 lbs)
6. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 32,675 lbs Total = 74,335 lbs

Mission 29 (Unmanned)
1. (1) Liquid Oxygen Production Plant Missions (33,333 lbs/each)
2. Expendable Lunar Lander (41,660 lbs)

Payload = 33,333 lbs Total = 74,993 lbs

Mission 30 (Manned)
1. Service Geochemical Materials Lab (500 lbs)
2. Expendable Lunar Ascent Vehicle (16,275 lbs)
3. Crew Logistics - 04/30 (900 lbs)
4. Crew Rotation - 04/30 (1,800 lbs)
5. Expendable Lunar Lander (41,660 lbs)
6. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 32,675 lbs Total = 74,335 lbs

Mission 31 (Manned to Farside)
1. Service Lunar Farside UV Telescope (2,000 lbs)

2. Expendable Lunar Ascent Vehicle (16,275 lbs)
3. Crew Logistics - 04/30 (900 lbs)
4. Crew Rotation - 04/30 (1,800 lbs)
5. Expendable Lunar Lander (41,660 lbs)
6. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 34,175 lbs Total = 75,835 lbs

Mission 32 (Manned)
1. Expendable Lunar Ascent Vehicle (16,275 lbs)
2. Crew Logistics - 04/30 (900 lbs)
3. Crew Rotation - 04/30 (1,800 lbs)
4. Expendable Lunar Lander (41,660 lbs)
5. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 32,175 lbs Total = 73,835 lbs

Year 2005

Mission 33 (Unmanned to Earth-Moon L1 Libration Point)
1. Communications Relay Satellite - Phase 3 (2,500 lbs)

Mission 34 (Unmanned to Lunar Orbit)
1. Propellant Depot/Refueling Station (40,000 lbs)

Surface: (548 K lbs)

Mission 35 (Unmanned)
1. Communications Relay Station - Phase 2 (2,500 lbs)
2. Module Interface Node (8,200 lbs)
3. Life Science Research Node (8,200 lbs)
4. Deep Drilling (4,000 lbs)
5. Expendable Lunar Lander (41,600 lbs)

Payload = 22,900 lbs Total = 64,560 lbs

Mission 36 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs)
2. Expendable Lunar Ascent Vehicle (16,275 lbs)
3. Crew Logistics - 04/180 (6,400 lbs)
4. Crew Rotation - 04/180 (1,800 lbs)
5. Expendable Lunar Lander (41,660 lbs)
6. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 38,175 lbs Total = 79,835 lbs

Mission 37 (Unmanned)
1. (1) Life Science Research Facility (40,000 lbs/each)
2. Expendable Lunar Lander (41,600 lbs)

Payload = 40,000 lbs Total = 81,600 lbs

Mission 38 (Manned)
1. Service Geochemical Materials Lab (500 lbs)
2. Expendable Lunar Ascent Vehicle (16,275 lbs)

3. Crew Logistics - 04/180 (6,400 lbs)
4. Crew Rotation - 04/180 (1,800 lbs)
5. Expendable Lunar Lander (41,660 lbs)
6. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 38,175 lbs Total = 79,835 lbs

Mission 39 (Unmanned)

1. (1) Life Science Research Facility (40,000 lbs/each)
2. Expendable Lunar Lander (41,660 lbs)

Payload = 40,000 lbs Total = 81,600 lbs

Mission 40 (Manned)

1. Expendable Lunar Ascent Vehicle (16,275 lbs)
2. Crew Logistics - 04/180 (6,400 lbs)
3. Crew Rotation - 04/180 (1,800 lbs)
4. Expendable Lunar Lander (41,660 lbs)
5. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 37,675 lbs Total = 79,335 lbs

Mission 41 (Manned)

1. Expendable Lunar Ascent Vehicle (16,275 lbs)
2. Crew Logistics - 04/180 (6,400 lbs)
3. Crew Rotation - 04/180 (1,800 lbs)
4. Expendable Lunar Lander (41,660 lbs)
5. Four-crew Personnel Transfer Module (13,200 lbs)

Payload = 37,675 lbs Total = 79,335 lbs

POST-2005

<u>Year 2006</u>

Lunar Orbit: (91 K lbs)

1. (2) Lunar Orbit Service Station Logistics (15,000 lbs/each)
2. Deliver Reusable Lunar Lander Vehicle (11,500 lbs)
3. (6) Liq. Hydrogen for Reusable Lander (7,000 lbs/each)
4. Six-crew Personnel Transfer Module (7,200 lbs)

Surface: (165 K lbs)

1. Habitat Module - Phase 3 (38,500 lbs)
2. Servicing Facility Shop Module (38,500 lbs)
3. Low Frequency Radio Array (20,000 lbs)
4. Lunar Science and Field Geology (500 lbs, return 100 lbs)
5. Service Geochemical Materials Lab (500 lbs)
6. Service Life Science Research Lab (500 lbs)
7. (3) Lunar Base Crew Rotations 04/180 (1,800 lbs/each)
8. (3) Lunar Base Crew Logistics 04/180 (6,400 lbs/each)
9. (3) Four-crew Personnel Transfer Modules (13,200 lbs/each)

<u>Year 2007</u>

Earth-Moon L2 Libration Point:
1. Communication Relay Satellite - Phase 3 (2,500 lbs)

Lunar Orbit: (79 K lbs)
1. (2) Lunar Orbit Service Station Logistics (15,000 lbs/each)
2. (7) Liq. Hydrogen for Reusable Lander (7,000 lbs/each)

Surface: (154 K lbs)
1. Communication Relay Station (2,500 lbs)
2. Pressurized Rover (38,500 lbs)
3. Radio Interferometry (20,000 lbs)
4. Service Shop Facility (2,000 lbs)
5. Service Low Frequency Radio Array (1,000 lbs)
6. Lunar Science and Field Geology (500 lbs, return 100 lbs)
7. Service Geochemical Materials Lab (500 lbs)
8. Service Life Science Research Lab (500 lbs)
9. (4) Lunar Base Crew Rotations 04/180 (1,800 lbs/each)
10. (4) Lunar Base Crew Logistics 04/180 (6,400 lbs/each)
11. (4) Four-crew Personnel Transfer Modules (13,200 lbs/each)

<u>Year 2008</u>

Lunar Orbit: (132 K lbs)
1. (2) Lunar Orbit Service Station Logistics (15,000 lbs/each)
2. (6) Liq. Hydrogen for Reusable Lander (7,000 lbs/each)
3. (4) Service Six-crew Personnel Transfer Module (15,000 lbs/each)

Surface: (61 K lbs)
1. Communication Relay Station (2,500 lbs)
2. Service Lunar Farside UV Telescope (2,000 lbs)
3. Service Radio Interferometry (1,000 lbs)
4. Service Shop Facility (2,000 lbs)
5. Service Low Frequency Radio Array (1,000 lbs)
6. Lunar Science and Field Geology (500 lbs, return 100 lbs)
7. Service Geochemical Materials Lab (500 lbs)
8. Service Life Science Research Lab (500 lbs)
9. (4) Lunar Base Crew Rotations 06/180 (2,700 lbs/each)
10. (4) Lunar Base Crew Logistics 06/180 (9,600 lbs/each)

<u>Year 2009</u>

Lunar Orbit: (139 K lbs)
1. (2) Lunar Orbit Service Station Logistics (15,000 lbs/each)
2. (7) Liq. Hydrogen for Reusable Lander (7,000 lbs/each)
3. (4) Service Six-crew Personnel Transfer Module (15,000 lbs/each)

Surface: (95 K lbs)
1. Soil Mover/Crane/Constructor - Phase 3 (38,500 lbs)
2. Service Radio Interferometry (1,000 lbs)
3. Service Shop Facility (2,000 lbs)

4. Service Low Frequency Radio Array (1,000 lbs)
5. Lunar Science and Field Geology (500 lbs, return 100 lbs)
6. Service Geochemical Materials Lab (500 lbs)
7. Service Life Science Research Lab (500 lbs)
8. (4) Lunar Base Crew Rotations 06/180 (2,700 lbs/each)
9. (4) Lunar Base Crew Logistics 06/180 (9,600 lbs/each)

Year 2010

Lunar Orbit: (132 K lbs)
1. (2) Lunar Orbit Service Station Logistics (15,000 lbs/each)
2. (6) Liq. Hydrogen for Reusable Lander (7,000 lbs/each)
3. (4) Service Six-crew Personnel Transfer Module (15,000 lbs/each)

Surface: (95 K lbs)
1. Ceramics Plant (38,500 lbs)
2. Service Radio Interferometry (1,000 lbs)
3. Service Shop Facility (2,000 lbs)
4. Service Low Frequency Radio Array (1,000 lbs)
5. Lunar Science and Field Geology (500 lbs, return 100 lbs)
6. Service Geochemical Materials Lab (500 lbs)
7. Service Life Science Research Lab (500 lbs)
8. (4) Lunar Base Crew Rotations 06/180 (2,700 lbs/each)
9. (4) Lunar Base Crew Logistics 06/180 (9,600 lbs/each)

Appendix B - Mission Manifests for the Scenario Used in this Study

Pre-1999

Earth/Moon L2 Libration Point:
1. Communication Relay Satellite in 1994 - CNDB No. 5078

Lunar Orbit:
1. Lunar Geoscience Orbiter in 1993 - CNDB No. 2064A
2. (2) Lunar Polar Penetrator Network in 1996 & 1997 - CNDB No. 5023
3. Advanced Lunar Geoscience Orbiter in 1997 - CNDB No. 5000

Surface:
1. (2) Lunar Polar Sample Returns in 1996 & 1997 - CNDB No. 5024
2. (2) Surface Surveying Rovers in 1997 & 1998 - CNDB No. 5034

B-1. Mission Manifest for Phase II Lunar Base

Year 1999

Surface:

Mission 1 (Unmanned, dedicated expendable lan
der to Lunar base site)
1. Surface Unmanned Surveying Rover (2,200 lbs) - CNDB No. 5034

Mission 2 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Unpressurized Rover (4,000 lbs) - CNDB No. 5031
3. Landing Instrumentation/Beacons (2,000 lbs, est.)
4. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
5. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
6. Crew Rotation - 4 crew/14 day mission/8 day surface stay (1,800 lbs) - CNDB 5002
7. Crew Logistics - 4 crew/14 day mission/8 day surface stay (300 lbs) - CNDB 5052
8. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 38,075 lbs   Total in LLO = 79,735 lbs   Payload available = 425 lbs

Year 2000

Surface:

Mission 3 (Unmanned)
1. Crane and cargo carrying trailer, Prime Mover (PM), PM trailer for carrying soil (dumpable), PM attachments (bulldozer blade, front loader shovel, etc.), PM attachment changeout fixture (38,500 lbs) - Similar to CNDB No. 5032
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 38,500 lbs   Total in LLO = 80,160 lbs   Payload available = 0

Mission 4 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Unpressurized Rover (4,000 lbs) - CNDB No. 5031
3. Landing Instrumentation/Beacons (2,000 lbs, est.)
4. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

5. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
6. Crew Rotation - 4 crew/14 day mission/8 day surface stay (1,800 lbs) - CNDB 5002
7. Crew Logistics - 4 crew/14 day mission/8 day surface stay (300 lbs) - CNDB 5052
8. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 38,075 lbs Total = 79,735 lbs Payload available = 425 lbs

Mission 5 (Unmanned)
1. Surface Communications Relay Station - Phase 2 (2,500 lbs) - CNDB No. 5036
2. Initial Power Plant (7,000 lbs) - CNDB No. 5013
3. Radiation Storm Shelter/Safe Haven Module (20,000 lbs est.)
4. Radiator/Thermal Control System (for 2 modules/2 nodes) (3,400 lbs est.)
5. Bulkheads and Hopper/Conveyor System (for covering module) (3,000 lbs est.)
6. Unpressurized Storage Shed (for vehicles & PM attachments) (2,000 lbs est.)
5. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5053

Payload = 37,900 lbs Total = 79,560 lbs Payload available = 600 lbs

Mission 6 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/14 day mission/8 day surface stay (1,800 lbs) - CNDB 5002
5. Crew Logistics - 4 crew/14 day mission/8 day surface stay (300 lbs) - CNDB 5052
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,075 lbs Total = 73,735 lbs Payload available = 6,425 lbs

Mission 7 (Unmanned - spare ascent vehicle for contingency/emergency return)
1. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
2. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
2. Crew Logistics - 4 crew/14 day mission/8 day surface stay (300 lbs) - CNDB No. 5052
3. Expendable Lunar Ascent Vehicle - CNDB No. 5053 (16,275+? lbs) (Apollo LM ascent = ~10K lbs, CM = 13,090 lb and SM = 54,074 lb)

Payload = 29,775+? lbs Total = 71,435+? lbs Payload available = 8,725-? lbs

Year 2001

Surface:

Mission 8 (Unmanned)
1. Module Interface Node (8,200 lbs) - CNDB No. 5082
2. Airlock (6,800 lbs est.)
3. (2) Initial Power Plants (7,000 lbs/each) - CNDB No. 5013
4. (Lunar Base) Geophysical Network Station (1,080 lbs, est.)
5. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 30,080 lbs Total = 71,740 lbs Payload available = 8,420 lbs

Mission 9 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/14 day mission/8 day surface stay (1,800 lbs) - CNDB 5002
5. Crew Logistics - 4 crew/14 day mission/8 day surface stay (300 lbs) - CNDB 5052

6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053
Payload = 32,075 lbs Total = 73,735 lbs Payload available = 6,425 lbs

Mission 10 (Unmanned)
1. Habitat Module - Phase 2 (38,500 lbs) - CNDB No. 5011
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
Payload = 38,500 lbs Total = 80,160 lbs Payload available = 0

Mission 11 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5002
5. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5052
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053
Payload = 32,675 lbs Total = 74,335 lbs Payload available = 5,825 lbs

Mission 12 (Unmanned)
1. Geochemical Materials Laboratory (38,500 lbs) - CNDB No. 5073
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
Payload = 38,500 lbs Total = 80,160 lbs Payload available = 0

Mission 13 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5002
5. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5052
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053
Payload = 32,675 lbs Total = 74,335 lbs Payload available = 5,825 lbs

Mission 14 (Unmanned - dedicated expendable lander to polar site)
1. (Polar) Geophysical Network Station (8,000 lbs est.)

<u>Year 2002</u>

Surface:

Mission 15 (Unmanned)
1. Liquid Oxygen Pilot Plant (38,500 lbs) - CNDB No. 5028
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
Payload = 38,500 lbs Total = 80,160 lbs Payload available = 0

Mission 16 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
5. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053
Payload = 32,675 lbs Total = 74,335 lbs Payload available = 5,825 lbs

Mission 17 (Unmanned)
1. Module Interface Node (8,200 lbs) - CNDB No. 5082
2. Airlock (6,800 lbs est.)
3. Radiator/Thermal Control System (for 2 modules/2 nodes) (3,400 lbs est.)
4. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 18,400 lbs Total = 60,060 lbs Payload available = 20,100 lbs

Mission 18 (Manned)
1. Service Geochemical Materials Lab (500 lbs) - CNDB No. 5074
2. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
3. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
4. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
5. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
6. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
7. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 33,175 lbs Total = 74,835 lbs Payload available = 5,325 lbs

Mission 19 (Unmanned)
1. (1) Life Science Research Facility (40,000 lbs/each) - CNDB No. 5015
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 40,000 lbs Total = 81,660 lbs Payload available = -1,500 lbs

Mission 20 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
5. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,675 lbs Total = 74,335 lbs Payload available = 5,825 lbs

Mission 21 (Unmanned)
1. (2) Pressurized Rovers (4,180 lbs/each - 8,360 lbs total)
2. Pressurized Garage (15,000 lbs est)
3. Optical Interferometer Telescope (15,000 lbs) - CNDB No. 5037
4. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 38,360 lbs Total = 80,020 lbs Payload available = 140 lbs

Mission 22 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
5. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,675 lbs Total = 74,335 lbs Payload available = 5,825 lbs

Mission 23 (Unmanned - dedicated expendable lander to near-side site)
1. (Near Side) Geophysical Network Station (8,000 lbs est.)

Year 2003

Mission 24 (Unmanned to Earth-Moon L2 Libration Point)
1. Communications Relay Satellite - Phase 2 (2,500 lbs) - CNDB No. 5078

Surface:

Mission 25 (Unmanned)
1. Life Science Research Node (8,200 lbs) - CNDB No. 5079
2. Crater Dating Experiment Equipment (1,000 lbs est.)
3. Deep Drilling (4,000 lbs) - CNDB No. 5065
4. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 13,200 lbs Total = 54,860 lbs Payload available = 25,300 lbs

Mission 26 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
5. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,675 lbs Total = 74,335 lbs Payload available = 5,825 lbs

Mission 27 (Unmanned, farside payload, deployable from lander, may be able to combine with Mission 28)
1. Lunar Farside UV Telescope (10,000 lbs) - CNDB No. 5009
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050 - or use dedicated lander

Payload = 10,000 lbs Total = 51,660 lbs Payload available = 28,500 lbs

Mission 28 (Unmanned, farside payload, deployable from lander, may be able to combine with Mission 27)
1. Lunar Based SETI (20,000 lbs) - CNDB No. 5008
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050 - or use dedicated lander

Payload = 20,000 lbs Total = 61,660 lbs Payload available = 18,500 lbs

Mission 29 (Unmanned, farside payload, dedicated expendable lander)
1. (Farside) Geophysical Network Station (8,000 lbs est.)

Mission 30 (Manned)
1. Service Geochemical Materials Lab (500 lbs) - CNDB No. 5074
2. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
3. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
4. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
5. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
6. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
7. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 33,175 lbs Total = 74,835 lbs Payload available = 5,325 lbs

Mission 31 (Manned)
1. Service Life Science Facility (500 lbs) - CNDB No. 5070
2. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
3. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

4. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
5. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
6. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
7. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 33,175 lbs Total = 74,835 lbs Payload available = 5,325 lbs

Mission 32 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
5. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,675 lbs Total = 74,335 lbs Payload available = 5,825 lbs

Year 2004

Surface:

Mission 33 (Unmanned)
1. Advanced Power Plant (38,500 lbs) - CNDB No. 5006
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 38,500 lbs Total = 80,160 lbs Payload available = 0

Mission 34 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
5. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,675 lbs Total = 74,335 lbs Payload available = 5,825 lbs

Mission 35 (Unmanned)
1. Oxygen Mining Equipment (38,500 lbs) - CNDB No. 5071
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 38,500 lbs Total = 80,160 lbs Payload available = 0

Mission 36 (Manned)
1. Service Geochemical Materials Lab (500 lbs) - CNDB No. 5074
2. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
3. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5018
4. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5068
5. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
6. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
7. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 33,175 lbs Total = 74,835 lbs Payload available = 5,325 lbs

Mission 37 (Unmanned)
1. Liquid Oxygen Production Plant Mission (33,333 lbs) - CNDB No. 5029
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5053

Payload = 33,333 lbs Total = 74,993 lbs Payload available = 5,167 lbs

Mission 38 (Manned)
1. Service Life Science Facility (500 lbs) - CNDB No. 5070
2. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
3. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
4. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
5. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
6. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
7. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 33,175 lbs Total = 74,835 lbs Payload available = 5,325 lbs

Mission 39 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
5. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,675 lbs Total = 74,335 lbs Payload available = 5,825 lbs

Year 2005

Mission 40 (Unmanned to Earth-Moon L1 Libration Point)
1. Communications Relay Satellite - Phase 3 (2,500 lbs) - CNDB No. 5026

Surface:

Mission 41 (Unmanned)
1. Communications Relay Station - Phase 2 (2,500 lbs) - CNDB No. 5036
2. Module Interface Node (8,200 lbs) - CNDB No. 5082
3. Logistics Module (19,220 lbs est.)
4. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 29,920 lbs Total = 71,580 lbs Payload available = 8,580 lbs

Mission 42 (Manned)
1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/180 day mission & surface stay (1,800 lbs) - CNDB No. 5067
5. Crew Logistics - 4 crew/180 day mission & surface stay (6,400 lbs) - CNDB No. 5076
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 38,175 lbs Total = 79,835 lbs Payload available = 325 lbs

Mission 43 (Unmanned)
1. Propellant Depot/Refueling Station on Surface (38,500 lbs est.)
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 40,000 lbs Total = 81,660 lbs Payload available = 0

Mission 44 (Manned)
1. Service Geochemical Materials Lab (500 lbs) - CNDB No. 5074
2. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027

3. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
4. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
5. Crew Rotation - 4 crew/180 day mission & surface stay (1,800 lbs) - CNDB No. 5067
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,275 lbs Total = 73,935 lbs Payload available = 6,225 lbs

Mission 45 (Unmanned)

1. (1) Life Science Research Facility (40,000 lbs) - CNDB No. 5015
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 40,000 lbs Total = 81,660 lbs Payload available = -1,500 lbs

Mission 46 (Manned)

1. Service Life Science Facility (500 lbs) - CNDB No. 5070
2. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
3. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
4. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
5. Crew Rotation - 4 crew/180 day mission & surface stay (1,800 lbs) - CNDB No. 5067
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,275 lbs Total = 73,935 lbs Payload available = 6,225 lbs

Mission 47 (Manned)

1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/180 day mission/180 day surface stay (1,800 lbs) CNDB 5067
5. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 31,775 lbs Total = 73,435 lbs Payload available = 6,725 lbs

B-2. Phase III Lunar Base Missions

POST-2005 (Modified original CNDB)

Year 2006

Surface:

1. Habitat Module - Phase 3 (38,500 lbs) - CNDB No. 5012
2. Servicing Facility Shop Module (38,500 lbs) - CNDB No. 5014
3. Low Frequency Radio Array (20,000 lbs) - CNDB No. 5062
4. Lunar Science and Field Geology (500 lbs, return 100 lbs) - CNDB No. 5027
5. Service Geochemical Materials Lab (500 lbs) - CNDB No. 5074
6. Service Life Science Research Lab (500 lbs) - CNDB No. 5070
7. (3) Lunar Base Crew Rotations 4 crew/180 day surface stay (1,800 lbs/each) 5067
8. Logistics Module Changeout (19,220 lbs est.)
9. (3) Four-crew Personnel Transfer Modules (13,200 lbs/each) - CNDB No. 5018
10. Deliver Reusable Lunar Lander Vehicle (11,500 lbs) - CNDB No. 5054
11. (6) Liq. Hydrogen for Reusable Lander (7,000 lbs/each) - CNDB No. 5080
12. Six-crew Personnel Transfer Module (7,200 lbs) - CNDB No. 5019

Year 2007

Earth-Moon L2 Libration Point:
1. Communication Relay Satellite - Phase 3 (2,500 lbs) - CNDB No. 5025

Surface:
1. Communication Relay Station (2,500 lbs) - CNDB No. 5035
2. Radio Interferometry (20,000 lbs) - CNDB No. 5064
3. Service Shop Facility (2,000 lbs) - CNDB No. 5072
4. Service Low Frequency Radio Array (1,000 lbs) - CNDB No. 5061
5. Lunar Science and Field Geology (500 lbs, return 100 lbs) - CNDB No. 5027
6. Service Geochemical Materials Lab (500 lbs) - CNDB No. 5074
7. Service Life Science Research Lab (500 lbs) - CNDB No. 5070
8. (4) Lunar Base Crew Rotations 4 crew/180 day surface stay (1,800 lbs/each) 5067
9. Logistics Module Changeout (19,220 lbs est.)
10. (4) Four-crew Personnel Transfer Modules (13,200 lbs/each) - CNDB No. 5018
11. (7) Liq. Hydrogen for Reusable Lander (7,000 lbs/each) - CNDB No. 5080

Year 2008

Surface:
1. Communication Relay Station (2,500 lbs) - CNDB No. 5035
2. Service Lunar Farside UV Telescope (2,000 lbs) - CNDB No. 5010
3. Service Radio Interferometry (1,000 lbs) - CNDB No. 5063
4. Service Shop Facility (2,000 lbs) - CNDB No. 5072
5. Service Low Frequency Radio Array (1,000 lbs) - CNDB No. 5061
6. Lunar Science and Field Geology (500 lbs, return 100 lbs) - CNDB No. 5027
7. Service Geochemical Materials Lab (500 lbs) - CNDB No. 5074
8. Service Life Science Research Lab (500 lbs) - CNDB No. 5070
9. (4) Lunar Base Crew Rotations 06/180 (2,700 lbs/each) - CNDB No. 5065
10. Logistics Module Changeout (19,220 lbs est.)
11. (6) Liq. Hydrogen for Reusable Lander (7,000 lbs/each) - CNDB No. 5080
12. (4) Service Six-crew Personnel Transfer Module (15,000 lbs/each) - CNDB No. 5069

Year 2009

Surface:
1. Soil Mover/Crane/Constructor - Phase 3 (38,500 lbs) - CNDB No. 5033
2. Service Radio Interferometry (1,000 lbs) - CNDB No. 5063
3. Service Shop Facility (2,000 lbs) - CNDB No. 5072
4. Service Low Frequency Radio Array (1,000 lbs) - CNDB No. 5061
5. Lunar Science and Field Geology (500 lbs, return 100 lbs) - CNDB No. 5027
6. Service Geochemical Materials Lab (500 lbs) - CNDB No. 5074
7. Service Life Science Research Lab (500 lbs) - CNDB No. 5070
8. (4) Lunar Base Crew Rotations 06/180 (2,700 lbs/each) - CNDB No. 5066
9. Logistics Module Changeout (19,220 lbs est.)
10. (7) Liq. Hydrogen for Reusable Lander (7,000 lbs/each) - CNDB No. 5080
11. (4) Service Six-crew Personnel Transfer Module (15,000 lbs/each) - CNDB No. 5069

Year 2010

Surface:
1. Ceramics Plant (38,500 lbs) - CNDB No. 5022
2. Service Radio Interferometry (1,000 lbs) - CNDB No. 5063
3. Service Shop Facility (2,000 lbs) - CNDB No. 5072
4. Service Low Frequency Radio Array (1,000 lbs) - CNDB No. 5061
5. Lunar Science and Field Geology (500 lbs, return 100 lbs) - CNDB No. 5027
6. Service Geochemical Materials Lab (500 lbs) - CNDB No. 5074
7. Service Life Science Research Lab (500 lbs) - CNDB No. 5070
8. (4) Lunar Base Crew Rotations 06/180 (2,700 lbs/each) - CNDB No. 5066
9. Logistics Module Changeout (19,220 lbs est.)
10. (6) Liq. Hydrogen for Reusable Lander (7,000 lbs/each) - CNDB No. 5080
11. (4) Service Six-crew Personnel Transfer Module (15,000 lbs/each) - CNDB No. 5069

Appendix C - Mission Payloads

C-1. Payload Descriptions

The following descriptions are for payloads delivered in this study's scenario that have changed slightly from the context of the CNDB. Most other payloads have been described in the CNDB (2) and are included in Section C-2 of Appendix C. Additional details of construction equipment, science experiments, and other payloads are described in Section 5.

1. Unmanned Surface Surveying Rover (Mission 1)

This mission utilizes a dedicated lander to deliver the rover surveyor to the surface (unlike the CNDB which used the huge over-capacity expendable lander designed for Lunar Base cargo missions). The rover would make a final site selection for the first manned landing since Apollo. Navigational beacons and other landing aids could be a part of this rover to assist in the manned mission.

2. Solar Flare Shelter (Mission 5)

This shelter to protect the crew from solar flare radiation is assumed to be a cylindrical pressurized module approximately the size of a logistics module (4.5 m diameter, 6 m long), and will need to be emplaced with a 4 m deep overburden of regolith to provide the crew adequate protection during the worse solar flares. The module is envisioned to be placed in a horizontal position, which means that for 4 m of soil for radiation protection a ~9 m deep hole would be required for the module to be buried in, or if it is covered, the top of the soil overburden would be ~9 m above the surface.

3. Contigency Expendable Lunar Ascent Vehicle (Mission 7)

This spare ascent vehicle will be used by base crew in the event of a problem with the primary return ascent vehicle or a medical emergency involving some of the crew when it is undesirable to abort the entire mission. This ascent vehicle could have capability for trans-Earth injection and direct entry to the Earth surface if fast return of an injuried crew person is required, otherwise it will be the standard 16,275 lb expendable ascent vehicle.

4. Geophysical Network Station

(Lunar Base - Mission 8)
The geophysical station is envisioned as a part of the automated instrument set that is landed by dedicated unmanned landers to determine the chemistry and internal structure of remote Lunar areas.

(Polar - Mission 14)
This mission to a polar site uses an expendable lander specifically designed for landing the geophysical stations that will eventually form a Lunar network. The mission will include a rover designed to map density variations and the seismic, magnetic, and electrical properties of the subsurface at a variety of sites. Portable seismometers and a number of explosive packages will be required, as well as portable magnetometers and gravimeters. The rover could also be outfitted with sampling capability, and include either on-board chemical analysis equipment or a sample return vehicle to return the samples to an Earth space station compatible orbit.

(Near Side - Mission 23)

A mission similar to Mission 14 is envisioned for another near side location. If this site is within the range of the pressurized rovers, a scenario similar to Mission 8 & 11 could be employed to accomplish this experiment.

(Farside - Mission 29)
This mission places a payload package similar to Mission 14 at a farside location.

5. Geochemical Materials Laboratory (Mission 12)

The geochemical materials laboratory will contain equipment such as X-ray fluorescence spectrometer, X-ray diffractometer, thin section facility, petrographic microscope, gas chromatograph, mass spectrometer, and other instruments to support Lunar sample analysis, Lunar materials processing, and oxygen pilot plant analytical/chemical laboratory support.

6. Pressurized Rovers and Pressurized Garage (Mission 21)

Two rovers are supplied to provide safety redundancy during longer duration Lunar traverses. The pressurized garage is envisioned as a convenient module to perform servicing and maintenance functions on the pressurized rovers in a shirt-sleeve environment. Reliability of the pressurized rovers will be important since the range of these vehicles are to be in the several hundred kilometer range, thus preventive maintenance is required. Also consumable resupply will be more time consuming for the pressurized rovers. The garage is in effect a large airlock for vehicles that cycles through pressurization and depressurization. A non-suited crew person can enter the pressurized garage, enter the rover, pressurize the rover, depressurize the garage, open the garage door, and drive out. The rover should contain an EVA suit(s) for survival during rover problems or emergencies.

7. Communications Relay Satellite to Earth-Moon L2 Libration Point (Mission 24)

A communications relay satellite to augment the L2 satellite deployed in 1994 is planned prior to the heavy farside activity planned during the year 2003.

8. Lunar Farside UV Telescope (Mission 27)

This unmanned mission to a farside location deploys a large UV/X-ray telescope for imaging, spectroscopy, and polarimetry of nearby sources and interstellar medium. The farside location should be selected to allow servicing at a later date by a manned or unmanned rover from the Lunar base. It is envisioned as deployable from the unmanned lander. It may be possible to combine this payload with Mission 28.

9. Lunar Based SETI (Mission 28)

Envisioned as deployable from the unmanned lander. May be able to combine with Mission 27. This unmanned mission to a farside location deploys a system to search for radio signals transmitted by intelligent life on other star systems.

10. Advanced Power Plant (Mission 23)

The advanced power plant would produce 1 MWe using a nuclear source.

C-2. CNDB Payload Descriptions (Ref. 2)

1999-2005: (7 missions) Lunar Science and Field Geology (500 lbs-return 100 lbs) CNDB No. 5027

Lunar science activities will include seismic studies, gravimetry, heatflow measurements, field geology, core sampling, and other activities required to support studies of the effects of the presence of man on the Moon. Samples would be taken, returned to the Geochemical Materials Lab (5073) for preliminary analysis, and packaged for return to Earth for more detailed studies.

1999: (1 mission) Surface Surveying Rover (2,200 lbs) CNDB No. 5034

A teleoperated rover will be used to survey and characterize potential lunar base sites. The rover should be able to lift samples for examination and characterization. Geochemical tests will be performed on the samples and the results will be relayed to Earth.

1999-2005: (22 missions) Expendable Lunar Ascent Vehicle (16,275 lbs) CNDB No. 5053

The expendable lunar ascent vehicles provide ascent for the Personnel Sortie Module (5018) from the lunar surface to the LTV waiting in lunar orbit. The LTV in lunar orbit is the same LTV that delivered the module and its lander (5050) and ascent stage on the inbound leg of the sortie. This element supports the lunar base during the early buildup of the lunar base, Phase II: Temporarily Occupied Scientific Outpost. The ascent stage is expended on each mission, because facilities do no exist to support a reusable lunar surface to lunar orbit transportation system. Studies are in work to determine techniques for structuring a lunar transportation system that will have reusable elements during the phase II lunar development.

1999-2001: (6 missions) Crew Logistics-4 crew/14 days (300 lbs) - CNDB No. 5052

Logistics resupply estimates are for crew life support requirements. The closure scenario for the lunar base assumes closed water and air revitalization subsystems, resupply of food, and open waste management (i.e., no recycling of waste products). An estimated 8.9 lb/person/day is for spares and consumables for the life support system and personal hygiene and clothes. A total of 300 lb per trip is estimated, exclusive of in-flight needs. These estimates are based on a 4 person crew, 14 day mission time, with an eight day staytime on the lunar surface.

1999-2001: (6 missions) Crew Rotation-04/14 (1,800 lbs) CNDB No. 5002

The entire crew of four is baselined for flight to the Moon in the early part of Phase II for staytimes on the lunar surface of 8 days (total mission time is 14 days). Payload mass estimates are based on 450 lb/crew member. This weight includes crew, suits and personal equipment.

1999-2005: (38 missions) Expendable Lunar Landers (41,660 lbs) CNDB No. 5050

The expendable lunar lander is used during Phase II of the lunar development. Its use for human transport is described in (5018) PERSONNEL TRANSFER MODULE (4 MAN). Its use for equipment delivery is similar. It will be required to deliver approximately 20 metric tons to the lunar surface. It will be transported as a mated unit with the delivery payload from the LEO station to LLO by the LTV. The LTV will immediately return to the LEO Space Station.

1999-2005: (22 missions) Four-crew Personnel Transfer Module (13,200 lbs) CNDB NO. 5018

During Phase II of the lunar base, the lunar Service Station is not in place and the advantages of using lunar oxygen are not available. In addition, the personnel module must be transported all the way to the lunar surface and back to LEO. Therefore, the transportation system is performance limited, and a smaller module is needed to keep the LTV systems design within reason. This 4-man module is used to transport personnel to/from the lunar surface during Phase II. The crew will live in the module during their short stays at the lunar surface. The module and its ascent stage (5023) are transported to the lunar surface using the expendable lunar lander (5050). The ascent stage will carry the module back to LLO to rendezvous with the LTV for return to Earth. The ascent stage is expended in lunar orbit, the lander remains on the lunar surface. The LTV must transport the module, the ascent stage, and the lander as a mated unit from LEO to LLO.

2000 & 2005: (2 missions) Communications Relay Station-Phase 2 (2,500 lbs) CNDB No. 5036

The surface communications relays which route, process, and relay lunar surface communications, will be located on the near and far sides of the Moon. Data and communications will be relayed to Earth and the Moon via GEO satellites and the L-2 relay (5078).

2000 & 2001: (3 missions) Initial Power Plant (7,000 lbs) CNDB No. 5013

A nuclear power source will provide the continuous electrical energy required for lunar base operations without the need for extensive energy storage systems. The initial power source will be a derivative of the SP-100 reactor system. The 100-kWe power plant will consist of the reactor, heat conversion systems, heat transfer systems, heat rejection systems, shielding, and power conditioning and control. If locally convenient, the system will be placed in a lunar crater for shielding from manned operations.

2000 & 2004: (2 missions) Unpressurized Rover (4,000 lbs) CNDB No. 5031

This is a small two-person vehicle used to transport personnel across the lunar surface for short distances during the initial Phase II set-up and servicing operations. The rover is very similar to the lunar rover used during the Apollo program. It has regenerative power systems and will be utilized in later stages of lunar development as a complement to the PRESSURIZED ROVER (5030).

2000: (1 mission) Soil Mover/Crane/Constructor-Phase 2 (38,500 lbs) CNDB No. 5032

This equipment is required for site preparation, construction, and assembly of the habitation facilities, pilot and full scale plants, and other lunar base elements. The site will be leveled and shallow trenches created to allow easy burial of the habitats (probably aided with explosives). Large payloads will be transported from the landing sites by a crane and trailer. A pressurized vehicle will be outfitted to mount both the front end loader or the bulldozer blade. Without the loader or blade, this vehicle can be used for near to mid proximity science exploration. A prototype pylon, cable, and scraper mechanism will demonstrate excavation techniques for resource production.

2000: (1 mission) Lunar Farside UV Telescope (10,000 lbs) CNDB No. 5009

A very large EUV/X-ray telescope on the moon would be utilized for imaging, spectroscopy, and polarimetry of nearby sources and interstellar medium. A lunar-based EUV/X-ray telescope would avoid the problems of absorption by the Earth's atmosphere and would be free of the second bremstrah lung radiation that a similar telescope would encounter in orbit (except when the Moon passes through the geomagnetic tail). This facility would be constructed with a modular approach. The initial module would allow data to be obtained; additional modules would be added gradually to increase the collecting area to yield the high sensitivity and resolution required. Each module would use either grazing incidence optics or a coded aperture array. Dimensions and mass represent the overall facility and consist of ten telescope modules.

2000: (1 mission) Lunar Based SETI (20,000 lbs) CNDB No. 5008

A lunar-based Search for Extraterrestrial Intelligence (SETI) system will be used to detect radio signals transmitted by intelligent beings. The mission would attempt to detect unintentional signals similar to radar and TV signals from Earth and intentional signals from nearby stars. The system could also be useful for general astrophysical investigations of radio sources. One mission concept consists of a spherical primary reflector made of lightweight mesh, with three Gregorian subreflectors and feed assemblies that permit three different stars to be searched simultaneously. A disk shaped shield would be placed between the antenna and Earth to protect against radio frequency interference. A series of relay satellites would permit the IF signal to be beamed to Earth for stationkeeping and attitude control. Basic equipment includes a 300-M antenna, 600-M diameter RFI shield, receivers, cryogen coolers, and transmitters. Modular construction will be necessary. The system would be based on the far side of the Moon.

2001,2003,2005: (3 missions) Module Interface Node (8,200 lbs) CNDB No. 5082

These nodes interconnect the habitat and other modules. They permit transfer of crew and equipment between individual modules and the lunar surface. Airlock and stowage capabilities are assumed.

2001: (1 mission) Liquid Oxygen Pilot Plant (38,500 lbs) CNDB No. 5028

This is a lunar liquid oxygen development unit. This facility, approximately one-third the mass of the full scale facility, has element masses that scale accordingly. This unit is used for engineering verification for the full scale plant and will be the core facility in which the full scale plant will develop.

2001: (1 mission) Optical Interferometer Telescope (15,000 lbs) CNDB No. 5037

A Y-shaped array of 27 telescopes which would operate as a coherent array would be used to study a wide variety of stellar and extragalactic fundamental processes associated with stars, black holes, and quasars. The lunar-based array avoids the difficulties associated with earth basing (atmosphere damages phase, coherence) and space-basing (structural stability, station-keeping, adjustment, control, etc.). Each arm of the array would be over 3 NM long for a maximum baseline of approximate 5.4 NM. Equipment requirements wold include the telescopes, shielding, a fixed station which would monitor telescope locations by laser interferometers, and special purpose transporters to move the telescopes. Each telescope would be approximately 3 ft in diameter.

2002: (1 mission) Habitat Module-Phase 2 (38,500 lbs) CNDB No. 5011

Habitat module is derived form Space Station technology and will accommodate a crew size of 6. Initial delivery is a fully outfitted habitat.

2002: (1 mission) Oxygen Mining Equipment (38,500 lbs) CNDB No. 5071

All the equipment necessary to extract the lunar regolith required for oxygen production will be provided. Also included are loaders which transport the regolith from stockpiles to the production facility feed vats. The various mining elements include shovels, scrapers, loaders, and haulers.

2002-2004 (12 missions) Crew Logistics- 4 crew/30 day mission (900 lbs) CNDB No. 5075

See 5052. The mass for this entry is exclusive of in-flight needs. These estimates are based on a 4 person crew, 30 day mission duration with a 24 day staytime on the lunar surface.

2002-2004: (12 missions) Crew Rotations-4 crew/30 days (1,800 lbs) CNDB No. 5068

The entire crew of four is baselined for flight to the Moon in the latter part of Phase II for staytimes on the lunar surface of 24 days (total mission time is 30 days). Payload mass estimates are based on 450 lb/crewmember. This weight includes crew, suits and personal equipment.

2003: (1 mission) Geochemical Materials Laboratory (38,500 lbs) CNDB No. 5073

The geochemistry/materials processing lab would support lunar science activities and materials processing evaluations. Analytical instruments, equipment, and process development experiments would be house din the lab. Equipment requirements include X-ray diffractometer, mass spectrograph, spectroscope, etc. A fully outfitted module is assumed to be delivered to the base.

2003-2004: (3 missions) Liquid Oxygen Production Plant Mission (33,333 lbs) CNDB No. 5029

The plant is designed to utilize hydrogen reduction of ilemenite. The oxygen plant production capabilities are expected to be on the order of 200 MT per year. The plant facility includes a benefication facility, processing facility, liquification facility, storage facility, and a thermal control system. This plant supplies the necessary liquid oxygen lunar lander flights and LTV return-to-LEO flights once the Lunar Service Station becomes operational. A portion of this mass is contained in the pilot plant and other supporting equipment.

2003: (1 mission) Advanced Power Plant (38,500 lbs) CNDB No. 5006

An advanced lunar power plant would utilize an expanded SP-100 reactor (see 5013) for power levels of 1 MWe.

2004 & 2005: (2 missions) Service Geochemical Materials Lab (500 lbs) CNDB No. 5074

Servicing requirements for the lab would include fluids, gases experiment changeout, and spares.

2004: (1 mission) Service Lunar Farside UV Telescope (2,000 lbs) CNDB No. 5010

Servicing activities will be conducted annually and involve detector gas/cryo replenishment, detection upgrade/changeout, and module additions.

2005: (1 mission) Communications Relay Satellite-Phase 3 (2,500 lbs) CNDB No. 5026

This mission wold place a nearside communications and data relay satellite at the cislunar libration point L-1. See 5078

2005: (1 mission) Propellant Depot/Refueling Station (40,000 lbs) CNDB No. 5021

The Lunar orbit service station is a servicing facility in low lunar orbit to provide capability for the transfer of propellants and equipment from/to the arriving/departing lunar space vehicles to/from the reusable lunar lander. This facility will not have the capability to support personnel; it is strictly an automated facility operated remotely by the crew or by the lunar surface staff.

2005: (2 missions) Life Sciences Research Facility (40,000 lbs) CNDB No. 5015

Life science and research applications on the Moon would be directed at understanding and predicting the effects of the lunar environment on man, developing the foundation for extended presence of man in space and, increasing our understanding of lunar environmental effects on biological processes. Research topics for the life science laboratory include human physiology and medicine; nutrition, die, and food processing; lower and higher order plant agriculture; animal agriculture; waste conversion and resource recover; and monitoring, control and sensor technology. This facility will consist of two modular laboratories and an interconnecting node.

2005: (1 mission) Life Science Research Node (8,200 lbs) CNDB No. 5079

The nodes would interconnect the two life science modules and serve as airlocks and stowage areas.

2005: (1 mission) Deep Drilling (4,000 lbs) CNDB No. 5065

A deep drilling capability would provide deep core samples in support of science missions and would support other lunar base missions as well. Deep drilling would produce samples of the lunar geological structure to depths of more than a few hundred meters. The lunar environment will have significant impact on drill requirements (i.e., cooling and core removal) because of the high vacuum and lack of water. The drilling device would need debris-handling systems, which would provide a closed circulation of debris-handling fluids and a loss-free debris/fluid separator. Essentially self-contained, remotely operated drill rig equipment is needed. Initially, man would have to be in the loop to closely monitor drilling operations for verification of drill performance.

2005: (4 missions) Crew Logistics-4 crew/180 day mission (6,400 lbs) CNDB No. 5076

See 5052. The mass for this entry is exclusive of in-flight needs. These estimates are based on a 4 person crew, 180 day mission.

2005: (4 missions) Crew Rotations-4 crew/180 days (1,800 lbs) CNDB 5067

A crew of four is baselined for flight to the Moon from in the early part of Phase III for staytimes on the lunar surface of 180 days. A total lunar crew size of eight is planned for this period. Payload mass estimates include the crewmember, suit, and personal equipment.

Appendix D - Surface Operations Subtasks and Time Estimates

Table D-1. Surface Operations Breakdown Into Subtasks With Time Estimates

Baseline Data For Calculations:

Baseline Variables

Mobility Speeds (m/min):		
a. Fast Transfer (Unloaded)	100	
b. Grading/Hauling	25	
c. Trenching	1	(for utility ways - 1.5 m deep x 30 cm wide)
d. Backfilling Trench	5	
Surveying Meas./Stake	6	(min./event)
Undesirable Boulders/m^2	0.25	
Utility segment length (m)	10	
Buldozer Blade Width (m)	3	
Prime Mover (PM) Width (m)	2	
PM Cart Capacity (m^3): 2m wide x 4m long x 1m deep	8	
Backhoe & Front Loader Shovel Capacity (m^3)	1	
Distance:		
Landing Pad to Base (m)	1000	
Storage Shed to Base (m)	100	
Number Prepared Pads	4	
Road Length (add 100m/pad)	1400	

	L (m)	W (m)	A (m^2)	Circumference (m)
Module Site Plan	50	50	2500	
Landing Pad Size (Circle)		50	1963	157

Module Dimensions (m)	Dia.	Length (inc. end cones)	Cylinder Length
HAB/LAB Modules	4.45	13.25	11.79
Node	4.45	5.38	
Airlock	3.66		
Log. Module	4.45	7.23	5.89
Rad. Shelter	4.45	7.23	5.89
Crane Trailer (Cargo Carrier) Width (m)			5
PM Buldozer Blade Height (m)			1

Distance:		
Storage Shed to Pad(m)	1000	
Pads to Used Lander Storage Area (m)		400
Dump Soil from Base Excavations (m)		50

Table D-1 (Cont). Surface Operations Breakdown Into Subtasks With Time Estimates

Activity Times	Equipment (PM = Prime Mover)	Comments	Events	Number of Passes (i.e. 1+ Repeats)	Time per event (min/event)	Time (hrs)	Earth Teleop (hrs)	Lunar Teleop (hr/person)	Lunar IVA Crew	Total IVA (hr)	EVA op (hr/person)	EVA Crew	Total EVA (hrs)
1. MODULE SITE GRADING													
1a. Survey/Layout	PM/Survey System												
- Place Benchmark		30 min to place benchmark.	1	1	30	0.5	0.5						
- Measurements		Measurements of 13 locations, repeat survey 3 times	13	3	6	3.9	3.9						
- Staking		Set 13 markers.	13	1	6	1.3	1.3						
Subtotal						5.7							
1b. Boulder clearing													
- Doze Site	PM/Blade	2500 m^2, 25m/min * 3m width = 75m^2/min, 33 min/pass	1	4	33.33	2.2	2.2						
- Remove boulders	PM/Cart/Backhoe	2500 m^2 * 0.25 boulders/m^2 = 625 boulders, 2 min/ea	625	1	2	20.8	20.8						
Subtotal						23.1							
1c. Grading/Backfill/Level	PM/Blade	2500 m^2, 25m/min * 3m width = 75m^2/min, 33 min/pass	1	8	33.33	4.4	4.4						
1d. Soil Compaction/Level	PM (Compactor)	2500 m^2, 25m/min * 2m width = 50m^2/min, 50 min/pass	1	3	50.00	2.5	2.5						
1e. Final Leveling	PM/Blade	2500 m^2, 25m/min * 3m width = 75m^2/min, 33 min/pass	1	4	33.33	2.2					2.2	2	4.4
1f. PM Attachment Changes	PM	max. 6 changes necessary	6	1	55.00	5.5	5.5						
1. SUBTOTAL						43.4	41.2				2.2		4.4
2. UTILITY-WAY INSTALLATION													
2a. Trenching	PM/Small Trencher	(3) trenches width of site & (3) length=300 m trench	1	1	300	5.0		5.0	1	5.0			
2b. Conduit Emplacement	PM/Cart	10 m utility tray seg.=30 segments/300 m @ 10 min/seg	30	1	10	5.0					5.0	2	10.0
2c. Backfill	PM/Grader	300 m trench @ 5 m/min.	1	1	60	1.0		1.0	1	1.0			
2d. PM Attachment Changes	PM	max. 3 changes necessary	3	1	55.00	2.8		2.8	1	2.8			
2. SUBTOTAL						13.8		8.8		8.8	5.0		10.0
TOTAL TO PREPARE MODULE SITE (SUM OF 1 & 2)						57.2	41.2	8.8	1	8.8	7.2	2	14.4
3. PRIME MOVER (PM) ATTACHMENT CHANGE-OUT (TIME PER SINGLE ATTACHMENT CHANGE FOR BASE OPS)													
3a. Move to Storage Shed	PM	half fast speed and half @ 25m/min	1	1	2.5	0.04	0.04						
3b. Detach old attachment	PM	Position 10 min., disconnect 10 min.	1	1	20	0.33	0.33						
3c. Attach new attachment	PM	Re-pos. 10 min, con. 10 min, check 10 min	1	1	30	0.50	0.50						
3d. Return to work area	PM	half fast speed and half @ 25m/min	1	1	2.5	0.04	0.04						
3. SUBTOTAL FOR BASE OPS						0.92	0.92						
3e. Roundtrip Landing Pad/Shed		fast speed	1	1	20	0.33	0.33						
3. SUBTOTAL FOR LANDING PAD OPS						1.25	1.25						
4. PREPARE LANDING PAD (SINGLE)													
4a. Survey, Set Markers	PM/Survey System	Benchmark(30 min), Meas.(repeat3)/Place 6 Markers (157m/25m/marker = 6 markers @ 6min ea)	1	1	180.8	3.0	3.0						
4b. Clear Boulders	PM/Cart/Backhoe	Doze 75m^2/min &4pass, Cart Rocks(0.25 boulders/m^2)	1	4	1086.5	18.1	18.1						
4c. Grade Surface	PM/Blade	1963 m^2, 25m/min * 3m width = 75m^2/min, 26 min/pass	1	8	26.2	3.5	3.5						
4d. Compact	PM (Compactor)	1963 m^2, 25m/min * 2m width = 50m^2/min, 39 min/pass	1	3	39.3	2.0	2.0						
4e. Final Leveling	PM/Blade	1963 m^2, 25m/min * 3m width = 75m^2/min, 26 min/pass	1	4	26.2	1.7					1.7	2	3.5
4f. PM Attachment Changes	PM	max. 6 changes necessary	6	1	75.0	7.5	7.5						
4. Subtotal - 1 Pad			1			35.8	34.1				1.7		3.5
Subtotal - 2 Pads			2			71.6	68.2				3.5		7.0
Subtotal - All Pads			4			143.3	136.3				7.0		14.0
5. EMPLACE LANDING PAD LIGHTS/NAVIGATION AIDS (SINGLE PAD) ASSUME LIGHTS AND NAV AIDS ARE SELF-CONTAINED UNITS (CONTAIN OWN POWER SOURCE)													
5a. Survey, Set Markers	PM/Survey System	Meas. (repeat) & Place 6 Markers	1	1	90	1.5	1.5						

ORIGINAL PAGE IS
OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

Table D-1 (Cont). Surface Operations Breakdown Into Subtasks With Time Estimates

Activity Times	Equipment (PM = Prime Mover)	Comments	Events	Number of Passes (i.e. 1+ Repeats)	Time per event (min/event)	Time (hrs)	Earth Teleop (hrs)	Lunar Teleop (hr/person)	Lunar IVA Crew	Total IVA (hr)	EVA op (hr/person)	EVA Crew	Total EVA (hrs)
5b. Emplace Nav. Aids	PM/trailer/Arm	2Nav/Pad; Unload pallet,Transport,Setup,Chk=30min/Nav	2	1	30	1.0	1.0						
5c. Emplace Lights	PM/trailer/Arm	4/Pad; Unload pallet,Transport,Setup,Check=10min/Lght	4	1	15	1.0	1.0						
5f. PM Attachment Changes	PM	Max 1 change necessary	1	1	75.0	1.3	1.3						
5. Subtotal - 1 Pad			1			4.8	4.8						
Subtotal - 2 Pads			2			9.5	9.5						
Subtotal - All Pads			4			19.0	19.0						
6. PREPARE ROADS FROM PAD(S) TO BASE		ROAD LENGTH (m) =	1400 Width (m)=		6	Area (m^2) =		8400					
6a. Survey, Set Markers	PM/Survey System	Bench (30 min), Meas.(repeat3)/Place 7 Markers	1	1	198.0	3.3	3.3						
6b. Clear Boulders	PM/Cart/Backhoe	Doze 75m^2/min &4pass, Cart Rocks(0.25 boulders/m^2)	1	4	4648.0	77.5	77.5						
6c. Grade Surface	PM/Blade	25m/min * 3m width = 75m^2/min	1	8	112.0	14.9	14.9						
6d. Compact	PM (Compactor)	25m/min * 2m width = 50m^2/min	1	3	168.0	8.4	8.4						
6e. Final Leveling	PM/Blade	25m/min * 3m width = 75m^2/min	1	4	112.0	7.5					7.5	2	14.9
6f. PM Attachment Changes	PM	max. 6 changes necessary	6	1	65.0	6.5	6.5						
6g. Emplace Lights	PM/trailer/Arm	1 Light/30 m,Self-contained,10 min/light	47	1	10	7.8	7.8						
6. SUBTOTAL						125.9	118.4				7.5		14.9
7. BUILD BLAST WALLS AT PADS FOR PROTECTING SUR		Wall Height (m) =	3	Repose Angle (deg)=	35	Wall Base Width (m)=	8.6	Total Length of Walls (assumed 250m wall on every other pad) (m)=	500		Volume (m^3)	6427	
7a. Survey, Set Markers	PM/Survey System	Meas.(repeat)/Place 8 Markers	1	1	144	2.4	2.4						
7b. Construct Walls	PM/Blade	Doze Blade 2 m^3/min (start 25 m away @ 25m/min)	1	1	3000	50.0	50.0						
7. SUBTOTAL						52.4	52.4						
8. REMOVE SPENT LANDER DESCENT STAGE FROM PAD													
8a. Travel to Pad	PM & Crane	Both at fast speed 100 m/min, 1000 m.	1	1	20	0.3		0.3	1	0.3	0.3	2	0.7
8b. Place Descent Stage	PM/Trailer & Crane		1	1	90	1.5		1.5	1	1.5	1.5	2	3.0
On Trailer (Tip over so flat part upside down, EVA Assist/Supervised)													
8c. Secure to Trailer	PM/Trailer		1	1	30	0.5					0.5	2	1.0
8d. Transport to Storage	PM/Trailer	Haul speed 25m/min, 400 m	1	1	16	0.3		0.3	1	0.3			
8e. Remove from Trailer	PM/Trailer & Crane		1	1	90	1.5		1.5	1	1.5	1.5	2	3.0
8. SUBTOTAL						4.1		3.6		3.6	3.8		7.7
9. CARGO HANDLING (Cargo:		Large individual payloads or pallet of smaller payloads)											
9a. Travel to Pad	PM/Trailer & Crane	Both at fast speed 100 m/min, 1000 m.	1	1	20	0.3	0.3						
9b. Position Crane	Crane		1	1	30	0.5	0.5						
Off-Load Cargo from Lander:													
9c. Spreader Bar Hookup	Crane		1	1	30	0.5					0.5	2	1.0
9d. Crane Lift to Trailer (IVA Assisted)	Crane, PM/trailer	(IVA Assist)	1	1	30	0.5		0.5	1	0.5	0.5	2	1.0
9e. Disconnect Hookup	Crane		1	1	15	0.3					0.3	2	0.5
9f. Secure to Trailer	PM/trailer		1	1	30	0.5					0.5	2	1.0
9. Subtotal Off-load Cargo Element						2.6	0.8	0.5		0.5	1.8		3.5
Transport Generic Cargo to Base Site Storage or Placement Area:													
9g. Payload to Base Area	PM/trailer	Haul speed 25m/min, 1000 m.	1	1	40	0.7					0.7	2	1.3
9h. Crane to Base Area	Crane	Fast Speed 100 m/min, 1000 m.	1	1	10	0.2		0.2	1	0.2			
Off-Load Trailer:													

Table D-1 (Cont). Surface Operations Breakdown Into Subtasks With Time Estimates

Activity Times	Equipment (PM = Prime Mover)	Comments	Events	Number of Passes (i.e. 1+ Repeats)	Time per event (min/event)	Time (hrs)	Earth Teleop (hrs)	Lunar Teleop (hr/person)	Lunar IVA Crew	Total IVA (hr)	EVA op (hr/person)	EVA Crew	Total EVA (hrs)
9i. Spreader bar hookup	Crane		1	1	30	0.5					0.5	2	1.0
9j. Crane Lift/Placement	Crane, PM/trailer	(IVA Assist)	1	1	30	0.5		0.5	1	0.5	0.5	2	1.0
9k. Disconnect Hookup	Crane		1	1	15	0.3					0.3	2	0.5
9l. Travel to Storage Shed	Crane, PM/trailer	Both at slow speed 25 m/min, 100 m.	1	1	8	0.1	0.1						
9. Subtotal Payload Placement						1.4	0.1	0.5		0.5	1.3		2.5
9. SUBTOTAL						4.8	1.0	1.2		1.2	3.7		7.3
10. EMPLACE EXPOSED (NON-BURIED) MODULES													
10a. Travel to Base Site	PM/front loader/cart	At slow speed 25 m/min, 100 m.	1	1	4	0.1	0.1						
10b. Excavate Mod. Trench	PM/front loader/cart												
Volume Soil to Remove:	(all modules 1 m deep, 2 m wider than actual dia.)												
Hab/Lab Module (m^3) =		85.5 Fill 8 m^3 cart, 2 min/m^3	11	1	16	2.9							
		Pull cart 50 m, dump (2min), return (25m/min)	11	1	6	1.1							
		Re-position PM	11	1	5	0.9							
		Subtotal Hab/Lab Module				5.0	5.0						
Node (m^3) =		34.7 Fill 8 m^3 cart, 2 min/m^3	4	1	16	1.1							
		Pull cart 50 m, dump (2min), return (25m/min)	4	1	6	0.4							
		Re-position PM	4	1	5	0.3							
		Subtotal Module Interface Node				1.8	1.8						
Airlock (m^3) =		20.7 Fill 8 m^3 cart, 2 min/m^3	3	1	16	0.8							
		Pull cart 50 m, dump (2min), return (25m/min)	3	1	6	0.3							
		Re-position PM	3	1	5	0.3							
		Subtotal Airlock				1.4	1.4						
Logistics Module (m^3) =		46.6 Fill 8 m^3 cart, 2 min/m^3	6	1	15	1.6							
		Pull cart 50 m, dump (2min), return (25m/min)	6	1	5	0.6							
		Re-position PM	6	1	5	0.5							
		Subtotal Logistics Module				2.7	2.7						
10c. Module Offload	Crane, PM/trailer	See #9 Subtotal for Off-Loading Generic Cargo Element	1	1		2.6	0.8	0.5	1	0.5	1.8	2	3.5
10d. Module Transport	PM/trailer	Haul speed 25m/min, 1000 m.	1	1	40	0.7					0.7	2	1.3
10e. Crane to Base	Crane	Fast Speed 100 m/min, 1000 m.	1	1	10	0.2		0.2	1	0.2			
10f. Module Placement	Crane	See #9 Subtotal for Placement of Generic Cargo	1	1		1.4	0.1	0.5	1	0.5	1.3	2	2.5
10g. Module Leveling		4 leveling positions, 5 min/position, repeat twice	4	3	5	1.0					1.0	2	2.0
10h. Module Mating	Crane	IVA Assisted, 30 min to position, 60 bolts x 3 min/bolt	1	1	210	3.5		0.5	1	0.5	3.5	2	7.0
10i. Module Interfaces Connection													
Power						0.5					0.5	2	1.0
Communications						0.5					0.5	2	1.0
Data Management System						0.5					0.5	2	1.0
Thermal						2.0					2.0	2	4.0
ECLSS						2.0					2.0	2	4.0
10i. Subtotal						5.5					5.5		11.0
10j. Power-Up Module													
Power-on						0.2		0.2	1	0.2			
Avionics						0.3		0.3	1	0.3			
Pressure/Fluid Systems						2.0		2.0	1	2.0			
10j. Subtotal						2.5		2.5		2.5			
10k. Integrated Test & Verification		Sequence through Earth, IVA, EVA checks				6.0	6.0	6.0	1	6.0	6.0	2	12.0
10. SUBTOTAL													
10. Subtotal Hab/Lab Module						28.3	12.0	10.2	1	10.2	19.7	2	39.3

ORIGINAL PAGE IS OF POOR QUALITY

Activity Times	Equipment (PM = Prime Mover)	Comments	Events	Number of Passes (i.e. 1+ Repeats)	Time per event (min/event)	Time (hrs)	Earth Teleop (hrs)	Lunar Teleop (hr/person)	Lunar IVA Crew	Total IVA (hr)	EVA Op (hr/person)	EVA Crew	Total EVA (hrs)
10. Subtotal Node						25.2	3.3	10.2	1	10.2	19.7	2	39.3
10. Subtotal Airlock						24.7	3.4	10.2	1	10.2	19.7	2	39.3
10. Subtotal Logistics Module						26.1	9.7	10.2	1	10.2	19.7	2	39.3
11. EMPLACE COVERED RADIATION SHELTER													
11a. Travel to Base Site	PM/front loader/cart	At slow speed 25 m/min, 100 m.	1	1	4	0.1	0.1						
11b. Excavate Mod. Trench	PM/front loader/cart												
Volume Soil to Remove:		(shelter 1 m deep, 2 m wider than actual dia.)											
Shelter Excavation (m^3) =	46.6	Fill 8 m^3 cart, 2 min/m^3	6	1	16	1.6							
		Pull cart 50 m, dump (2min), return (25m/min)	6	1	6	0.6							
		Re-position PM	6	1	5	0.5							
		Subtotal Radiation Shelter				2.7	2.7						
11c. Offload Bulkhead, Conveyor,Tunnels	Crane,PM/trailer	See #9 Subtotal for Off-Loading Generic Cargo Element	1	1		2.6	0.8	0.5	1	0.5	1.8	2	3.5
11d. Transport to Base	PM/trailer	Haul speed 25m/min, 1000 m.	1	1	40	0.7					0.7	2	1.3
11e. Crane to Base	Crane	Fast Speed 100 m/min, 1000 m.	1	1	10	0.2		0.2	1	0.2			
11f. Conveyor System Assembly													
Conveyor Truss Structure	Crane,PM	(IVA Assist)	1	1	20	0.3		0.3	1	0.3	0.3	2	0.7
Conveyor,Hopper	Crane,PM	(IVA Assist)	1	1	75	1.3		1.3	1	1.3	1.3	2	2.5
11g. Layout Bulkhead Retainer System													
Layout Side,End Bulkheads	Crane	(IVA Assist)	1	1	30	0.5		0.5	1	0.5	0.5	2	1.0
Install Retainer Straps			1	1	30	0.5					0.5	2	1.0
11h. Place Tunnels in Temp Storage	Crane,PM/trailer	(IVA)	1	1	30	0.5		0.5	1	0.5			
11i. Shelter Offload	Crane,PM/trailer	See #9 Subtotal for Off-Loading Generic Cargo Element	1	1		2.6	0.9	0.5	1	0.5	1.8	2	3.5
11j. Transport to Base	PM/trailer	Haul speed 25m/min, 1000 m.	1	1	40	0.7					0.7	2	1.3
11k. Crane to Base	Crane	Fast Speed 100 m/min, 1000 m.	1	1	10	0.2		0.2	1	0.2			
11l. Shelter Placement	Crane	See #9 Subtotal for Placement of Generic Cargo	1	1		1.4	0.1	0.5	1	0.5	1.3	2	2.5
11m. Shelter Leveling		4 leveling positions, 5 min/position, repeat twice	4	3	5	1.0					1.0	2	2.0
11n. Tunnel (2) Placement	Crane	See #9 Subtotal for Placement of Generic Cargo	2	1		1.4	0.1	0.5	1	0.5	1.3	2	2.5
11o. Tunnel (2) Leveling		4 leveling positions, 5 min/position, repeat twice	8	3	5	2.0					2.0	2	4.0
11p. Shelter/Tunnel Mating	Crane	IVA Assisted,30 min to position,60 bolts x 3 min/bolt	2	1	210	7.0		0.5	1	0.5	7.0	2	14.0
11q. Shelter Interfaces Connection													
Power						0.5					0.5	2	1.0
Communications						0.5					0.5	2	1.0
Data Management System						0.5					0.5	2	1.0
Thermal						2.0					2.0	2	4.0
ECLSS						2.0					2.0	2	4.0
11q. Subtotal						5.5					5.5		11.0
11r. Power-Up Shelter Systems													
Power-on						0.2		0.2	1	0.2			
Avionics						0.3		0.3	1	0.3			
Pressure/Fluid Systems						2.0		2.0	1	2.0			
11r. Subtotal						2.5		2.5		2.5			
11s. Integrated Test & Verification		Sequence through Earth, IVA, EVA checks				6.0	6.0	6.0	1	6.0	6.0	2	12.0
11t. Bulkhead Setup													
Lift sides & Retain	Crane (IVA Assist)	10 cross-straps, 6min/strap;6 compres. rods,5 min/rod	1	1	90	1.5		1.5	1	1.5	1.5	2	3.0
Lift Ends & Retain	Crane (IVA Assist)	4 corners, 30min/corner;8 retain.straps,6 min/strap	1	1	168	2.8		2.8	1	2.8	2.8	2	5.6
Place Hopper/Conveyor	Crane,PM	15 min to position, 45 min to check/verif. sys.	1	1	60	1.0		0.3	1	0.3	1.0	2	2.0
11u. Soil Placement Using Hopper/Conveyor system													
Vol. Soil to Place (m^3) =	1395.7	Fill 8 m^3 cart, 2 min/m^3	174	1	16	46.4							

ORIGINAL PAGE IS
OF POOR QUALITY

Table D-1 (Cont). Surface Operations Breakdown Into Subtasks With Time Estimates

Activity Times	Equipment (PM = Prime Mover)	Comments	Events	Number of Passes (i.e. 1+ Repeats)	Time per event (min/event)	Time (hrs)	Earth Teleop (hrs)	Lunar Teleop (hr/person)	Lunar IVA Crew	Total IVA (hr)	EVA op (hr/person)	EVA Crew	Total EVA (hrs)
		Pull cart 50 m, dump (2min), return (25m/min)	174	1	6	17.4							
		Re-position PM	174	1	5	14.5							
		Subtotal Radiation Shelter				78.3	78.3						
11v. Buried Shelter Int. Test & Verif.		Sequence through Earth, IVA, EVA checks				6.0	6.0	6.0	1	6.0	6.0	2	12.0
11w. PM Attachment Changes	PM	max. 2 changes necessary	2	1	55	1.8		1.8	1	1.8			
11. SUBTOTAL						130.9	95.0	26.3	1	26.3	42.7	2	85.4
12. EMPLACE COVERED RADIATION SHELTER WITHOUT BULKHEADS													
12a. Travel to Base Site	PM/front loader/cart	At slow speed 25 m/min, 100 m.	1	1	4	0.1	0.1						
12b. Excavate Mod. Trench	PM/front loader/cart												
Volume Soil to Remove:		(shelter 1 m deep, 2 m wider than actual dia.)											
Shelter Excavation (m^3) =	46.6	Fill 8 m^3 cart, 2 min/m^3	6	1	16	1.6							
		Pull cart 50 m, dump (2min), return (25m/min)	6	1	6	0.6							
		Re-position PM	6	1	5	0.5							
		Subtotal Radiation Shelter				2.7	2.7						
12c. Offload Tunnels	Crane,PM/trailer	See #9 Subtotal for Off-Loading Generic Cargo Element	1	1		2.6	0.8	0.5	1	0.5	1.8	2	3.5
12d. Transport to Base	PM/trailer	Haul speed 25m/min, 1000 m.	1	1	40	0.7					0.7	2	1.3
12e. Crane to Base	Crane	Fast Speed 100 m/min, 1000 m.	1	1	10	0.2		0.2	1	0.2			
12f. Conveyor System Assembly													
Conveyor Truss Structure	Crane,PM	(IVA Assist)	1	1	20	0.3		0.3	1	0.3	0.3	2	0.7
Conveyor,Hopper	Crane,PM	(IVA Assist)	1	1	75	1.3		1.3	1	1.3	1.3	2	2.5
12g. Place Tunnels in Temp Storage	Crane,PM/trailer	(IVA)	1	1	30	0.5		0.5	1	0.5			
12h. Shelter Offload	Crane,PM/trailer	See #9 Subtotal for Off-Loading Generic Cargo Element	1	1		2.6	0.8	0.5	1	0.5	1.8	2	3.5
12i. Transport to Base	PM/trailer	Haul speed 25m/min, 1000 m.	1	1	40	0.7					0.7	2	1.3
12j. Crane to Base	Crane	Fast Speed 100 m/min, 1000 m.	1	1	10	0.2		0.2	1	0.2			
12k. Shelter Placement	Crane	See #9 Subtotal for Placement of Generic Cargo	1	1		1.4	0.1	0.5	1	0.5	1.3	2	2.5
12l. Shelter Leveling		4 leveling positions, 5 min/position, repeat twice	4	3	5	1.0					1.0	2	2.0
12m. Tunnel (2) Placement	Crane	See #9 Subtotal for Placement of Generic Cargo	2	1		1.4	0.1	0.5	1	0.5	1.3	2	2.5
12n. Tunnel (2) Leveling		4 leveling positions, 5 min/position, repeat twice	8	3	5	2.0					2.0	2	4.0
12o. Shelter/Tunnel Mating	Crane	IVA Assisted,30 min to position,60 bolts x 3 min/bolt	2	1	210	7.0		0.5	1	0.5	7.0	2	14.0
12p. Shelter Interfaces Connection													
Power						0.5					0.5	2	1.0
Communications						0.5					0.5	2	1.0
Data Management System						0.5					0.5	2	1.0
Thermal						2.0					2.0	2	4.0
ECLSS						2.0					2.0	2	4.0
12p. Subtotal						5.5					5.5		11.0
12q. Power-Up Shelter Systems													
Power-on						0.2		0.2	1	0.2			
Avionics						0.3		0.3	1	0.3			
Pressure/Fluid Systems						2.0		2.0	1	2.0			
12q. Subtotal						2.5		2.5		2.5			
12r. Integrated Test & Verification		Sequence through Earth, IVA, EVA checks				6.0	6.0	6.0	1	6.0	6.0	2	12.0
12s. Soil Placement Using Hopper/Conveyor system													
Place Hopper/Conveyor	Crane,PM	15 min to position, 45 min to check/verif. sys.	1	1	60	1.0		0.3	1	0.3	1.0	2	2.0
Vol. Soil to Place (m^3) =	2556.5	Fill 8 m^3 cart, 2 min/m^3	320	1	16	85.3							
		Pull cart 50 m, dump (2min), return (25m/min)	320	1	6	32.0							
		Re-position PM	320	1	5	26.7							
		Subtotal Radiation Shelter				144.0	144.0						
12t. Buried Shelter Int. Test & Verif.		Sequence through Earth, IVA, EVA checks				6.0	6.0	6.0	1	6.0	6.0	2	12.0

Table B-1 (Cont). Surface Operations Breakdown into Subtasks With Time Estimates

Activity Times	Equipment (PM = Prime Mover)	Comments	Events	Number of Passes (i.e. 1+ Repeats)	Time per event (min/event)	Time (hrs)	Earth Teleop (hrs)	Lunar Teleop (hr/person)	Lunar IVA Crew	Total IVA (hr)	EVA op (hr/person)	EVA Crew	Total EVA (hrs)
12u. PM Attachment Changes	PM	max. 2 changes necessary	2	1	55	1.8		1.8	1	1.8			
12. SUBTOTAL						190.3	160.7	21.3	1	21.3	36.4	2	72.8
13. EMPLACE POWER SYSTEM - Initial Power System Assumed to be Photovoltaic Array & Fuel Cells (no allocation for fuel cell system).													
13a. Travel to Site	PM	At slow speed 25 m/min, 100 m.	1	1	4	0.1	0.1						
13b. Survey, Set Markers	PM/Survey System	Meas.(repeat)/Place 8 Markers	1	1	144	2.4	2.4						
13c. Install Utility-Ways													
Trenching	PM/Small Trencher	50 m trench	1	1	50	0.8		0.8	1	0.8			
Conduit Emplacement	PM/Cart	10 m utility tray seg.=5 segments/50 m @ 10 min/seg	5	1	10	0.8					0.8	2	1.7
Backfill	PM/Grader	50 m trench @ 5 m/min.	1	1	10	0.2		0.2	1	0.2			
PM Attachment Changes	PM	max. 3 changes necessary	3	1	55	2.8		2.8	1	2.8			
13c. Subtotal						4.6		3.8		3.8	0.8		1.7
13d. Off-Load Power System	Crane,PM/trailer	See #9 Subtotal for Off-Loading Generic Cargo Element	1	1		2.6	0.8	0.5	1	0.5	1.8	2	3.5
13e. Transport to Base	PM/trailer	Haul speed 25m/min, 1000 m.	1	1	40	0.7					0.7	2	1.3
13f. Crane to Base	Crane	Fast Speed 100 m/min, 1000 m.	1	1	10	0.2		0.2	1	0.2			
13g. Off-Load Trailer	Crane	See #9 Subtotal for Placement of Generic Cargo	1	1		1.4	0.1	0.5	1	0.5	1.3	2	2.5
13h. Emplace Power System													
Deploy Support Structure	PM/trailer	2 supports/array, (2)10.5m x27m arrays/18.8kW*system*	4	1	30	2.0					2.0	2	4.0
Deploy Systems	PM/trailer	PV Array, PV Storage, Control, Rad. (60 min/ea)	4	1	60	4.0					4.0	2	8.0
13i. Interface Connections													
Power						0.5					0.5	2	1.0
Data Management System						0.5					0.5	2	1.0
Thermal						2.0					2.0	2	4.0
13j. Integrated Test & Verification		Sequence through Earth, IVA, EVA checks				6.0	6.0	6.0	1	6.0	6.0	2	12.0
13. SUBTOTAL						26.9	9.4	10.9	1	10.9	19.5	2	39.0
14. EMPLACE RADIATOR SYSTEM													
14a. Travel to Site	PM	At slow speed 25 m/min, 100 m.	1	1	4	0.1	0.1						
14b. Survey, Set Markers	PM/Survey System	Meas.(repeat)/Place 2 Markers	1	1	36	0.6	0.6						
14c. Install Utility-Ways		Completed in Site Preparation.											
14d. Off-Load Radiator	Crane,PM/trailer	See #9 Subtotal for Off-Loading Generic Cargo Element	1	1		2.6	0.8	0.5	1	0.5	1.8	2	3.5
14e. Transport to Base	PM/trailer	Haul speed 25m/min, 1000 m.	1	1	40	0.7					0.7	2	1.3
14f. Crane to Base	Crane	Fast Speed 100 m/min, 1000 m.	1	1	10	0.2		0.2	1	0.2			
14g. Off-Load Trailer	Crane	See #9 Subtotal for Placement of Generic Cargo	1	1		1.4	0.1	0.5	1	0.5	1.3	2	2.5
14h. Emplace Thermal Control System													
Deploy Support Structure	PM/trailer	2 supports/rad.	2	1	30	1.0					1.0	2	2.0
Deploy Systems	PM/trailer	Rad., Control (30 min/ea)	2	1	60	2.0					2.0	2	4.0
14i. Interface Connections													
Power						0.5					0.5	2	1.0
Data Management System						0.5					0.5	2	1.0
Thermal						2.0					2.0	2	4.0
14j. Integrated Test & Verification		Sequence through Earth, IVA, EVA checks				6.0	6.0	6.0	1	6.0	6.0	2	12.0
14. SUBTOTAL						17.5	7.6	7.2	1	7.2	15.7	2	31.3
15. EMPLACE COMMUNICATIONS SYSTEM													
15a. Travel to Site	PM	At slow speed 25 m/min, assume 200 m.	1	1	8	0.1	0.1						
15b. Survey, Set Markers	PM/Survey System	Meas.(repeat)/Place 2 Markers	1	1	36	0.6	0.6						
15c. Install Utility-Ways													
Trenching	PM/Small Trencher	200 m trench	1	1	200	3.3		3.3	1	3.3			

ORIGINAL PAGE IS
OF POOR QUALITY

Table D-1 (Cont). Surface Operations Breakdown Into Subtasks With Time Estimates

Activity Times	Equipment (PM = Prime Mover)	Comments	Events	Number of Passes (i.e. 1+ Repeats)	Time per event (min/event)	Time (hrs)	Earth Teleop (hrs)	Lunar Teleop (hr/person)	Lunar IVA Crew	Total IVA (hr)	EVA op (hr/person)	EVA Crew	Total EVA (hrs)
Conduit Emplacement	PM/Cart	10 m utility tray seg.=20 segments/200 m @ 10 min/seg	20	1	10	3.3					3.3	2	6.7
Backfill	PM/Grader	200 m trench @ 5 m/min.	1	1	40	0.7		0.7	1	0.7			
PM Attachment Changes	PM	max. 3 changes necessary	3	1	55	2.8		2.8	1	2.8			
15c. Subtotal						10.1		6.8		6.8	3.3		6.7
15d. Off-Load Com. System	Crane,PM/trailer	See #9 Subtotal for Off-Loading Generic Cargo Element	1	1		2.6	0.8	0.5	1	0.5	1.8	2	3.5
15e. Transport to Base	PM/trailer	Haul speed 25m/min, 1000 m.	1	1	40	0.7					0.7	2	1.3
15f. Crane to Base	Crane	Fast Speed 100 m/min, 1000 m.	1	1	10	0.2		0.2	1	0.2			
15g. Off-Load Trailer	Crane	See #9 Subtotal for Placement of Generic Cargo	1	1		1.4	0.1	0.5	1	0.5	1.3	2	2.5
15h. Emplace Communications Station													
Construct Tower Structur	PM/trailer	Deployable Tower (15 min), (4) guy-wires (15 min/ea)	1	1	75	1.3					1.3	2	2.5
Deploy Systems	PM/trailer		1	1	60	1.0					1.0	2	2.0
15i. Interface Connections													
Power						0.5					0.5	2	1.0
Data Management System						0.5					0.5	2	1.0
Thermal						2.0					2.0	2	4.0
15j. Integrated Test & Verification		Sequence through Earth, IVA, EVA checks				6.0	6.0	6.0	1	6.0	6.0	2	12.0
15. SUBTOTAL						26.9	7.7	13.9	1	13.9	18.3	2	36.5
16. EMPLACE LO2 PILOT PLANT													
16a. Travel to Sites	PM	At slow speed 25 m/min, pilot 200 m from base, pilot plant 700 m from feedstock mine area, return.	1	1	54	1.1	1.1						
16b. Survey, Set Markers	PM/Survey System	Meas.(repeat)/Place 6 Markers	1	1	108	1.8	1.8						
16c. Install Utility-Ways													
Trenching	PM/Small Trencher	200 m trench	1	1	200	3.3		3.3	1	3.3			
Conduit Emplacement	PM/Cart	10 m utility tray seg.=20 segments/200 m @ 10 min/seg	20	1	10	3.3					3.3	2	6.7
Backfill	PM/Grader	200 m trench @ 5 m/min.	1	1	40	0.7		0.7	1	0.7			
PM Attachment Changes	PM	max. 3 changes necessary	3	1	55	2.8		2.8	1	2.8			
16d. Off-Load LO2 Pilot	Crane,PM/trailer	See #9 Subtotal for Off-Loading Generic Cargo Element	1	1		2.6	0.8	0.5	1	0.5	1.8	2	3.5
16e. Transport to LO2 Site	PM/trailer	Haul speed 25m/min, 800 m.	1	1	32	0.5					0.5	2	1.1
16f. Crane to LO2 Pilot	Crane	Fast Speed 100 m/min, 800 m.	1	1	8	0.1		0.1	1	0.1			
16g. Off-Load Trailer	Crane	See #9 Subtotal for Unloading Generic Cargo	1	1		1.4	0.1	0.5	1	0.5	1.3	2	2.5
16h. Deploy Systems	Crane,PM/trailer	5 modules (Feed Hopper, Beneficiation, Reactor, Refriguration, Storage) @ 30 min/ea	5	1	30	2.5		2.5	1	2.5	2.5	2	5.0
16i. Interface Connections													
Power						0.5					0.5	2	1.0
Communications						0.5					0.5	2	1.0
Data Management System						0.5					0.5	2	1.0
Thermal						2.0					2.0	2	4.0
16j. Power Up Systems													
Power-on						0.2		0.2	1	0.2			
Control Systems						0.3		0.3	1	0.3			
Pressure/Fluid Systems						2.0		2.0	1	2.0			
16k. Integrated Test & Verification		Sequence through Earth, IVA, EVA checks				6.0	6.0	6.0	1	6.0	6.0	2	12.0
16. SUBTOTAL						32.1	9.8	18.9	1	18.9	18.9	2	37.7
17. OPERATE LO2 PILOT PLANT (ON MONTHLY BASIS = 720 hrs)													
17a. Normal System Monitoring and Control		Earth responds to 80% of alarms, alarms 4% of time	1	1	41472	691.2	691.2						
17b. Respond to Alarms	Rover	Lunar IVA assist on 15% alarms, IVA&EVA on 5%	1	1	1728	28.8	28.8	5.8	1	5.8	1.4	2	2.9
17c. Load Feed Hopper	PM/Front Loader/Cart	Assume Pilot produces 1 mt LO2/month											
LO2 Prod. (mt/month)	1												
Ilmenite Feed Conc. (wt.%)	10%												

ORIGINAL PAGE IS OF POOR QUALITY

Table D-1 (Cont). Surface Operations Breakdown Into Subtasks With Time Estimates

Activity Times	Equipment (PM = Prime Mover)	Comments	Events	Number of Passes (i.e. 1+ Repeats)	Time per event (min/event)	Time (hrs)	Earth Teleop (hrs)	Lunar Teleop (hr/person)	Lunar IVA Crew	Total IVA (hr)	EVA op (hr/person)	EVA Crew	Total EVA (hrs)
Excavated Feed (m tons) =	94.8												
Excavated Feed (m^3) =	55.8	Fill 8 m^3 cart, 2 min/m^3	7	1	15	1.9		1.9	1	1.9			
Dist from feed to pilot (m)	700.0	Pull cart 700 m, dump in feed hopper (2min), return	7	1	58	6.8		6.8	1	6.8			
		Re-position PM	7	1	5	0.6		0.6	1	0.6			
17d. Dump Tailings	PM/Front Loader/Cart												
Tailings (m tons) =	93.8												
Tailings Vol. (m^3) =	55.2	Fill 8 m^3 cart, 2 min/m^3	7	1	16	1.9		1.9	1	1.9			
Dist from pilot to dump (m)	700.0	Pull cart 700 m, dump in feed hopper (2min), return	7	1	58	6.8		6.8	1	6.8			
		Re-position PM	7	1	5	0.6		0.6	1	0.6			
17e. Remove LO2 (return to base for analysis)		Assume in 167 kg batches (weighs 60 lbf on Moon)											
Travel to Pilot	Rover	200 m @ fast speed (100 m/min)	6	1	2	0.2					0.2	2	0.4
Retrieve LO2			6	1	30	3.0					3.0	2	6.0
Return to Base	Rover	200 m @ fast speed (100 m/min)	6	1	2	0.2					0.2	2	0.4
17. SUBTOTAL						741.8	720.0	24.2	1	24.2	4.8	2	9.7
18. EMPLACE LO2 PRODUCTION PLANT													
18a. Travel to Sites	PM	At slow speed 25 m/min, plant 800 m from base, plant 100 m from feedstock mine area, return.	1	1	40	0.7	0.7						
18b. Survey, Set Markers	PM/Survey System	Meas.(repeat)/Place 6 Markers	1	1	108	1.8	1.8						
18c. Install Utility-Ways													
Trenching	PM/Small Trencher	600 m trench (dist. from pilot to plant)	1	1	600	10.0		10.0	1	10.0			
Conduit Emplacement	PM/Cart	10 m utility tray seg.=60 segments/600 m @ 10 min/seg	60	1	10	10.0					10.0	2	20.0
Backfill	PM/Grader	600 m trench @ 5 m/min.	1	1	120	2.0		2.0	1	2.0			
PM Attachment Changes	PM	max. 3 changes necessary	3	1	75	3.8		3.8	1	3.8			
18d. Off-Load LO2 Plant	Crane,PM/trailer	See #9 Subtotal for Off-Loading Generic Cargo Element	1	1		2.6	0.8	0.5	1	0.5	1.8	2	3.5
18e. Trans. to Plant Site	PM/trailer	Haul speed 25m/min, 200 m.	1	1	8	0.1					0.1	2	0.3
18f. Crane to LO2 Plant	Crane	Fast Speed 100 m/min, 200 m.	1	1	2	0.0		0.0	1	0.0			
18g. Off-Load Trailer	Crane	See #9 Subtotal for Unloading Generic Cargo	1	1		1.4	0.1	0.5	1	0.5	1.3	2	2.5
18h. Deploy Systems	Crane,PM/trailer	5 modules (Feed Hopper, Beneficiation, Reactor,	5	1	60	5.0		5.0	1	5.0	5.0	2	10.0
18i. Interface Connections		Refriguration, Storage) @ 60 min/ea											
Power (not including stringing power cable from advanced power plant)			5	1	30	2.5					2.5	2	5.0
Communications			5	1	30	2.5					2.5	2	5.0
Data Management System			5	1	30	2.5					2.5	2	5.0
Thermal			5	1	120	10.0					10.0	2	20.0
18j. Power Up Systems													
Power-on			5	1	12	1.0		1.0	1	1.0			
Control Systems			5	1	18	1.5		1.5	1	1.5			
Pressure/Fluid Systems			5	1	120	10.0		10.0	1	10.0			
18k. Integrated Test & Verification		Sequence through Earth, IVA, EVA checks	5	1	360	30.0	30.0	30.0	1	30.0	30.0	2	60.0
18. SUBTOTAL						97.4	33.4	64.3	1	64.3	65.6	2	131.3
19. OPERATE LO2 PLANT (ON MONTHLY BASIS)													
19a. Normal System Monitoring and Control		Lunar IVA controlled	1	1	41472	691.2		691.2	1	691.2			
19b. Respond to Alarms	Rover	Alarm 4% of time, IVA&EVA on 5% of alarms	1	1	1728	28.8		28.8	1	28.8	1.4	2	2.9
19c. Load Feed Hopper	PM/Front Loader/Cart	Assume Pilot produces 1 mt LO2/month											
LO2 Prod. (mt/month)	26.25												
Ilmenite Feed Conc. (wt.%)	10%												
Excavated Feed (m tons) =	2488.8												
Excavated Feed (m^3) =	1464.0	Fill 8 m^3 cart, 2 min/m^3	183	1	16	48.8		48.8	1	48.8			

Table D-1 (Cont). Surface Operations Breakdown Into Subtasks With Time Estimates

Activity Times	Equipment (PM = Prime Mover)	Comments	Events	Number of Passes (i.e. 1+ Repeats)	Time per event (min/event)	Time (hrs)	Earth Teleop (hrs)	Lunar Teleop (hr/person)	Lunar IVA Crew	Total IVA (hr)	EVA op (hr/person)	EVA Crew	Total EVA (hrs)
Dist from feed to plant (m)	200.0	Pull cart 200 m, dump in feed hopper (2min), return	183	1	18	54.9		54.9	1	54.9			
		Re-position PM	183	1	5	15.3		15.3	1	15.3			
19d. Dump Tailings	PM/Front Loader/Cart												
Tailings (m tons) =	2462.6												
Tailings Vol. (m^3) =	1448.6	Fill 8 m^3 cart, 2 min/m^3	181	1	16	48.3		48.3	1	48.3			
Dist from pilot to dump (m)	200.0	Pull cart 200 m, dump in feed hopper (2min), return	181	1	18	54.3		54.3	1	54.3			
		Re-position PM	181	1	5	15.1		15.1	1	15.1			
19. SUBTOTAL						956.6	0.0	956.6	1	956.6	1.4	2	2.9
20. EMPLACE REUSABLE LANDER REFUELING FACILITIES													
(Assume Tank Car and Loading Facilities are required)													
20a. Travel to Site	PM	At slow speed 25 m/min, facility 800 m from base.	1	1	40	0.7	0.7						
20b. Survey, Set Markers	PM/Survey System	Meas.(repeat)/Place 4 Markers	1	1	72	1.2	1.2						
20c. Off-Load Tank Car & Loading Structure&Piping	Crane,PM/trailer	See #9 Subtotal for Off-Loading Generic Cargo Element	1	1		2.6	0.8	0.5	1	0.5	1.8	2	3.5
20d. Trans. to Fac. Site	PM/trailer	Haul speed 25m/min, 200 m.	1	1	8	0.1					0.1	2	0.3
20e. Crane to Facility	Crane	Fast Speed 100 m/min, 200 m.	1	1	2	0.0		0.0	1	0.0			
20f. Off-Load Trailer	Crane	See #9 Subtotal for Unloading Generic Cargo	1	1		1.4	0.1	0.5	1	0.5	1.3	2	2.5
20g. Construct Loading Pad	PM/Grader/Cart	20mx20m Pad; Ratio to Subtotal for Grading from #1	1	1	362	6.0	5.7				0.3	2	0.6
20h. Deploy Systems													
Structure/Piping	Crane, PM	50m pipe, 10m sections, 60 min/sect. + 60 min loader	5	1	60	5.0					5.0	2	10.0
Emplace Cable Tray (Extend Existing Plant System)	PM/trailer	10 m utility tray seg.=5 segments/50 m @ 10 min/seg	5	1	10	0.8					0.8	2	1.7
20i. Power Up Systems													
Power-on			1	1	12	0.2		0.2	1	0.2			
Control Systems			1	1	18	0.3		0.3	1	0.3			
20j. Integrated Test & Verification		Sequence through Earth, IVA, EVA checks	1	1	360	6.0	6.0	6.0	1	6.0	6.0	2	12.0
20k. Demonstration Test:													
Load Tank Car	Tank Car	26.25 MT LOX @ 400 kg/min. (Using station pump)	1	1	66	1.1					1.1	2	2.2
Travel to Landing Pad	Tank Car	200 m @ 25 m/min.	1	1	8	0.1					0.1	2	0.3
Load Reusable Lander	Tank Car	26.25 mt LOX @ 200 kg/min. (Using Tank Car Pump)	1	1	131	2.2					2.2	2	4.4
Return to Refueling Station		200 m @ 100 m/min.	1	1	2	0.0					0.0	2	0.1
20. SUBTOTAL						27.8	14.6	7.5	1	7.5	18.7	2	37.4
21. REFUELING REUSABLE LANDER (LOX only)													
21a. Travel to Refuel Site	Rover	800 m @ 100 m/min.	1	1	8	0.1					0.1	2	0.3
21b. Load Tank Car	Tank Car	26.25 MT LOX @ 400 kg/min. (Using station pump)	1	1	66	1.1					1.1	2	2.2
21c. Drive to Landing Pad	Tank Car	200 m @ 25 m/min.	1	1	8	0.1					0.1	2	0.3
21d. Load Reusable Lander	Tank Car	26.25 mt LOX @ 200 kg/min. (Using Tank Car Pump)	1	1	131	2.2					2.2	2	4.4
21e. Return to Refuel Site	Tank Car	200 m @ 100 m/min.	1	1	2	0.0					0.0	2	0.1
21f. Return to Base	Rover	800 m @ 100 m/min.	1	1	8	0.1					0.1	2	0.3
21. SUBTOTAL						3.7					3.7	2	7.4
22. CONDUCT LUNAR GEOPHYSICAL STATION EXPERIMENT FROM LUNAR BASE													
(Assume station system consists of unmanned teleoperated rover, scientific experiments including seismic packages, and sample collection equipment)													
22a. Off-Load Geo Station	Crane,PM/trailer	See #9 Subtotal for Off-Loading Generic Cargo Element	1	1		2.6	0.8	0.5	1	0.5	1.8	2	3.5
22b. Trans. to Base	PM/trailer	Haul speed 25m/min, 1000 m.	1	1	40	0.7					0.7	2	1.3
22c. Crane to Base	Crane	Fast Speed 100 m/min, 1000 m.	1	1	10	0.2		0.2	1	0.2			
22d. Off-Load Trailer	Crane	See #9 Subtotal for Unloading Generic Cargo	1	1		1.4	0.1	0.5	1	0.5	1.3	2	2.5

ORIGINAL PAGE IS OF POOR QUALITY

Table D-1 (Cont). Surface Operations Breakdown Into Subtasks With Time Estimates

Activity Times	Equipment (PM = Prime Mover)	Comments	Events	Number of Passes (i.e. 1+ Repeats)	Time per event (min/event)	Time (hrs)	Earth Teleop (hrs)	Lunar Teleop (hr/person)	Lunar IVA Crew	Total IVA (hr)	EVA op (hr/person)	EVA Crew	Total EVA (hrs)
22e. Checkout System			1	1	60	1.0					1.0	2	2.0
22f. Deploy Rover w/ Sys.	Unmanned Rover	Assume 100 km traverse outbound @ 100 m/min.	1	1	1000	16.7		16.7	1	16.7			
22g. Deploy Seismic Sources &		10 packages @ 10 min/ea with 1 km traverse between	10	1	10	1.7		1.7	1	1.7			
science equipment		each @ 25 m/min	10	1	40	6.7		6.7	1	6.7			
22h. Carryout other tests & sampling			1	1	720	12.0		12.0	1	12.0			
22i. Return Samples to Base for analysis	Unmanned Rover	100 km traverse @ 100 m/min.	1	1	1000	16.7		16.7	1	16.7			
22. SUBTOTAL						59.5	1.0	54.8	1	54.8	4.7	2	9.3
23. EMPLACE OPTICAL INTERFEROMETER													
(optical interferometer: system of 27 individually mobile telescopes, stationed in Y shape with each leg 6 km long, and also includes central correlation station. Each element is assumed mounted on an unmanned, teleoperated rover. Also includes 1 teleoperated cable laying rover and a spare telescope. Assume manifest 15 elements/pallet on expendable lander for a total of 2 pallets.)													
23a. Travel to Site	PM	At fast speed 100 m/min, 1 km to beginning of site	1	1	10	0.2	0.2						
23b. Survey, Set Markers	PM/Survey System	Meas.(repeat 3)/Place 28 Markers	28	1	672	313.6	313.6						
		Travel 2/3 km between meas.& markers @ 25 m/min	84	1	27	37.4	37.4						
23c. Return to Base site	PM	11 km at 100 m/min	1	1	110	1.9	1.8						
23d. Inspect Locations	Pressurized Rovers	Travel total of 35km @ 100 m/min (Count as IVA) &	1	1	350	5.8		5.8	2	11.7			
		20 min inspection at each site (EVA)	28	1	20	9.3					9.3	2	18.7
23e. Unload Optical Int.	Crane,PM/trailer	See #9 Subtotal for Off-Loading Generic Cargo Element	2	1		2.6	0.8	0.5	1	0.5	1.8	2	3.5
23f. Transport to Base	PM/trailer	Haul speed 25m/min, 1000 m.	2	1	40	1.3					1.3	2	2.7
23g. Crane to Base	Crane	Fast Speed 100 m/min, 1000 m.	2	1	10	0.3		0.3	1	0.3			
23h. Off-Load Trailer	Crane	See #9 Subtotal for Unloading Generic Cargo	2	1		1.4	0.1	0.5	1	0.5	1.3	2	2.5
23i. Checkout System		30 min/each	30	1	30	15.0					15.0	2	30.0
23j. Deploy Rovers w/ sys.	Unmanned Rover	Assume average of 8 km traverse per rover @ 25 m/min.	28	1	320	149.3	149.3						
23k. Lay Cable	Cable Laying Rover	Travel total of 35 km @ 25 m/min &	1	1	1400	23.3	23.3						
		30 min/connection (54 connections)	54	1	30	27.0	27.0						
23l. Test & Verification		Earth tests.	28	1	120	56.0	56.0						
	Pressurized Rovers	(2) Lunar EVAs to correct problems, 35 km roundtrip	2	1	350	11.7		11.7	2	23.3			
		at 100 m/min (IVA) & 2 hr/problem resolution (EVA).	2	1	120	4.0					4.0	2	8.0
23. SUBTOTAL						660.1	609.6	18.8	1-2	36.3	32.7	2	65.3
24. OPERATE OPTICAL INTERFEROMETER (MONTHLY BASIS - LUNAR ON MISSION BASIS)													
(Assume normal operation/control from Earth, Lunar Base provides IVA inspections & EVA service)													
24a. Normal Operation/Control			1	1	43200	720.0	720.0						
24b. Inspections	Teleoperated Rover	Travel total of 35 km @ 25 m/min	1	1	1400	23.3		23.3	1	23.3			
24c. Service	Pressurized Rovers	(1) Lunar EVAs to correct problems, 35 km roundtrip	1	1	350	5.8		5.8	2	11.7			
		at 100 m/min & 2 hr/problem resolution (EVA).	1	1	120	2.0					2.0	2	4.0
24. SUBTOTAL						751.2	720.0	29.2	1-2	35.0	2.0	2	4.0
25. CRATER DATING (50 craters >= 5 km diameter)													
(Assume requires samples and short cores from approximately 50 craters >= 5 km diameter)													
25a. Unload Exp. Equipment	Crane,PM/trailer	See #9 Subtotal for Off-Loading Generic Cargo Element	1	1		2.6	0.8	0.5	1	0.5	1.8	2	3.5
25b. Transport to Base	PM/trailer	Haul speed 25m/min, 1000 m.	1	1	40	0.7					0.7	2	1.3
25c. Crane to Base	Crane	Fast Speed 100 m/min, 1000 m.	1	1	10	0.2		0.2	1	0.2			
25d. Off-Load Trailer	Crane	See #9 Subtotal for Unloading Generic Cargo	1	1		1.4	0.1	0.5	1	0.5	1.3	2	2.5
25e. Load Equip. on Rovers	Pres. Rovers												
25f. Travel Time	Pres. Rovers	(Count Pressurized Rover time as IVA)											
No. Craters >= 5km dia. =	3E+05												

Table D-1 (Cont). Surface Operations Breakdown Into Subtasks With Time Estimates

Activity Times	Equipment (PM = Prime Mover)	Comments	Events	Number of Passes (i.e. 1+ Repeats)	Time per event (min/event)	Time (hrs)	Earth Teleop (hrs)	Lunar Teleop (hr/person)	Lunar IVA Crew	Total IVA (hr)	EVA op (hr/person)	EVA Crew	Total EVA (hrs)
Radius Moon (km)	1738												
S.A. Moon (km^2)	3.796E+07												
Area for 50 craters (km^2)	6326.4												
Radius of Traverse (km)	44.9												
Roundtrip Traverse (km)	371.7	Assume 100 m/min	1	1	3717	62.0		62.0	2	123.9			
25g. Coring, Sampling	Pres. Rovers	Assume 6 hr. per crater, count as EVA	50	1	360	300.0					300.0	2	600.0
25. SUBTOTAL						366.8	1.0	63.1	1-2	125.1	303.7	2	607.3
26. DEEP DRILLING (1 core, 1 km deep)													
(Assume pressurized rig pulled by prime mover)													
26a. Unload Exp. Equipment	Crane,PM/trailer	See #9 Subtotal for Off-Loading Generic Cargo Element	1	1		2.6	0.8	0.5	1	0.5	1.8	2	3.5
26b. Transport to Base	PM/trailer	Haul speed 25m/min, 1000 m.	1	1	40	0.7					0.7	2	1.3
26c. Crane to Base	Crane	Fast Speed 100 m/min, 1000 m.	1	1	10	0.2		0.2	1	0.2			
26d. Off-Load Trailer	Crane	See #9 Subtotal for Unloading Generic Cargo	1	1		1.4	0.1	0.5	1	0.5	1.3	2	2.5
26e. Checkout Systems	Drill Rig		1	1	60	1.0					1.0	2	2.0
26f. Hitchup Rig	PM/Rig		1	1	30	0.5					0.5	2	1.0
26g. Pull to Drill Site	PM/Rig	Site 5 km away, 25 m/min.	1	1	200	3.3		3.3	1	3.3			
26h. Position Rig	PM/Rig		1	1	60	1.0		1.0	1	1.0			
26i. PM Return to Base	PM	@ 100 m/min	1	1	50	0.8		0.8	1	0.8			
26j. Crew to Rig	Rovers	@ 100 m/min	1	1	50	0.8					0.8	4	3.3
26k. Drill	Rig	1 km @ 5 m/hr, Count as IVA	1	1	12000	200.0		200.0	4	800.0			
26l. PM to Rig	PM	@ 100 m/min	1	1	50	0.8		0.8	1	0.8			
26m. Hitchup Rig	PM/Rig		1	1	30	0.5					0.5	2	1.0
26n. Crew Return w/Samples	Rovers	@ 100 m/min	1	1	50	0.8					0.8	4	3.3
26o. Return Rig to Base	PM/Rig	Base 5 km away, 25 m/min.	1	1	200	3.3		3.3	1	3.3			
26. SUBTOTAL						217.8	1.0	210.5	1-4	810.5	7.3	2-4	18.0

COMMENT: These time estimates assume a well trained crew that has rehearsed these operations several times on Earth. The estimates do not include any contingency factors for things that go wrong or items forgotten.

ORIGINAL PAGE IS OF POOR QUALITY