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Proceedings of the FY90 Workshop on Extraterrestrial Mining and Construction, 7-9 August 1990

by
Alvin Smith

This report documents the proceedings of a workshop on issues involved in extraterrestrial planet surface activities involving mining and construction. In this second workshop dedicated to the subject, participants formed three discussion groups: (1) Construction and Mining Concepts and Equipment Designs, (2) Design Standards and Codes, and (3) Operations and Performance.

Mining and construction tasks were categorized into 11 primary functions. Several equipment types and designs were reviewed for specific surface tasks, and surface and underground mining techniques were reviewed. It was noted that there is a need to develop separate codes and specifications for extraterrestrial construction, although earth-based codes provide a good starting point, and existing Corps of Engineers' Construction criteria and specifications may be a good model on which to base the new codes. Several key operational tasks, and concepts for accomplishing them were developed. One such important principle is to progress from simple to complex. Any lunar base should begin construction with modular, self-contained units, and gradually progress to more complex construction using locally derived/developed materials.

All groups emphasized that mission plans should be formed as concretely as possible, including crew size and mission timetable, to help establish realistic operations and performance criteria.

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FOREWORD

The FY90 Workshop on Extraterrestrial Mining and construction was jointly sponsored by the National Aeronautics and Space Administration (NASA), Headquarters, U.S. Army Corps of Engineers (HQUSACE), and the U.S. Department of Interior, Bureau of Mines (BOM). The workshop was hosted by the Colorado School of Mines (CSM) at Golden, CO. Partial funding support was provided from NASA under MIPR No. T947P, "Extraterrestrial Surface Construction Technologies." The NASA technical monitor was Mr. John Connolly (IE2).

The workshop was coordinated by the Engineering and Materials Division (EM) of the U.S. Army Construction Engineering Research Laboratory (USACERL). Most of the participant's expenses were provided by their organizations. The contributions of each participant are appreciated; their interest demonstrated a commitment to the "national goal" of the Space Exploration Initiative (SEI). Special acknowledgement is given to session co-chairpersons Ms. Lisa Bell, Mr. Walter Boles, Mr. Peter Chamberlain, Mr. Mason Lancaster, Mr. Ray Leonard, and Mr. Philip Richter for leading the working groups and contributing ideas. Mr. Lloyd Walker of John Frassanito and Associates provided the artist's sketches from the workshop; thanks to him, many of the ideas explored in the workshop became easier to organize. Special gratitude is owed to Dr. William Sharp of CMS and to the Students for the Exploration and Development of Space (SEDS) members who provided administrative assistance throughout the workshop. Dr. Paul A. Howdyshell is Chief, USACERL-EM. The USACERL technical editor was Mr. William J. Wolfe, Information Management Office.

COL Daniel Waldo, Jr. is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

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1 INTRODUCTION

1.1 Background

The FY90 workshop on extraterrestrial mining and construction was the second special meeting dedicated to this subject. Like the first, participants were limited in number to about 40 individuals, representing a range of expertise from academia, industry, and government. There was a conscious effort to prevent overloading the group with a particular interest area.* Many of the participants in the second workshop had also participated in the first, giving the workshop some continuity and reducing the time required to familiarize individuals with the subjects.

The first workshop participants had specified several goals for a future workshop. These goals were stated in the Proceedings (Bridget Mentz Register et al. 1990) and served as a primary list used to select the goals of the second workshop. In fact, 11 were included in the goals and organization of the second workshop.

Several important events, which occurred after the first workshop, influenced the timing and emphasis of the second:

1. President George Bush's 20 July 1989 address to commemorate the 20th anniversary of the first manned landing on the Moon. In this speech he laid out some goals for a Space Exploration Initiative (SEI) over the next three decades (Appendix B).

2. A NASA 90-day study to examine options and the feasibility of accomplishing the SEI goals. The *Planet Surface Systems Study Period Summary* (NASA Planet Surface Systems Office 1989) documented the part of this study pertinent to this workshop.

3. NASA formed a special study group, the "Synthesis Group." Chaired by former astronaut Gen. Thomas Stafford, this group's charter was to gather from a broad national input (consisting of private citizens, academia, industry, and other Federal agencies) of ideas on SEI, and to synthesize these ideas into at least two different mission "architectures" (The Synthesis Group 1991).

4. The Planet Surface Systems Office of NASA Johnson Space Center (JSC) followed the 90-day study with a more in-depth study of one of the options described in their Study Period Summary; this study was based on Option 5 in the 90-day study and was captured in "Reference Architecture 5a (option 5 with ISRU Emphasis)" (Appendix C).

5. SPACE 90, an international conference on Engineering, Construction and Operations in Space was held by the American Society of Civil Engineers (ASCE) along with numerous cosponsors. This second biennial conference provided a forum for exposition of study results and ideas, many of which dealt with construction and mining on other planets. Each of these influenced the second workshop by adding to the emphasis and ideas in various areas.

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* Appendix A lists the workshop participants.

1.2 Workshop Goals

The combined goals of this workshop were:

1. To develop a detailed outline showing pertinent engineering standards needed to design facilities for the lunar and martian surfaces

2. To describe the tasks, functions and kinematics, and the inter-relationships of the various construction and mining activities that may be performed

3. To develop a list of surface operations required to build and operate a lunar base facility and to develop probable performance levels and ranges for each operation.

To avoid random speculations, group discussions focused on a single reference document that provided a scenario and conditions as a basis for exchange. This document, the "Reference Architecture Description Option 5a (Option 5 with ISRU Emphasis)," was developed after the NASA 90-day Study and contained a detailed consideration of implementation methods.

1.3 Workshop Format

Three working groups met over a 3-day period to discuss topics of interest.* Joint meetings were held twice a day to foster more interaction and exchange among the groups (a need identified in the first workshop). Small group meetings were conducted in rooms close to the joint meeting room. This simplified movement among groups during working sessions and shortened the time required for travelling between meetings.

The opening half-hour of each of the second and third days was set aside for reorientation and realignment. Based on the previous afternoon summaries, course corrections were made and individuals could choose to change groups to provide assistance or gain information. Figure 1.3.1 shows the workshop format and schedule.

1.4 Workshop Topics

Individual working groups addressed three principal topics. The topics, group identifications, and group objectives were outlined in the following sections:

1.4.1 Group M: Construction and Mining Concepts and Equipment Designs

This group's objectives were to (1) develop descriptions of the various construction and mining activities that may be related to each other, i.e., excavating regolith; (2) describe in as much detail as possible, the task, function, and kinematics of each activity; (3) provide concepts for equipment alternatives for performing the tasks, including uncommon tasks; and (4) provide sketches sufficiently well done for later artist rendering into technical illustrations.

* The storyboard for the first-day planning talk is included in Appendix D.

EXTRATERRESTRIAL CONSTRUCTION AND MINING
WORKSHOP II, FY90, AUGUST 7-9, 1990

Co-sponsored by: NASA, U.S. Army Corps of Engineers and the Bureau of Mines
Hosted by: The Colorado School of Mines, Golden, CO

	August 7	August 8	August 9
8:00	Administrative announcements; introduction; plenary talks	Reorientation/ realignment	Reorientation/ realignment
9:00		Groups D,M,&P working session	Groups D,M,&P working session
10:00			
11:00	All participants: 10-minute group direction	All participants meet; 20-minute review by each small-group chairperson	
12:00	Lunch	Lunch	Lunch
1:00	Groups D,M,&P working session	Groups D,M,&P working session	All participants meet; final presentations/overall review by group chairpersons
2:00			Wrap-up session/ next workshop planning
3:00			
4:00	All participants meet; 20-minute review by each small-group chairperson	All participants meet; 20-minute review by each small-group chairperson	Executive session
5:00			

Figure 1.3.1. Workshop Format and Schedule.

1.4.2 Group D: Design Standards and Codes

The objective of this group was to develop a detailed outline showing the pertinent features needed to: (1) design a facility for the lunar and martian surfaces; (2) organize the outline in a logical, procedural way; and (3) provide brief descriptions for the listed major categories.

1.4.3 Group P: Operations and Performance

Group P's objectives were to: (1) develop a list of surface operations required to build and operate a base facility, including power production, mining/extraction plant, and landing/launch facilities; (2) describe each operation in as much detail as possible; (3) using the operations identified, develop realistic performance levels and ranges for each, including human extra-vehicular activity (EVA), tele-operations, and robotic and automated operations; and (4) if possible, describe required sensory inputs, kinematics of each operation and controls/limits that should be applied.

2 CONSTRUCTION AND MINING CONCEPTS AND EQUIPMENT DESIGNS

2.1 Group Definition of Goals

Working group M (Construction and Mining Concepts and Equipment Designs) redefined the general guidance provided into a series of eight goals:

1. Identify and evaluate large and small-scale tasks
2. Define the working environment
3. Develop machinery concepts
4. Outline task kinematics
5. Review needed technology (bearings, materials, power, etc.)
6. Document strong and weak points of concepts
7. Explore links and syngergies to other disciplines
8. Define research and development.

The group decided that all categories or goals must have an applicable list of experience-based rules. Engineering design criteria and standards, once developed and verified, would presumably constitute the desired lists.

2.2 Task Identification

Major tasks served as starting points for discussions. Interspersed with the major tasks were a few high-level issues or concerns that were not actually tasks but which the participants felt should be included in their area. Major tasks/issues identified were:

1. Offloading
2. Site analysis
3. Transportation infrastructure
4. Excavating/trenching
5. Maintenance/repair
6. ISRU operations
7. Facility construction/assembly
8. Foundation/stability
9. Construction materials manufacturing
10. Utility emplacement infrastructure
11. Underground mining.

The tasks/issues were expanded into subtasks, methods/techniques, applicable vehicles, devices, or implements. The discussions generally did not differentiate between subtasks or means of accomplishment. Sample task breakdowns are:

1. Offloading
   a. Specific
      (1) Vehicles
      (2) Habitats
      (3) Logistics (supplies)
      (4) Power units

(5) Crew
(6) Science equipment
b. General
(1) Large and heavy
(2) Small and light

2. Site analysis
   a. Remote sensing
   b. Surface geophysics
   c. Core sampling
   d. Sub-surface geophysics and testing
   e. Verify "excavatability"
   f. Sample analysis
   g. Concepts
   h. Rover-based drilling
   i. Seismic/electromagnetic
   j. Trenching and scraping
   k. Telerobotic controls

3. Transportation infrastructure
   a. Pallets
   b. Bulk cargo (liquid, loose, hard)
   c. Lunar materials
   d. Crew
   e. Concepts
      (1) Flatbed
      (2) Conveyor
      (3) Trajectory
      (4) Cable-tram
      (5) Piping
      (6) Drive machanisms (e.g., wheeled, track, hybrid, cable, etc.)
      (7) Ramp
      (8) Winch
      (9) Crane
      (10) Unloader
      (11) Integrated with lander
      (12) Rigging (towers, cables, etc.)
      (13) Cherry picker
      (14) Manipulator

4. Excavating/trenching
   a. Backhoe
   b. Clamshell
   c. Bull dozer
   d. Ripper
   e. Front end loader
   f. "Snow blower"
   g. "Weasel"
   h. Scraper
   i. Explosives
   j. Auger

k. Traxcavator
l. Disc harrow
m. Slusher
n. Laser
o. Potato picker
p. Tunnel melter
q. Benching
r. Bucket wheel excavator
s. Wire brush
t. Mobile miner
u. Flail
v. Drag line
w. Splitter
x. Tunneline machine

5. Maintenance/repair
   a. Modular replacement
   b Welding/assembly
   c. Consumables
   d. Maintenance area/facility
   e. Artificial intelligence (AI) (monitoring/testing)
   f. Robots or humans
   g. Logistics
   h. "Tool kit"

6. ISRU operations
   a. Process list and tradeoffs
   b. Crushing
   c. Screening
   d. Magnetic separation
   e. Gravity separation
   f. Magma electrolysis
   g. Hydrogen reduction
   h. See excavating
   i. See transportation
   j. Storage: equipment, raw materials, material byproducts
   k. Process monitoring (lab analysis)
   l. Environmental assessment
   m. Disposal/waste

7. Facility construction/assembly

8. Foundation/stabilization
   a. Landing site
   b. Habitat site
   c. Process plant
   d. Underground openings
   e. Tower/rigging
   f. Scientific instruments
   g. Roads
   h. Power plant

i. Techniques
   (1) Sintering
   (2) Melting
   (3) Vibration compaction
   (4) Expose bedrock
   (5) Netting (geogrid)
   (6) Excavate/remove loose regolith
   (7) Replacement
   (8) Anchoring

9. Construction materials manufacturing
   a. Fabrication/machining of extraterrestrial raw materials
   b. ISRU
      (1) Sintering blocks
      (2) Casting (basalt)
      (3) Concrete
      (4) Quarry
      (5) Glass/ceramic
      (6) Metals
   c. Regolith
      (1) See excavation
      (2) See transportation infrastructure
      (3) Storage
      (4) Direct dumping
      (5) Dust control
      (6) Regolith flow
   d. Concepts
      (1) Hopper w/vibrator
      (2) Auger
      (3) Conveyor

10. Utility emplacement infrastructure
   a. Connections
   b. Surface, underground, overhead
   c. Protection, insulation
   d. Structural
   e. Components
      (1) Power plant
      (2) Fluids
      (3) Electrical
      (4) Gases
      (5) Waste
      (6) Communication

11. Underground mining.

The group decided that equipment design should follow the general sequence of: (1) task/need/-function identification (including alternatives), (2) subtask identification, (3) concept development, (4) constraints clarification, (5) point design, (6) development, test and evaluation, etc. and (7) verification for space use.

2.2.1 Offloading Task Analysis

The working group discussed a number of ways to offload cargo from a lander onto the lunar surface. Considered techniques and equipment ranged widely in complexity. Table 2.2.1.1 lists these techniques covered and itemizes the perceived advantages and disadvantages of each. Figure 2.2.1.1 through 2.2.1.5 pictorally represent the concepts.

2.2.2 Surface Transportation Task Analysis

The working group addressed the surface transportation task confined to an area close to the lunar outpost. The methods considered were appropriate for both human and cargo transport. Cargo was characterized as solid, bulk, or fluid, and also by quantity to be transported (Table 2.2.2.1). The remarks in the comments column portray views expressed on other criteria, as shown in the key. Figures 2.2.2.1 through 2.2.2.3 show some of the surface transportation ideas discussed.

2.3 Construction Activities

Construction Activities were briefly addressed. The nature of the regolith is of great importance (Figure 2.3.1). Habitats and support infrastructure components were discussed and some salient points were identified. Mission specifics will be required for deeper discussion of the subject.

The group determined that future planning should include these features:

- The habitat should be self-contained in the initial phases.
- Support infrastructure in the early phase *if outpost development should* be deployable.
- Support infrastructure in later phases may involve more significant construction.
- Modular designs should be used, although with carefully controlled interfaces.
- Provisions must be made for unpackaging cargo.
- Positioning of elements in proper alignments must be carefully planned.
- Everything should be simply, quickly and easily deployed.
- Stay time/available work time may be limited; consider autonomous operation.
- Radiation protection alternatives must consider:
  - The need to move habitat from one location to another
  - That regolith should be moved at the least expense of energy
  - That explosive charges may be judiciously used to displace regolith
  - The use of a standoff structure to support radiation shield
  - The potential for using the lander structure as a standoff should be considered
  - Minimizing equipment support should be minimized.
- Nuclear power plant may be necessary and will require:
  - A design that allows trouble free unloading, moving, unpacking and constructing
  - "Self connecting" parts
  - Pressurized aligning and connecting fluid lines (a special problem).

Some alternate habitats configurations were discussed. Three possible alternatives for the initial outpost were discussed and evaluated (Table 2.3.1). A possible lander/habitat combination with automatic regolith covering capability is shown in Figure 2.3.2.

Table 2.2.1.1

Offloading Task Analysis

Technique/Quality	Advantages	Disadvantages
LEVPU	Lift & move	Rough surface could pose problems
(High labor productivity)	Freedom of movement	Massive
	Can load & unload	Mechanically complex
	Can upgrade to other tasks	Stability
		Redundant load path
		No manual overdrive
		Lift hazard
Ramp/winch	Simple	Limited other uses
(Slightly labor intensive)	Low mass	Requires another piece of equipment • transport • manipulation
	Easily integrated into lander	Requires special cargo configuration
	Available technology	
Winch	Simple	Requires rigging
(Labor intensive)	Low mass	Requires anchor
	Versatile	Single point failure
	Available technology	Requires another piece of equipment for horizontal movement
	Can integrate with lander	
	High forces possible	
Pre-assembled crane	Can be mobile	High mass
(High productivity)	No assembly	Limited capacity
	Multifunctional	Mechanically complex
	More difficult initial deployment	
Kit crane	Low mass	Requires assembly
(High productivity)	High capacity	Limited functionality
	Mechanically simple	
	Easy initial deployment	
Kit crane integrated with lander	No equipment required	Adds mass to lander

Table 2.2.1.1 (Cont'd)

Technique/Quality	Advantages	Disadvantages
Forklift/front end loader/backhoe (lhd vehicle)	Highly versatile	Limited capacity
(High labor productivity)	Multifunctional	High mass
	3 degrees of freedom	Mechanically complex
	Modularity	Limited reach
Manipulator	6 degrees of freedom	Requires platform/carrier
(High productivity)	Dexterous	Limited capacity
	Versatile	Highly complex
	Less EVA	
	More intra-vehicular activity (IVA)/earth	
Cable with block & tackle	Low mass	Requires • anchors
(High labor productivity)	Simple	• min assembly
Tip/tilt lander	Low mass	Requires • winches
	Simple	• cables • anchors • special equipment
Jacks	Lightweight	4 degrees of freedom
(Moderate labor productivity)	Simple	
	High capacity	Limited accessibility
	Can be used for other items of infrastructure	Single task
	Initial capability	Long term capability
	Can also load	
Inverter rings	Low mass	Requires • assembly • anchors • winches • cables
(Low-medium productivity)	Mechanically simple	Needs additional equipment

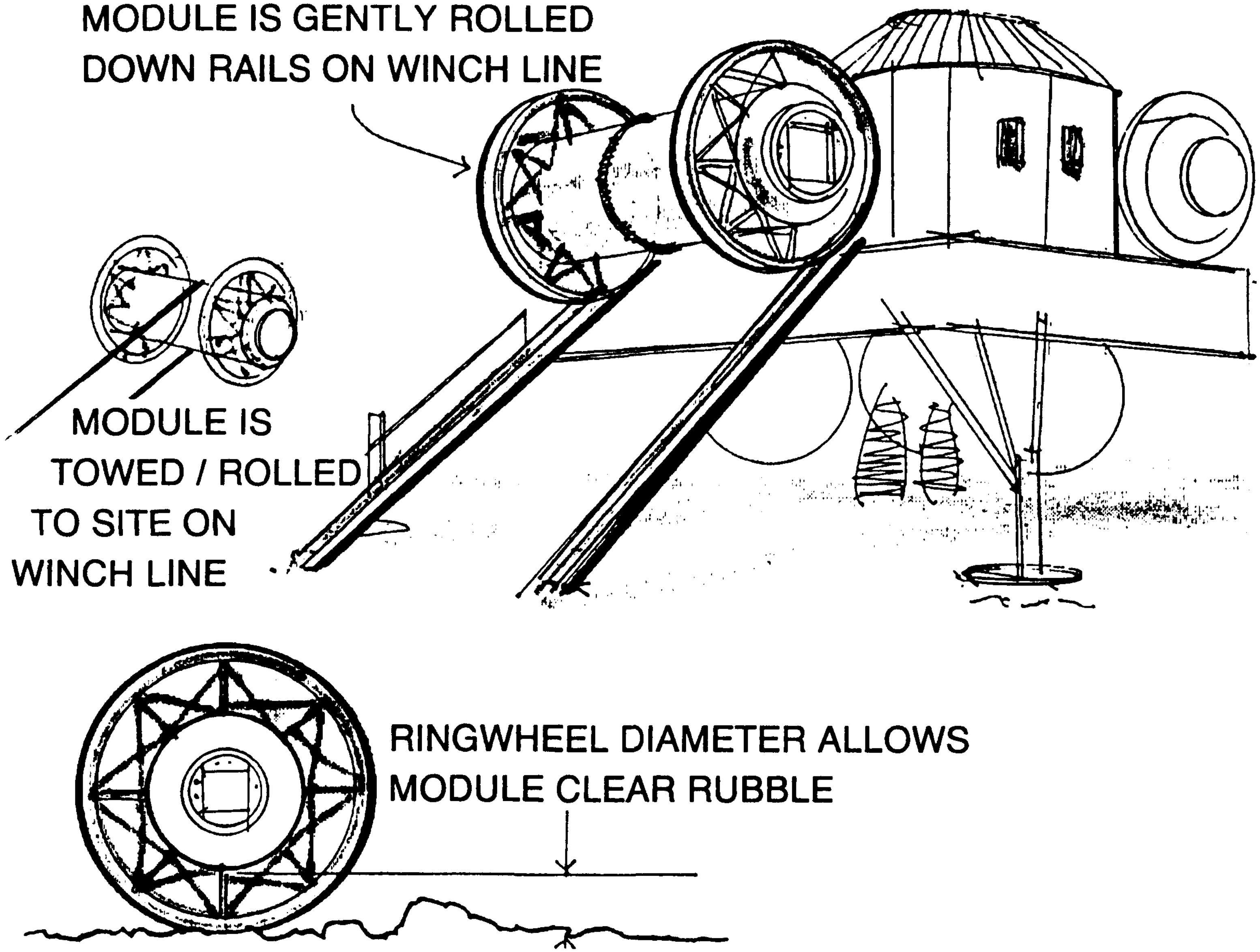

Figure 2.2.1.1 "Ringwheel" Offloading.

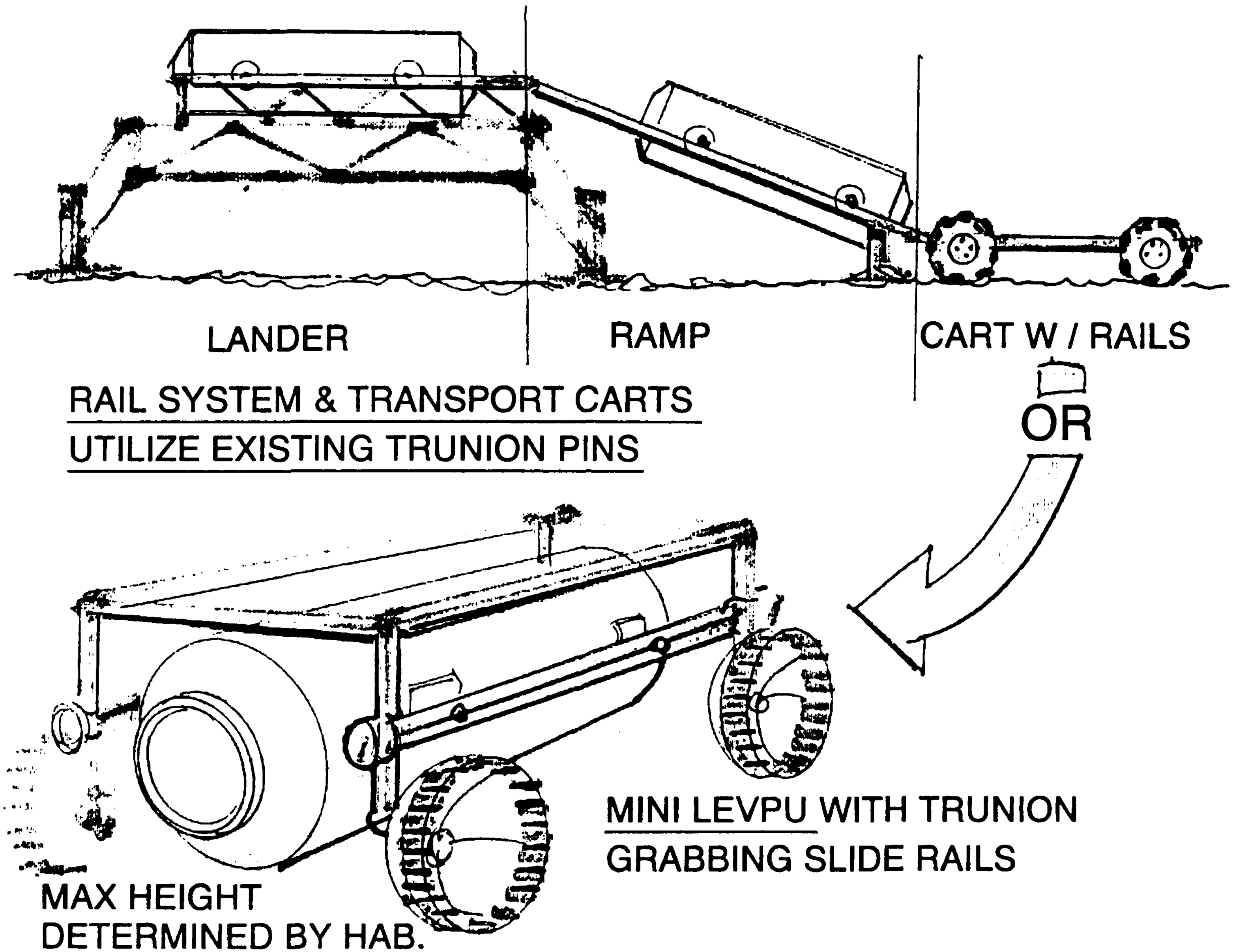

Figure 2.2.1.2. Trunion Rails Offloading.

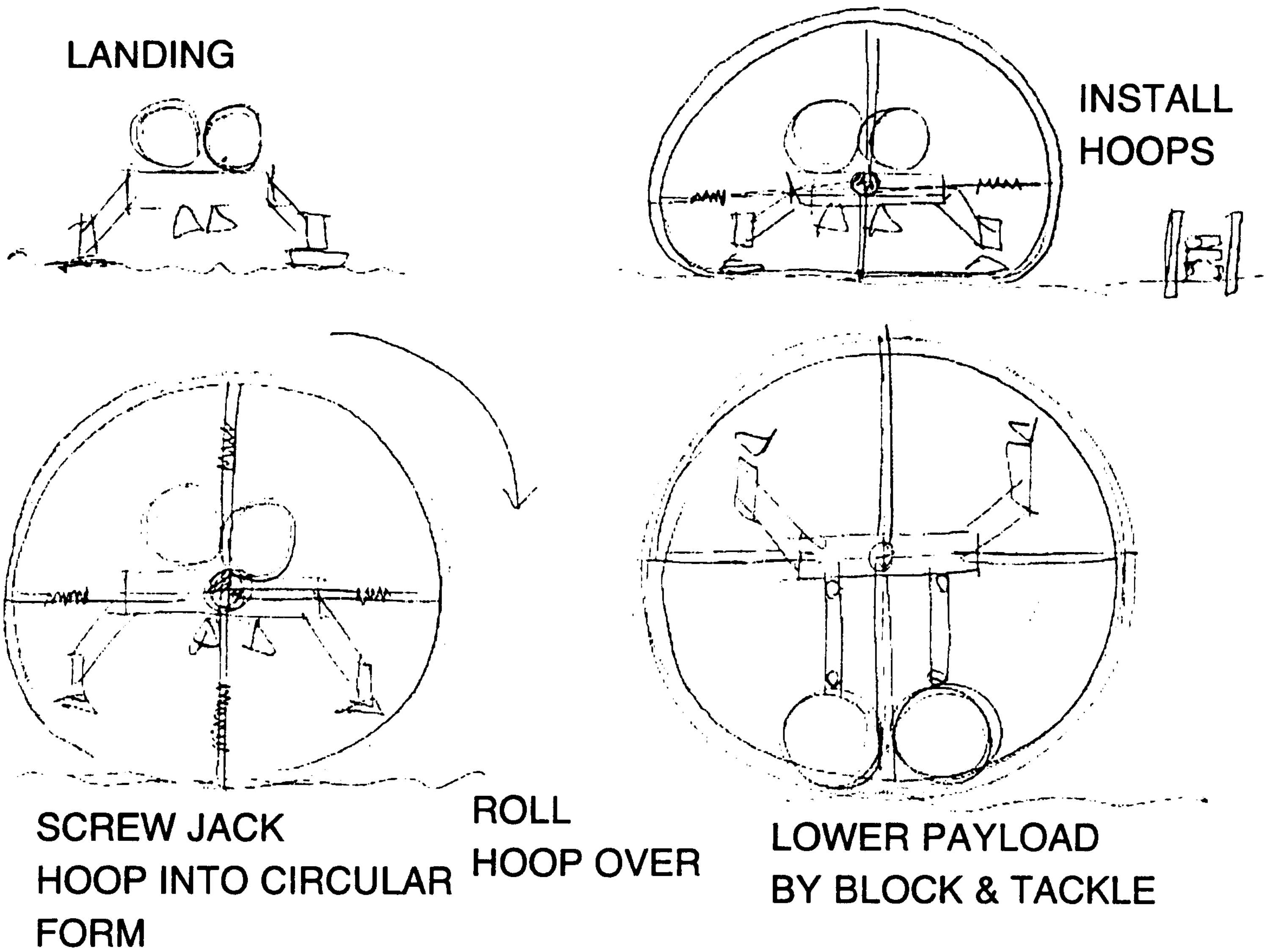

Figure 2.2.1.3. "Hoop Roller" Unloading.

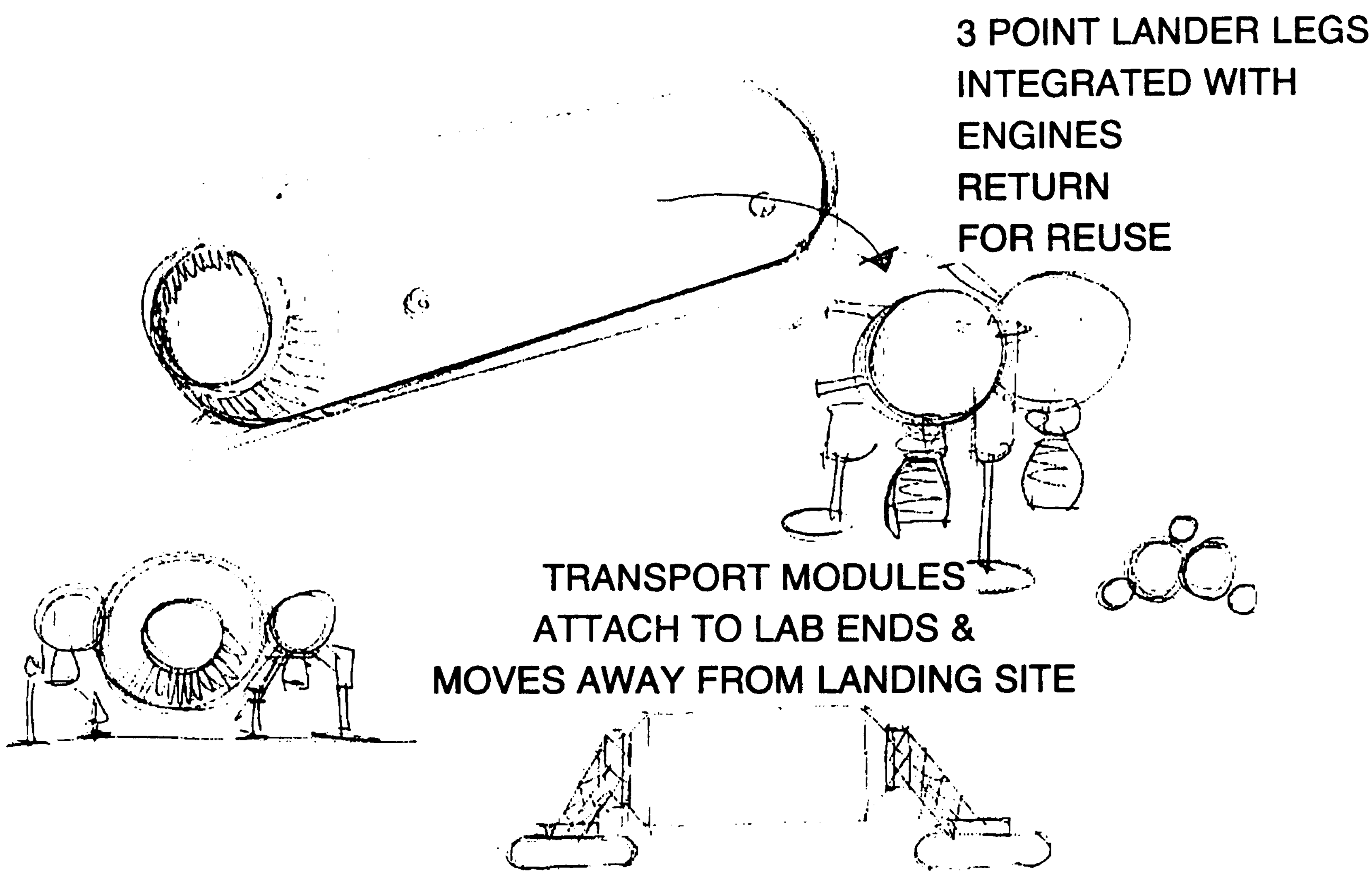

Figure 2.2.1.4. Hab Module/Lander.

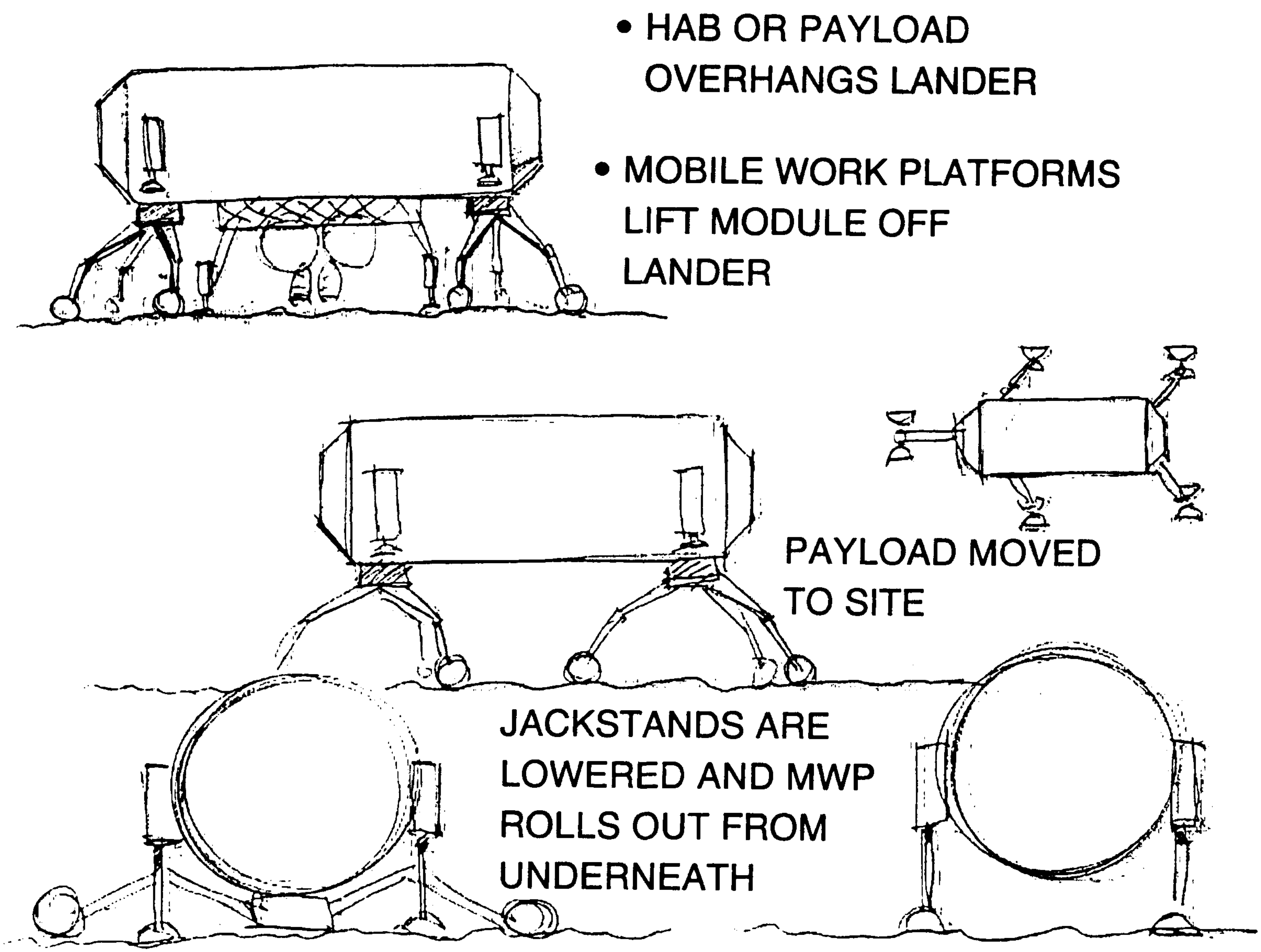

Figure 2.2.1.5. "Mobile Work Platform" Unloading.

Table 2.2.2.1

Surface Transportation Task Analysis

Method	Comments	People		100 kg			100 kg-1 MT			1-10 MT			10-30 MT			Other Uses
		P	UNP	S	B	F	S	B	F	S	B	F	S	B	F	
Vehicles	F,M,C,W,E PS,A	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Y
Tramway	PS,W, A,P F,C,E		X	X	X	X	X	X		X	X		X	X		YL
Piplines	PS,A, E,P F,C,P				X				X			X			X	N
Two Rail	PS,A, E,P F,W,C	X														N
Pneumatic Tubes	PS,W, A,E F,C,P			X	X	X										N
Conveyors	A,E, PS,F, W,SP			X	X			X			X			X		N
Rocket Prop	PS,F,M, C,E W*,A, P	X	X							X			X			N
Monorail	PS,A, E,P F,W,C	X														N
Ballistic Trajectory	PS,F,W,C,A,E,P			X	X		X	X								N

Column-Head Legend:
P - Pressurized
UNP - Unpressurized

S - Solid
B - Bulk
F - Fluid

Comments Legend:
Y - Yes
N - No
YL- Yes/limited

F - Flexibility
M - Mobility
W - Mass
PS - Productivity/speed

C - Ease of construction
A - Complexity of automation
E - Expandability
P - Power and energy efficiency

Footnotes:
* Assuming no in-situ
- Could not evaluate with vehicles
- Are power/energy efficient

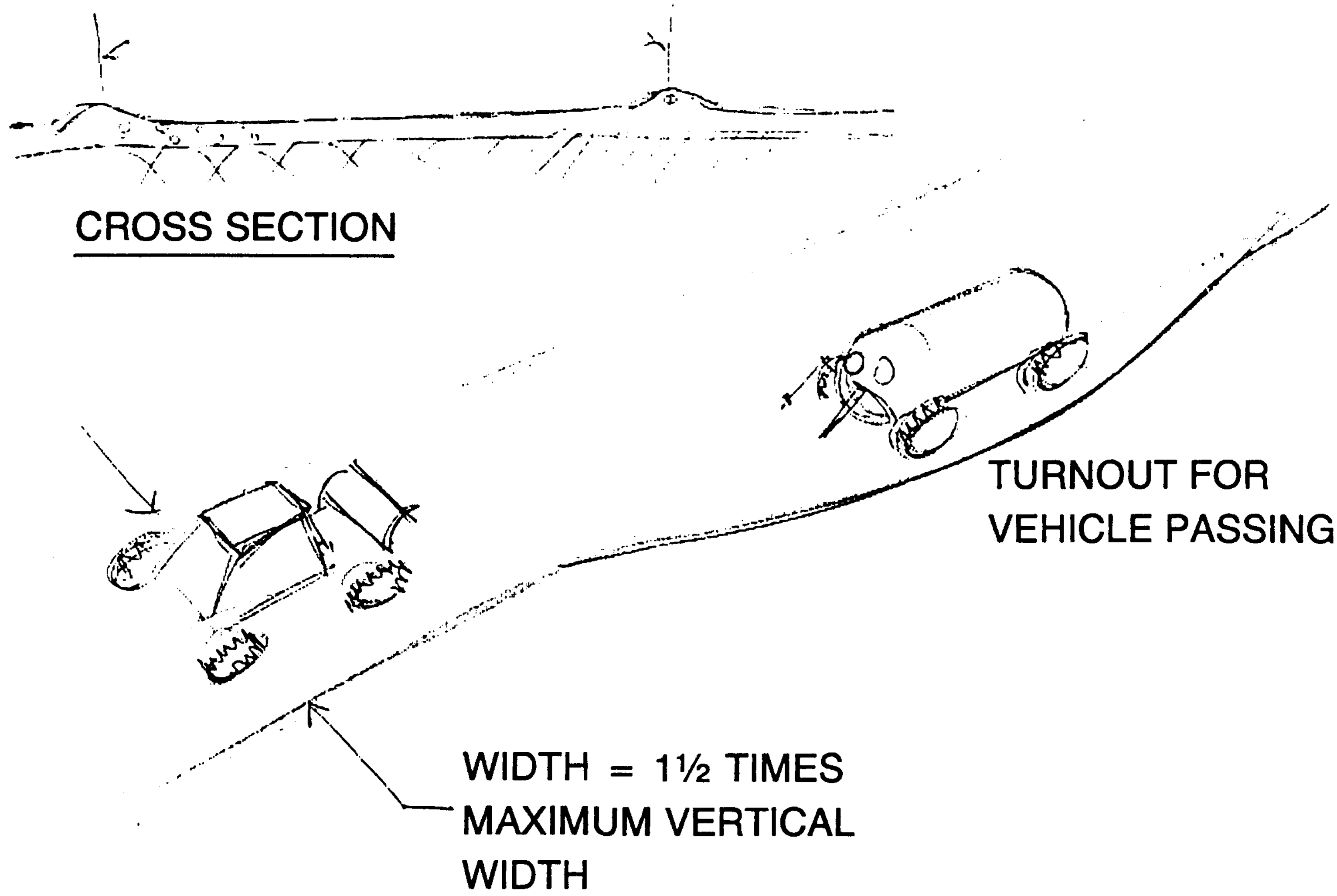

Figure 2.2.2.1. Lunar Base Tram.

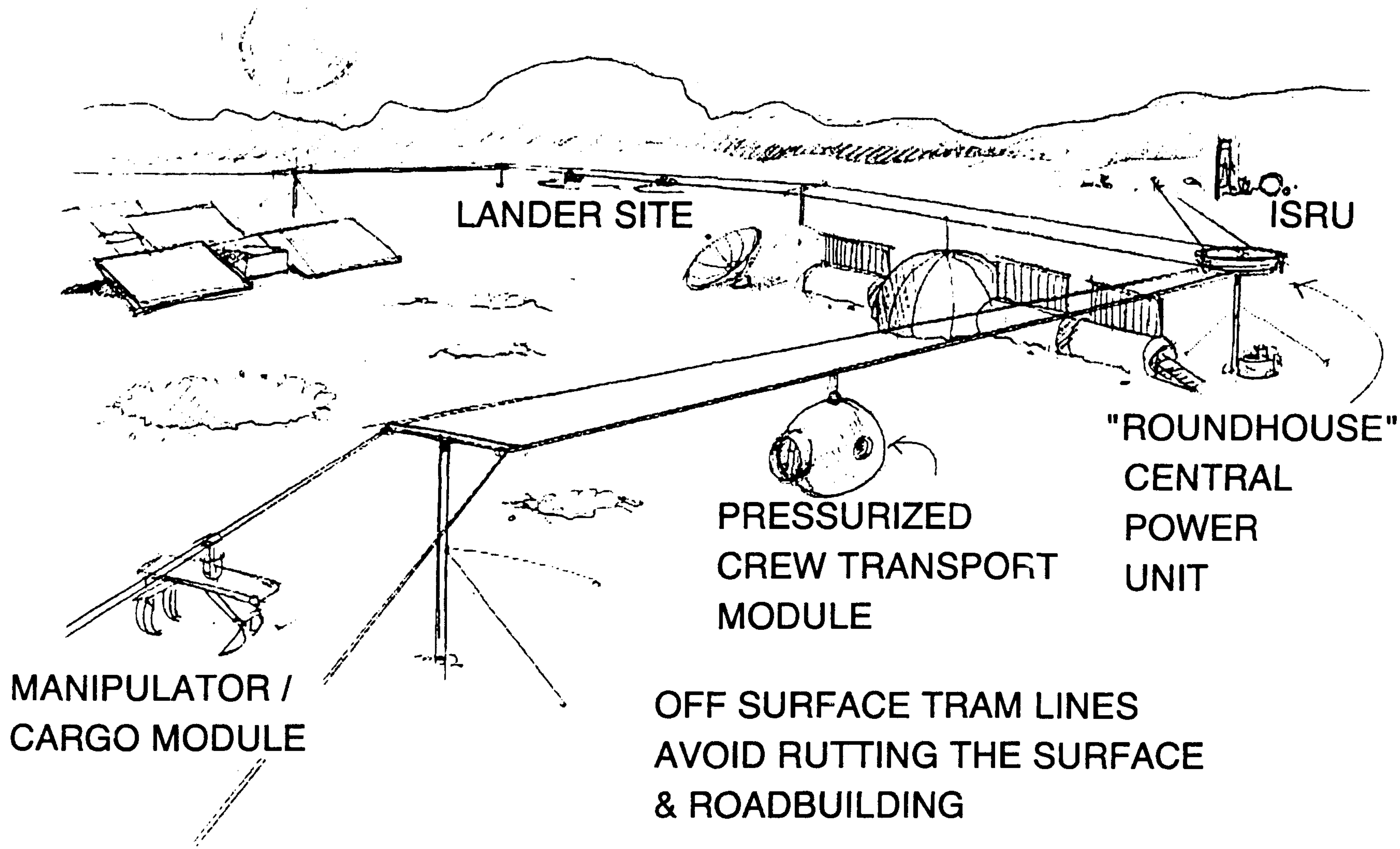

Figure 2.2.2.2. Rover-Based Payload.

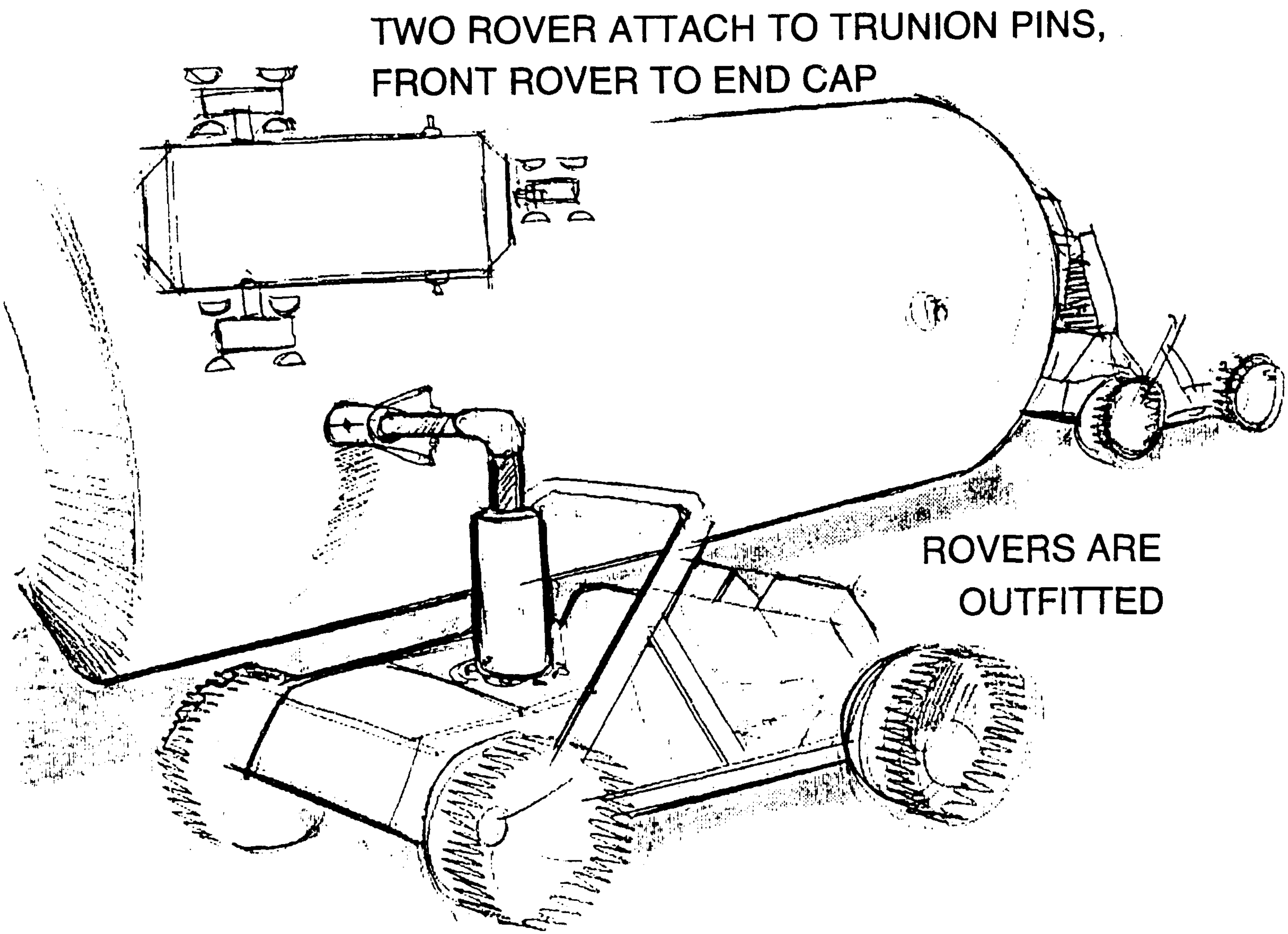

Figure 2.2.2.3. Road Specifications.

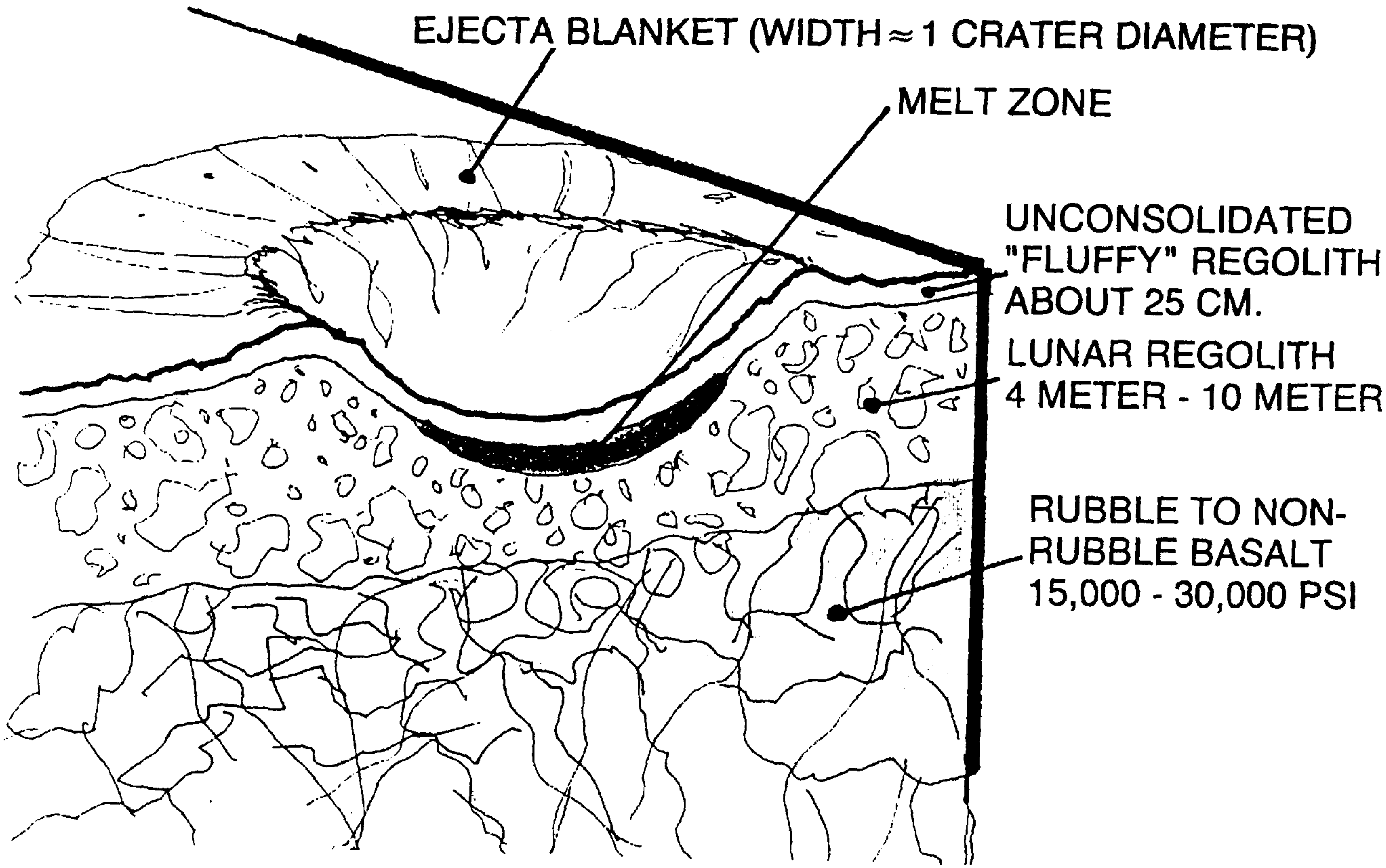

Figure 2.3.1. Generic Lunar Surface Section.

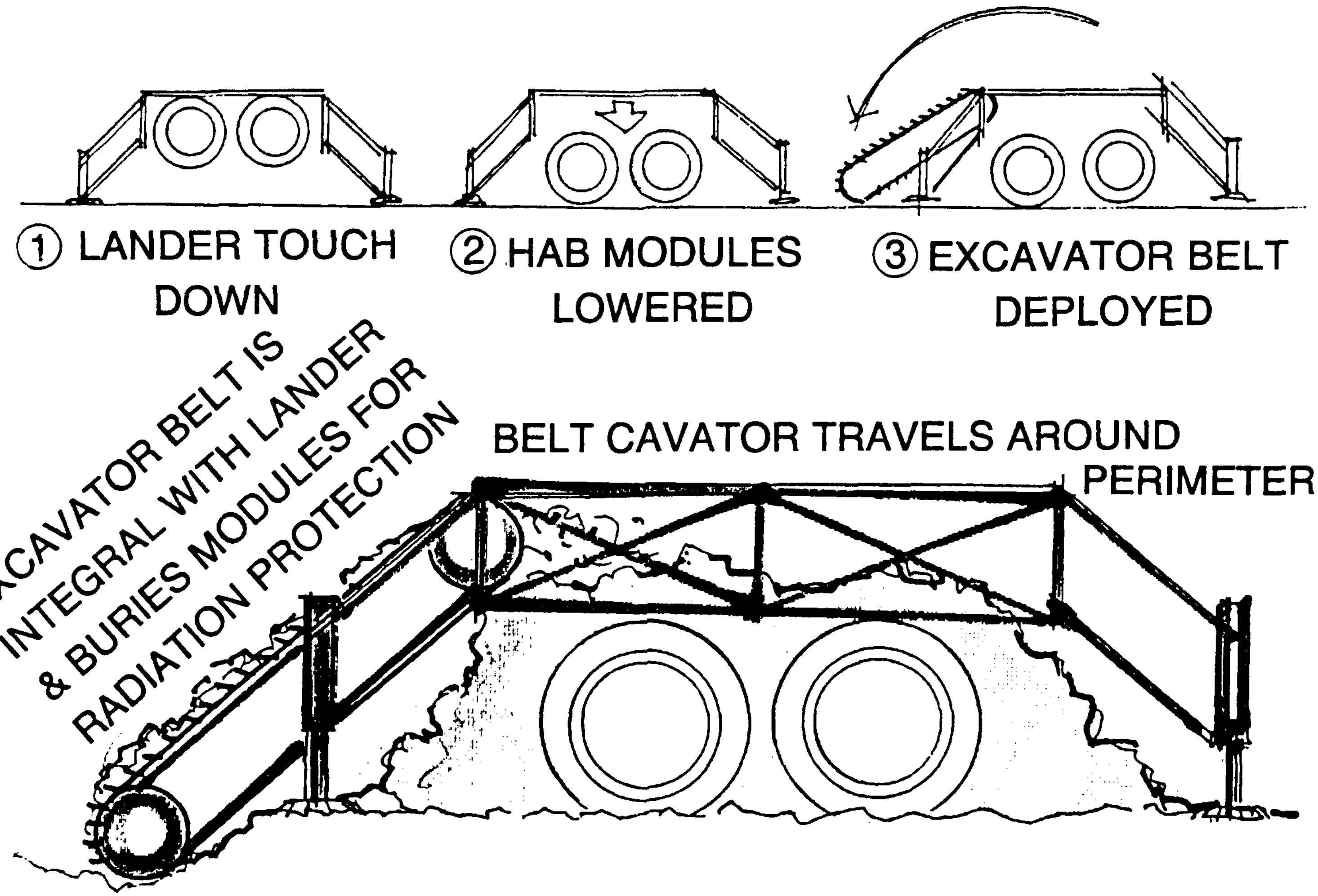

Figure 2.3.2. Lander With Integrated Regolith Excavator.

2.4 Utilities Tasks

Utility emplacement methods were discussed. Four ways of running lines, analogous to terrestrial practice, were documented. Table 2.4.1 describes the advantages and disadvantages of the four methods. Figure 2.4.1 represents these methods graphically.

Table 2.3.1

Habitat Considerations/Analysis

Initial Hab on Lander	
Advantages	**Disadvantages**
Simple operations Quickly deployable safety	Requires radiation protection Limited space Cannot reuse lander easily
Easy to unload Flexibility in location	Operationally complex Long time required to outfit EVA required
Integrate Hab with Rover	
Flexible location Longer traverses Could reduce EVA	Mass Reduced initial weight Dedicated to habitat Complex Requires radiation protection

Table 2.4.1

Utilities Emplacement Analysis

Surface	Below Grade/Bare
Exposed Requires protection Transportation impediment Safety Minimum emplacement effort Accessible for maintenance Expansion/contraction problem	Accessibility for maintenance Requires some emplacement efficiency May be transportation impediment Difficult modification Less expansion and contraction
Below Grade/Vault	**Overhead**
Difficult emplacement More materials protection Very protected Very accessible Not transportation impediment Easy modification Minimum expansion/contraction problem	Intense emplacement Exposed May require protection Very accessible Less expansion and contraction

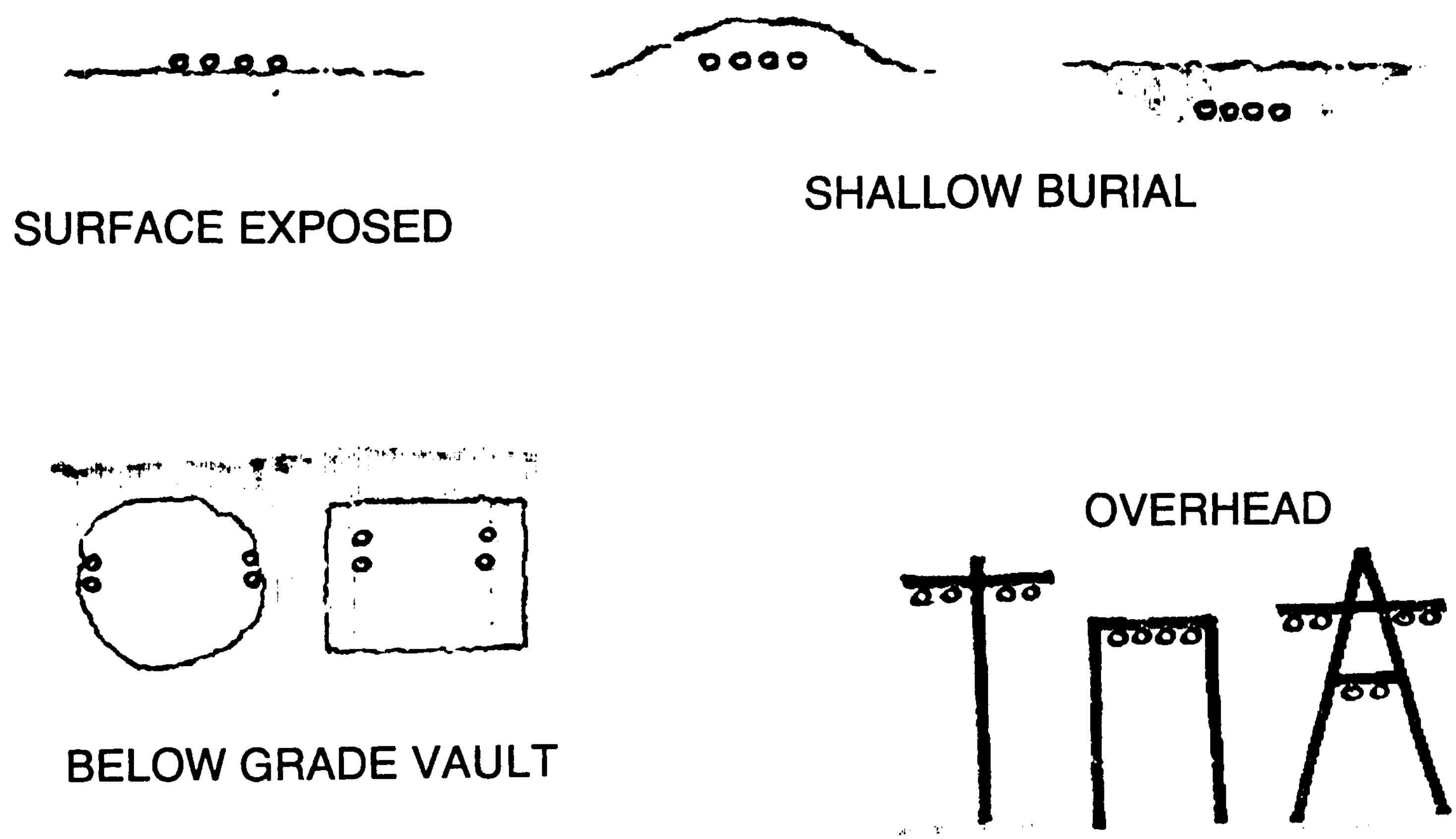

Figure 2.4.1. Utility Corridor Concepts.

2.5 In Situ Resource Utilization

The following In Situ Resource Utilization (ISRU) processes, issues, and equipment needs were covered:

1. Gathering engineering data, at some subsurface depth, of potential lunar sites

2. Focusing the ISRU process from the list of 20 to a few best candidates

3. Creating an energy budget for all elements of mining and construction activities

4. Exploring the concept of phased stages of lunar development in a definite time frame

5. Planning now to establish a proper sequence of R&D to meet the long-term schedule. (Some more distant requirements may need a longer R&D path, which may require an early start. Decision mechanism should be identified.)

Two ISRU processing concepts were described. One was "conventional" in the sense that it has previously been examined. The other process is less well known although some similar terrestrial analogs have been used. Figure 2.5.1 shows the process flow. The conventional ISRU extraction process/facility consists of the following steps:

1. Haul vehicle dumps on regolith grizzly into hopper. ("Oversize" goes to waste disposal area.)

2. Bucket conveyor transports to dry separator. ("Reject" goes to waste disposal area.)

3. Gravity fall from separator to preheating bin.

4. Screw convey to universal vat/furnace.

   a. If magma electrolyses, a furnace will be needed.
   b. If chemical process, a furnace will not be needed.

5. At modest heat level, surface gases are driven off.

6. Gases pass through preheating bin via heat exchange coils to gas separation (H, He, etc.).

7a. Elevate heat to melt ore if magma electrolysis. Collect fluid products.

7b. Complete chemical process if a magma electrolysis process is not used. If H_2 is added for extraction, collect H_2O.

8. Water collected passed through electrolysis process to recover H_2 (for recycle and O_2).

Required equipment for the process includes:

1. Coarse screen (grizzly)

2. Hoppers

3. Bucket or other simple conveyor

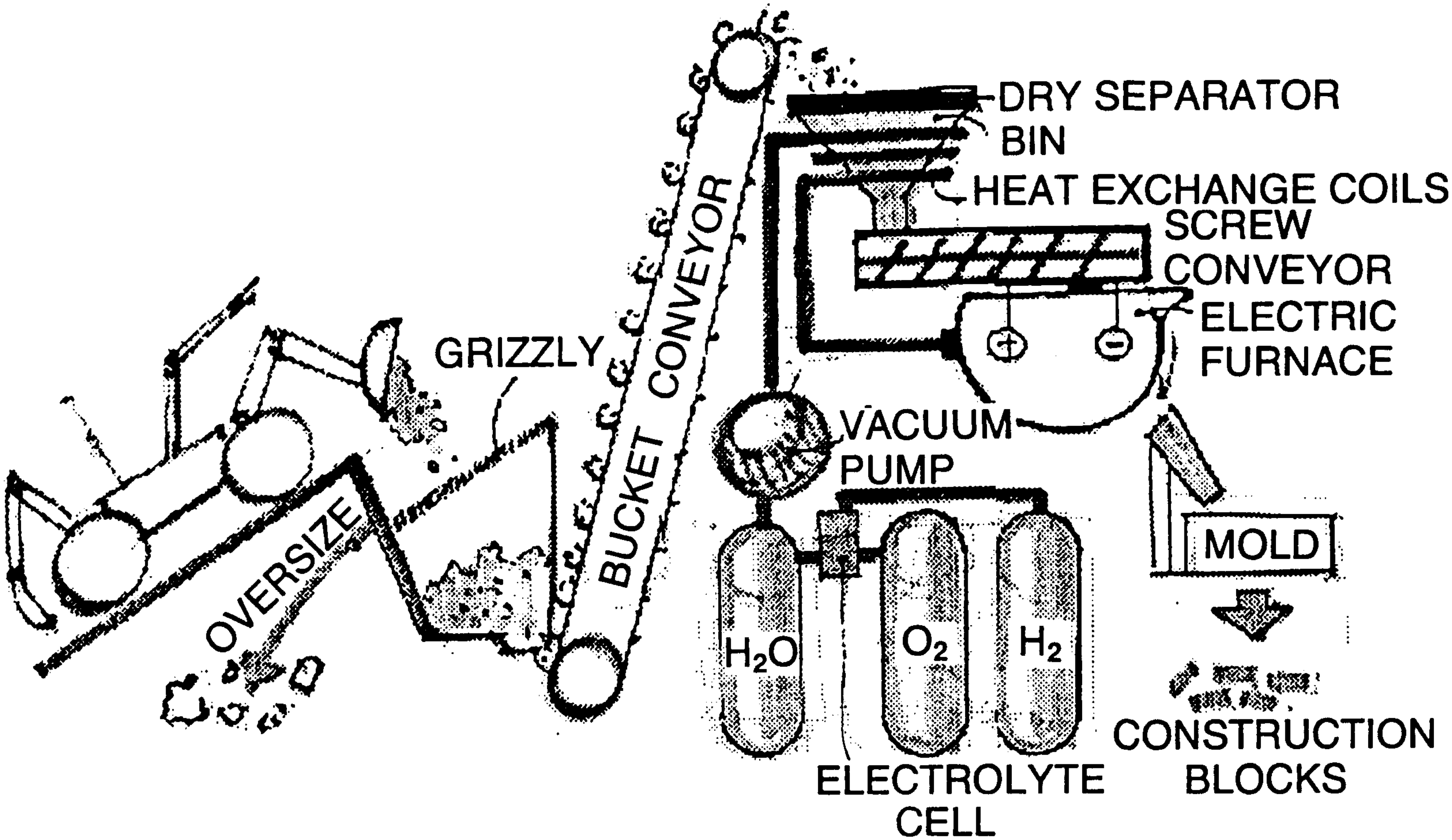

Figure 2.5.1. ISRU Initial Facility.

4. Dry separator (electrostatic or magnetic)

5. Screw conveyor

6. Heat transfer coil

7a. Furnace, ceramic-brick lined moly, titanium, or platinum cathodes/anodes capable of being tilted for pouring

7b. Nonfurnace vat (simple tank with simple electrical heat to recovery surface gases)

8. Storage tanks at pressure

9. Electrolyses unit separating the water into H_2 and O_2

10. Molds for metallic product or other waste to be converted to construction products.

Technical issues relevant to implementation of this conventional concept are:

1. Performing a process selection critical to further equipment design, including: (a) energy tradeoffs, (b) capability of dry separators, depending on material being processed and the process, (c) heating vs. chemical processing.

2. Devising an energy budget, including a trade-off of energy consumption for crusher (for underground ore) and energy savings for other uses of underground openings

3. Outlining heat sources for furnace (microwave vs. electric).

Either of these sources could be fully automated. However, both would be heavy power consumers, would require resolving problems of sealing/gas capture, and would entail the transport of heavy equipment from earth.

A less conventional concept for an in-situ ISRU process was described. In it a "solvent" is pumped into a well in the regolith or rock. The solvent is selected to dissolve or react with the desired mineral constituent. The resulting solution is pumped out of the well and processed to separate the desired product; the solvent may be recycled. The process, shown in Figure 2.5.2, would follow these steps:

1. Drill wells into regolith and/or hard rock; cased and grouted (If hard rock, generate fracture zone with a microwave).

2. Inject solvents (for example H_2) in series of wells under pressure.

3. Draw fluid product out of adjacent series of wells, probably with vacuum pump.

4. If water is the recovered product, pipe to electro-separator.

5. Store O_2, recycle H_2 to injection wells.

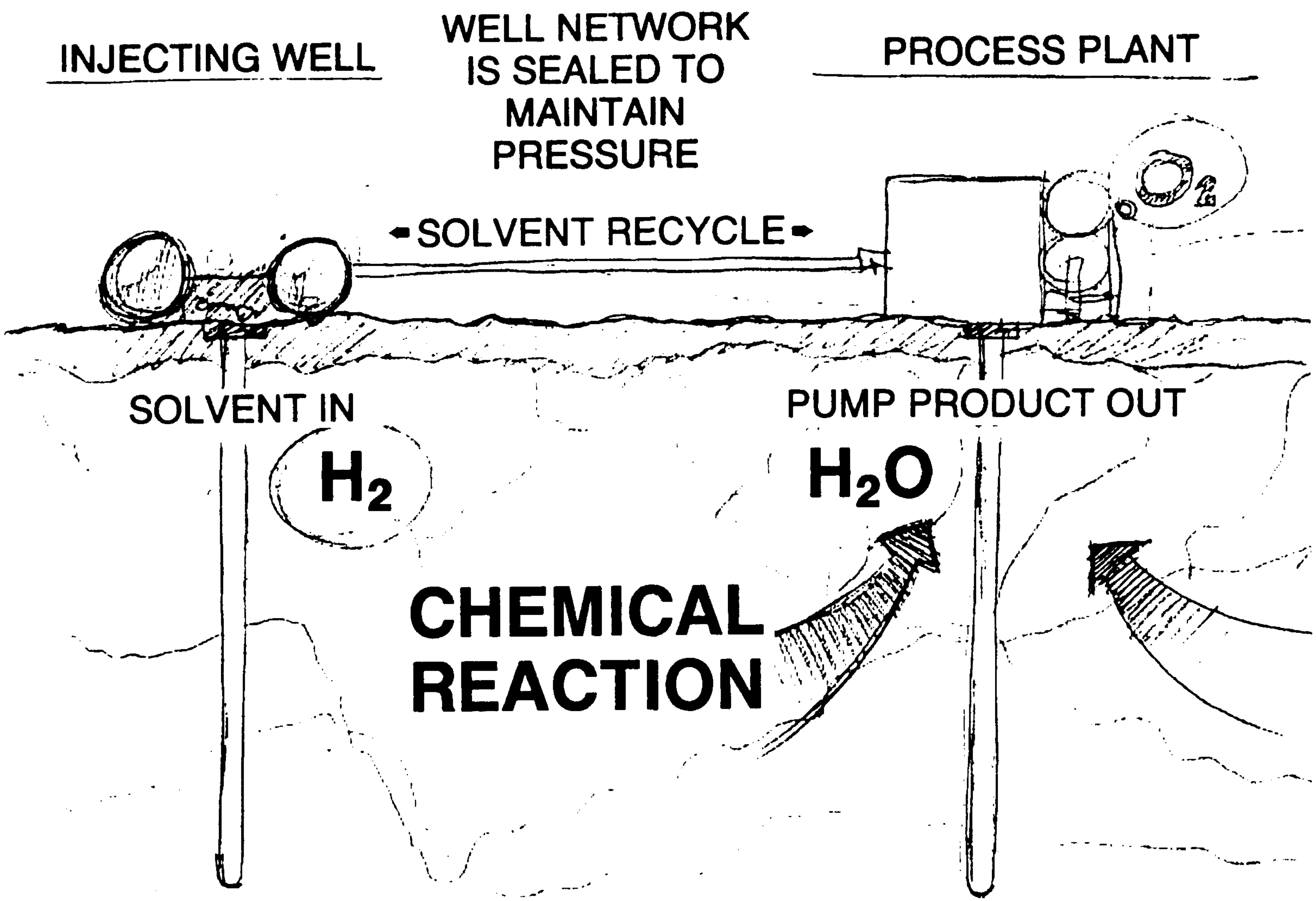

Figure 2.5.2. In-Situ Injection Processing.

Required equipment for the process would include:

1. Well casing
2. Grout
3. Pressure pumps
4. Suction or mechanical "vacuum" pump
5. Pipe manifold system
6. Unit for separating (recovery) desired product for solvent (O_2 from water).

Technical issues involved in this process are:

1. Determining the right pressure distribution to be created underground to assure recovery of fluid product

2. Examining the possible processes that will allow the reactions to take place at ambient conditions

3. Sealing of well heads with grout

4. Gaining the ability to generate controlled fracturing in rock, if method is to be used in rock.

This new technology would require research that may be justified by the simplicity of the process, the small size and mass of the equipment, and its modest energy requirement.

2.6 Mining Methods and Equipment

The two very broad categories are surface or pit mining, and subsurface (underground) mining were discussed. The excavation equipment required to perform the mining may be very different for the two cases. Relative characteristics of underground and surface mining are listed in Table 2.6.1.

Many aspects and factors must be evaluated to choose between subsurface or surface mining (Table 2.6.2). One important consideration is that the underground area excavated for mining may be used later as an area for constructible habitat. Figure 2.6.1 illustrates this concept. Once in full-scale operation, the

Table 2.6.1

Relative Characteristics of Underground and Pit Mining

Underground	Pit
• Provides radiation protection • Temperature stability • Meteorite protection • No diurnal cycle • Simplified vehicle design (temperature) • Maintenance of vehicles simpler • Thermal management may be easier • Less environmental effects on surface	• High ground support requirement • Sealing for "shirt sleeve" may be difficult • Access/egress problem • More energy intensive • Complex operating conditions • Utilities runs • Large volume to fill with air • Need geotechnical info to depth • Dust control • Productivity lower (initially) • High initial mass

Table 2.6.2

Underground Mining Methods Analyses

Advantages	**Disadvantages**
Auger	
• Operates dry • Simple • Can bore vertically • Less energy than thermal • High productivity	• Works only in soft rocks or soil • Spoils disposal (true of any highly productive method) • Portal required • Roof support may be problem
Microwave	
• Can change frequency and seal surface • Can excavate hard rock • May do in situ processing	• Energy intensive • Complex safety problems • Can't control particle size • Maintenance of unit
Mobile Miners *	
• High productivity • Well understood method • Lower transportation • Muck size favorable • Operates dry • Produces relatively smooth walls	• High mass • Complex and/or traction problems • Maintenance intensive • Dust producing • Flexibility of operation depends on type
* Examples: Continuous pick drum miner tunnel boring, road header, splitter, and long wall shearer.	
Drill and Blast	
• Low energy/high efficiency • Operationally simple • Lower mass • Low technology • Flexible • Can automate drilling • Productivity medium to high • Very cyclic	• Safety • Requires local resources • Drilling difficulties • Vibration induced damage to seals/structure • Small muck size • Time
Impact Projectiles	
• Mechanically simple • May use with shape charge	• Method of projecting (rail gun or other) • Not well understood for rack mining
Fluid Fracture	
	• Pressurized fluids hazards

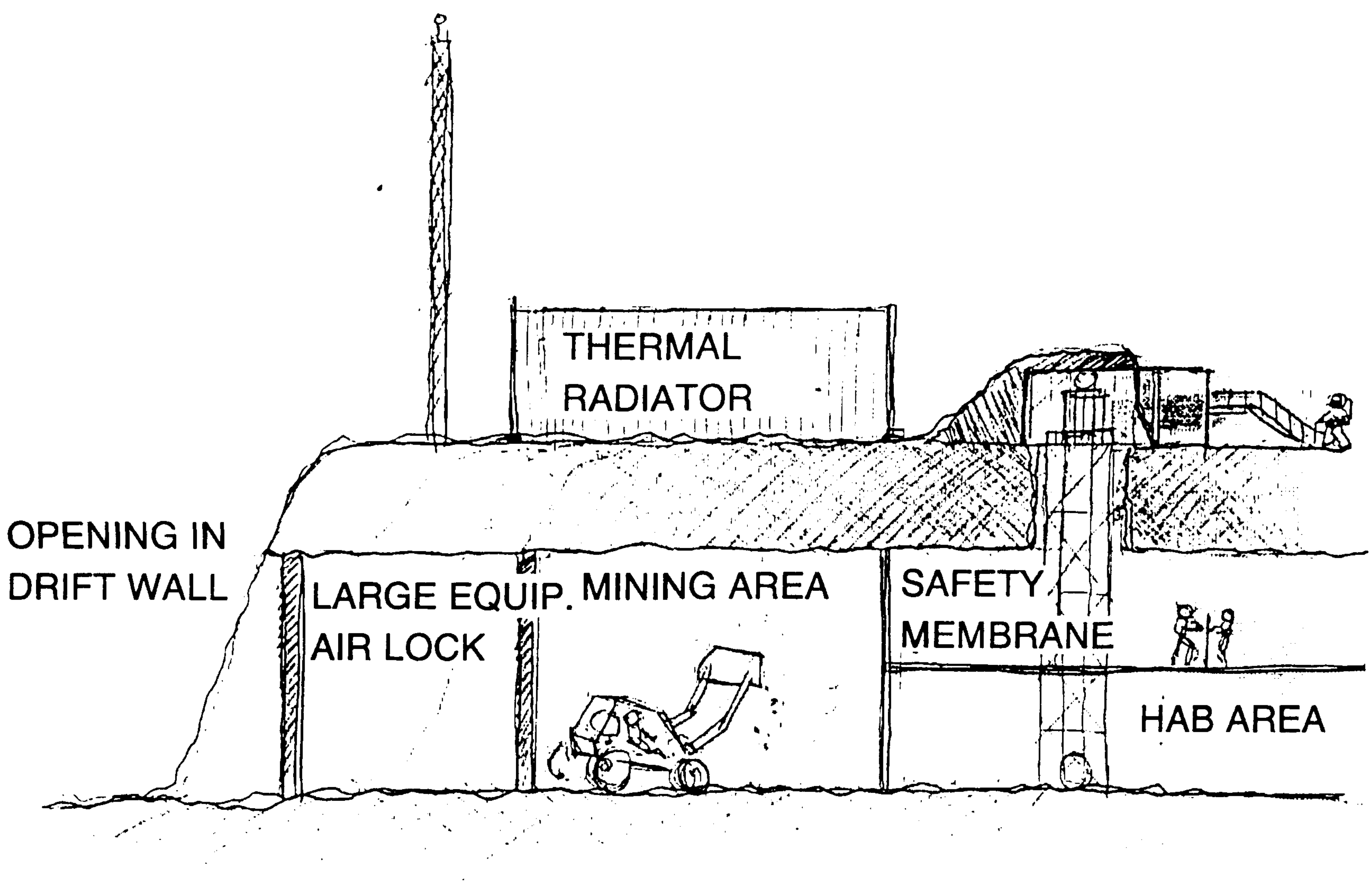

Figure 2.6.1. Subterranean Shirtsleeve Environment.

productivity in the underground mine can be high. All underground mining will require a lot of infrastructure. For example, specialized tunnelling/mining equipment, means of excess rock removal, power distribution, etc., are likely to be more complex than will be required for surface mining.

Several underground mining techniques and equipment were compared to each other. Whether a method will work sometimes has a strong dependence on the competency (compressive strength) of the rock. In general, rock with a compressive strength greater than 30,000 psi is considered hard (competent), e.g., granite and basalt. Rock with a compressive strength less than 10,000 psi is soft, e.g., sandstone, tuft, coal, concrete, and some limestones. The following comparisons and positive/negative features are relative to other underground mining methods. Figures 2.6.2 through 2.6.4 illustrate some of the discussed alternatives. Operational questions were raised on whether underground mining should be done by humans, robots, or automated machines. The response was that no broad, generally applicable answer could be given. Whether a man-rated shirt-sleeve environment can be developed within a mine tunnel, and possible means of sealing a tunnel were discussed, will require future study. Several terrestrially-used methods for supporting mine roofs were suggested: (1) self-supporting by size/shape, (2) supports made of local resources ("timbers"), (3) microwave or thermal scaling, (4) lightweight rock bolts, (5) cable bolting with grout and (6) shotcreting. The competence of the rock is a significant factor in evaluating and selecting a preferred mining method.

Surface mining methods and equipment were reviewed. Figures 2.6.5 through 2.6.8 show some of the equipment. The types of equipment were compared relative to trenching, leveling, excavating and covering (piling up regolith). Table 2.6.3 compares the equipment only against other pieces of surface equipment surface. It should be noted that direct comparisons cannot yet be made because of variances in mass, power, complexity, and maintainability of the various methods.

2.7 Construction and Mining Concepts and Equipment Design Session Summary

As yet, too many variables exist to select a favored method of surface mining or to rank the methods by preference. However, loosening or deconsolidating regolith before attempting to dig it, is favored over forceful penetration such as with a clamshell or front-end loader.

There are many common tasks shared in both construction and surface mining excavation activities, especially in the early development of a base. One piece of equipment may be alternately used for both tasks. As the magnitude of the mining increases, however, specialized equipment for mining will be warranted.

The following general observations were made:

1. The current plan to select a lunar outpost site based on lunar-observing orbiter data lacks the multiple coring samples required to characterize surface and subsurface properties.

2. All lunar construction and mining operations must be verified in a relevant Earth test environment before beginning emplacement on the Moon.

3. All equipment shall be designed to do multiple/overlapping tasks (i.e., so no single piece of equipment will sit on the sidelines unused during any phase of activity). The equipment used to excavate for construction, if possible, should be used for mining later.

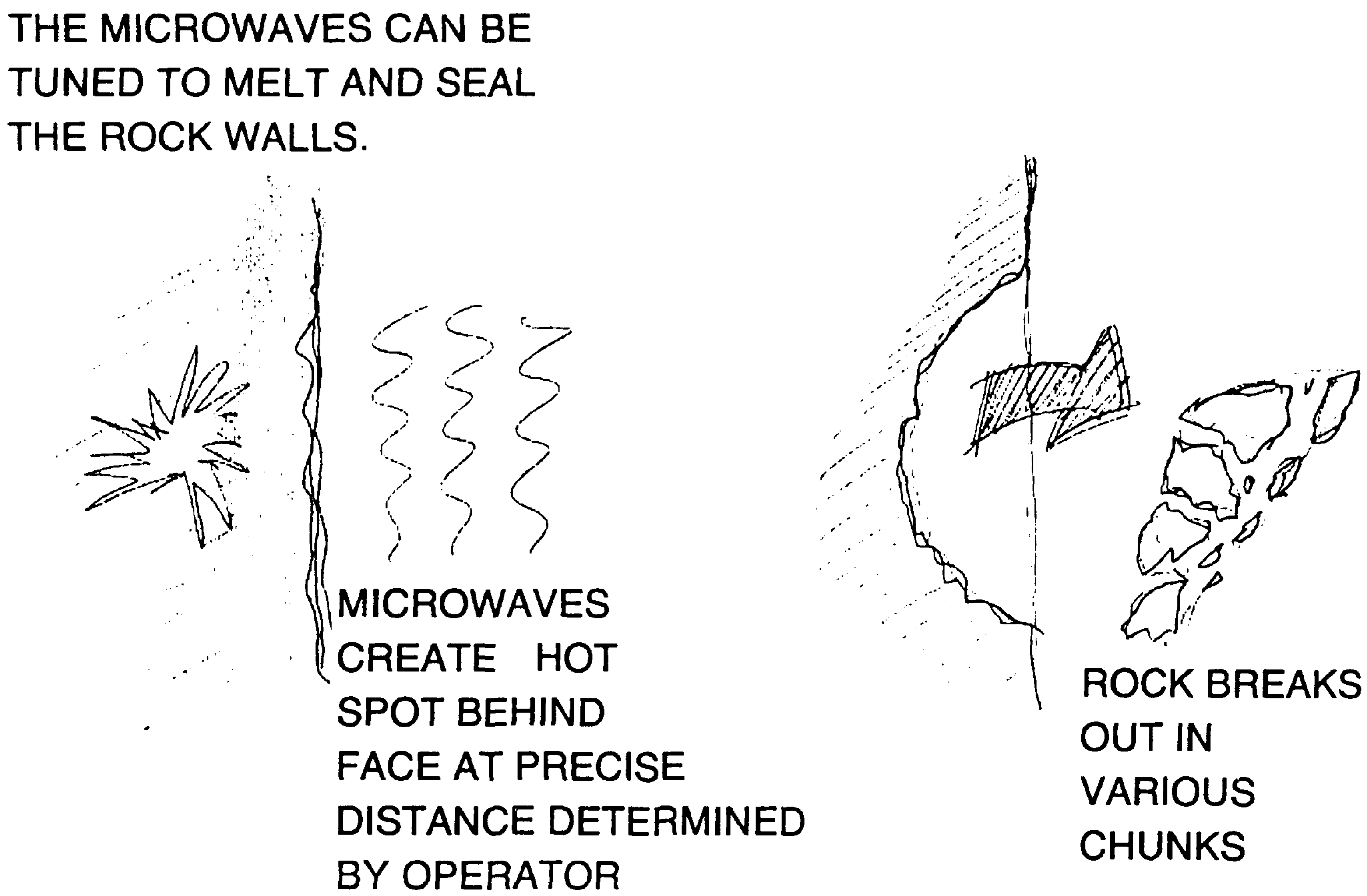

Figure 2.6.2. Microwave Tunneling.

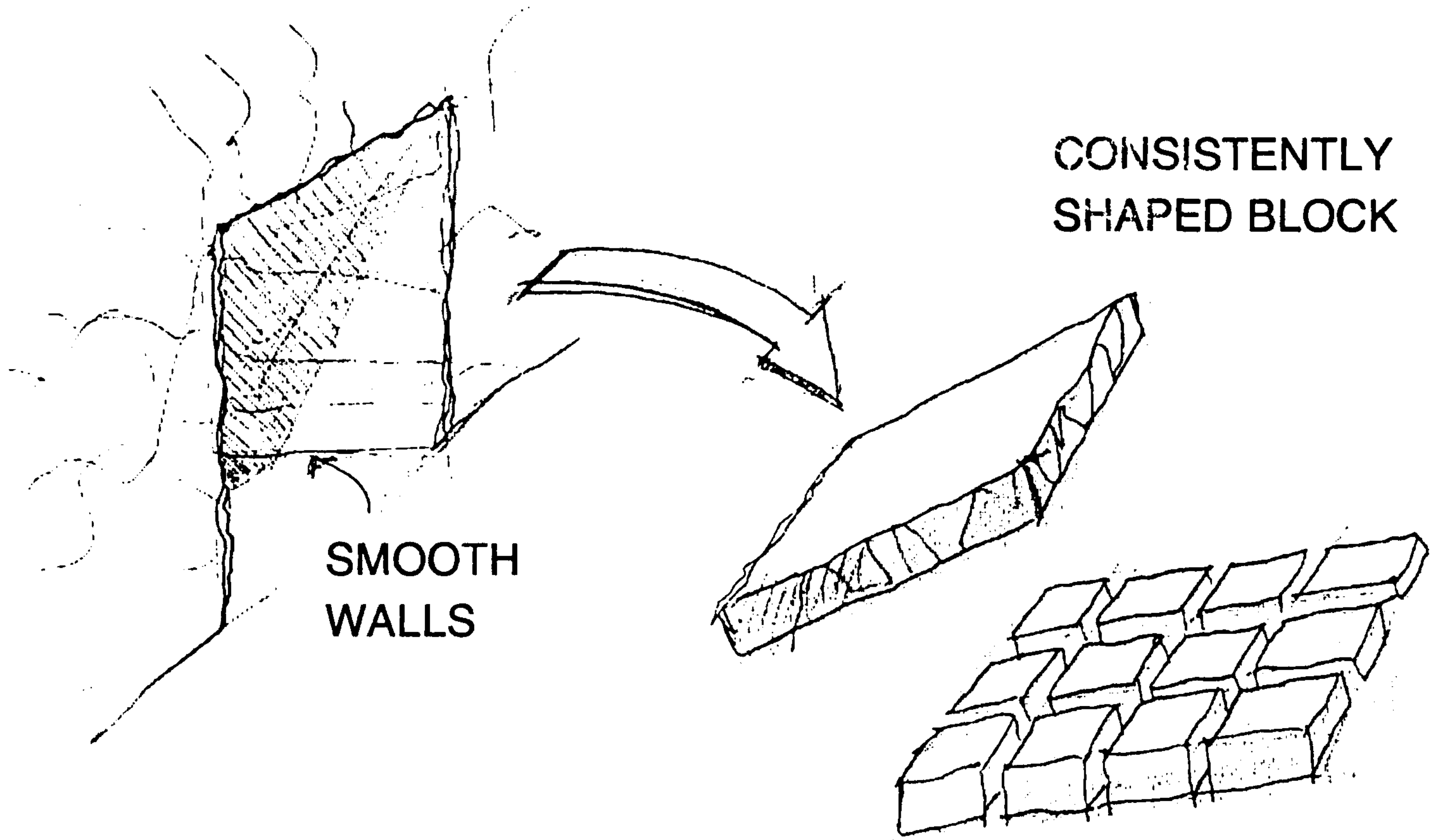

Figure 2.6.3. Laser Tunneling.

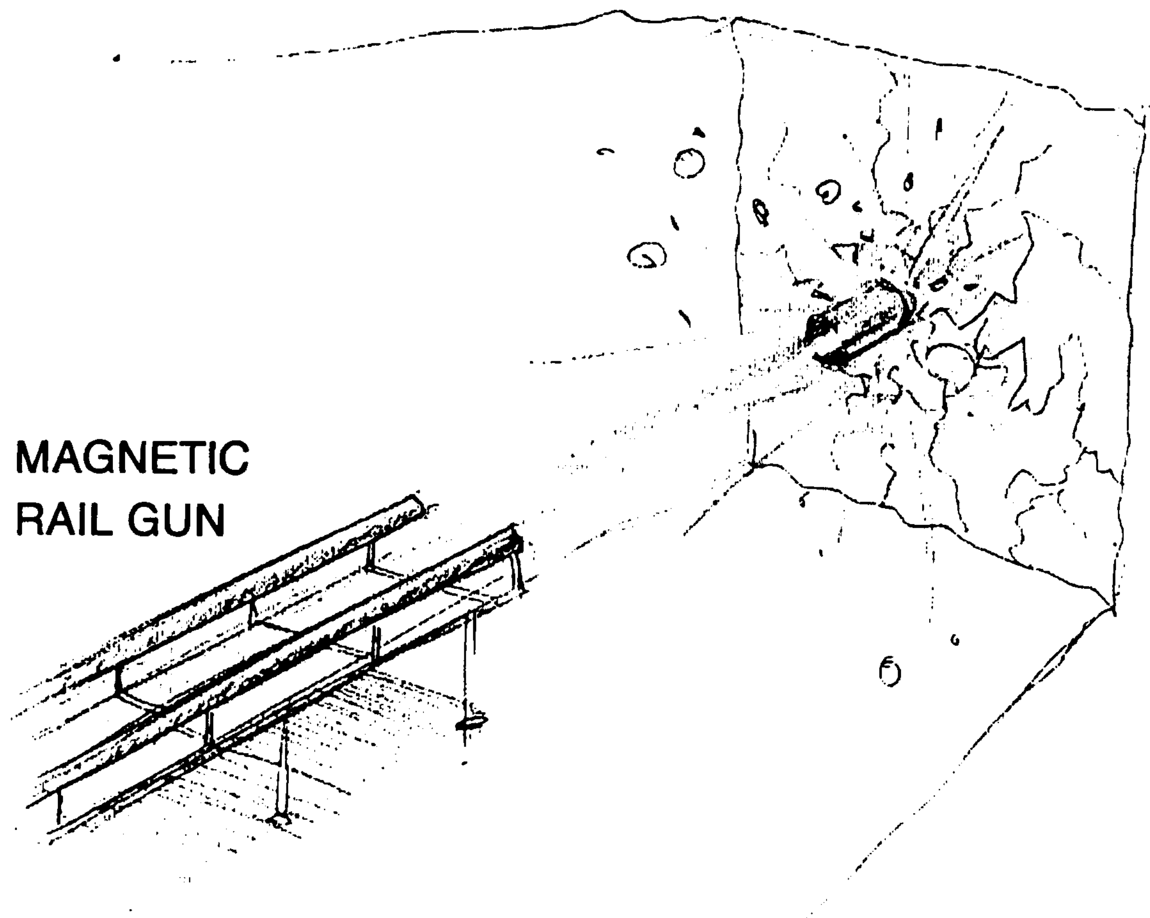

Figure 2.6.4. Projectile Tunneling.

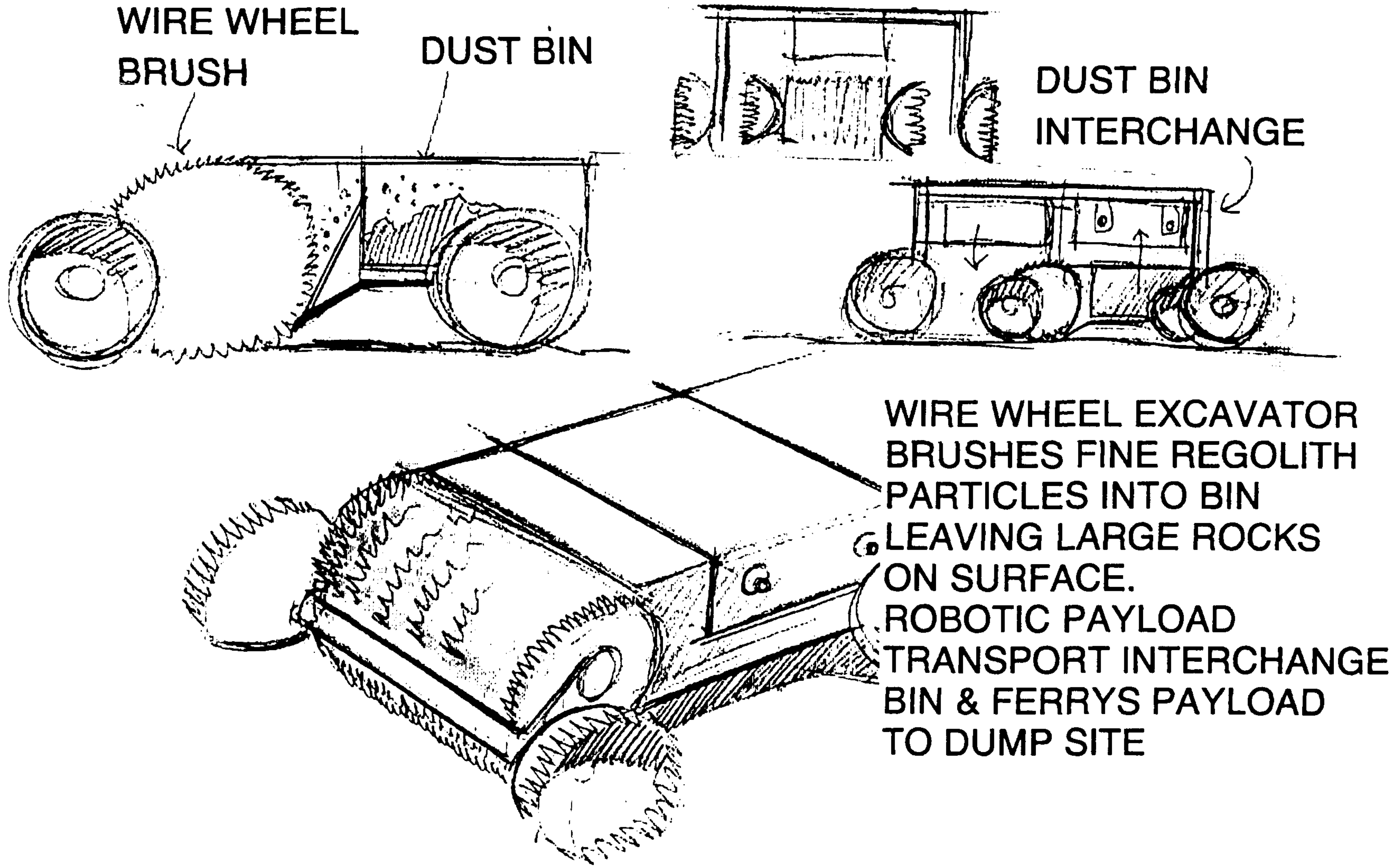

Figure 2.6.5. Wire Brush Regolith Excavator.

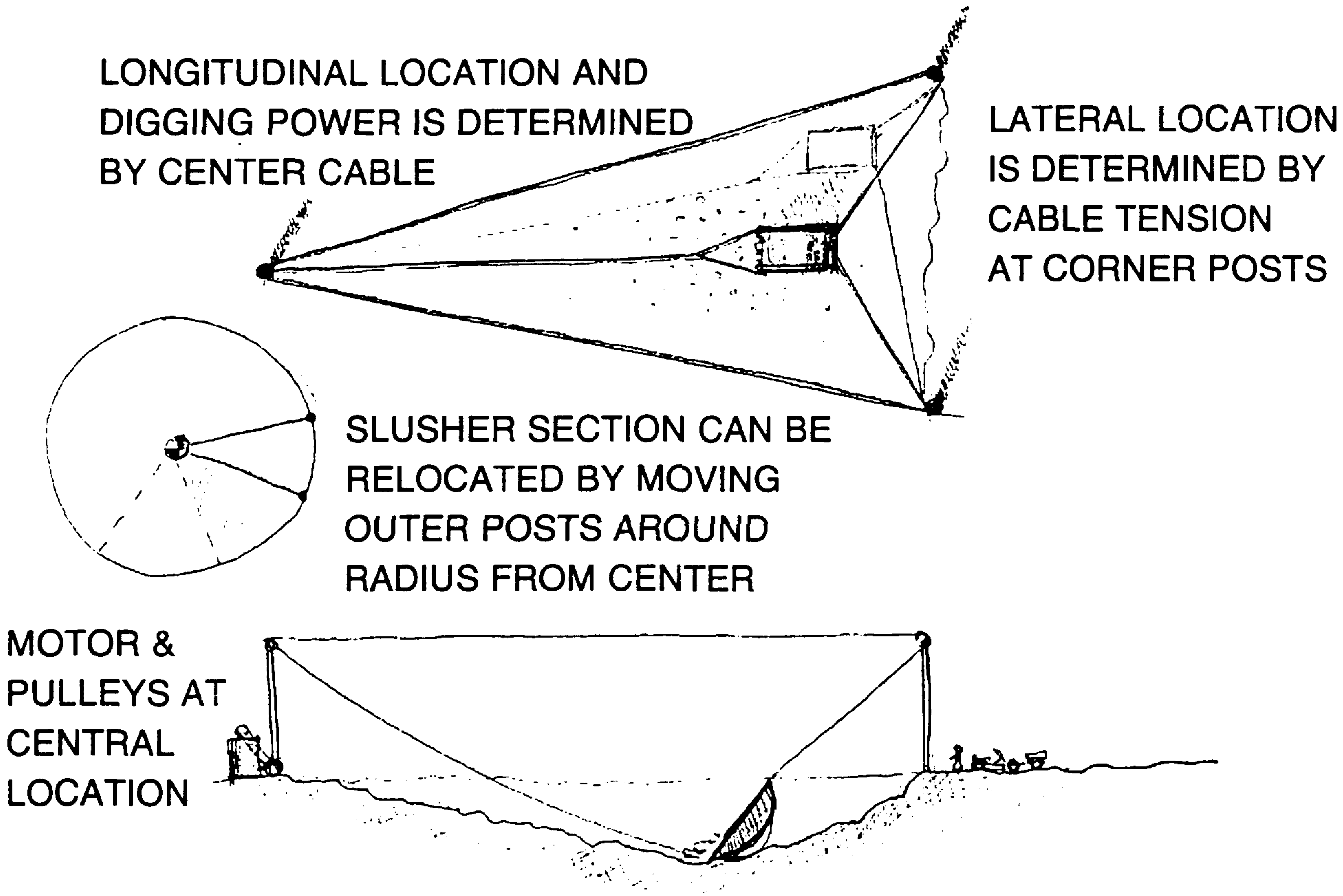

Figure 2.6.6. "Slusher" Excavator.

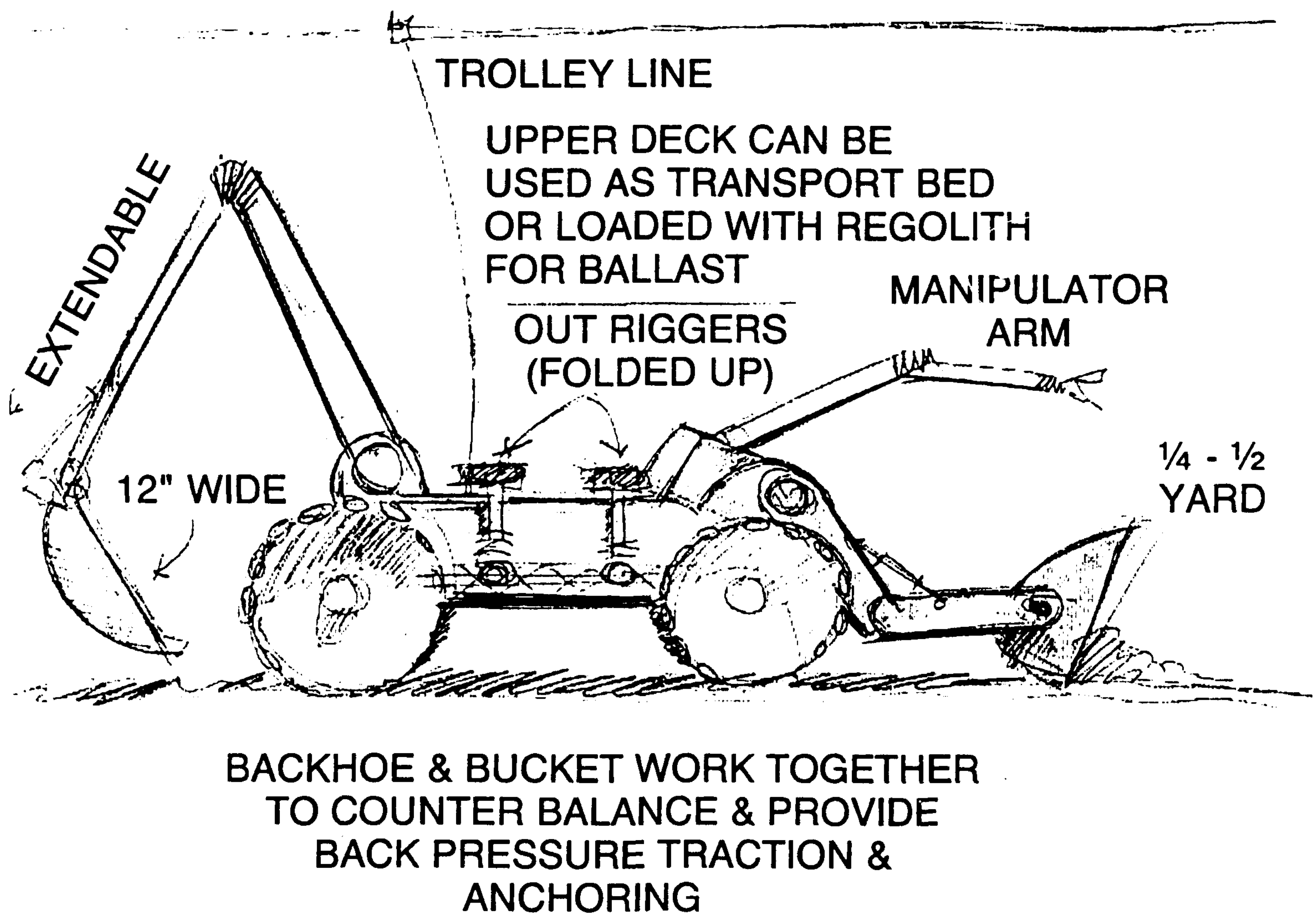

Figure 2.6.7. Multipurpose Construction Rover.

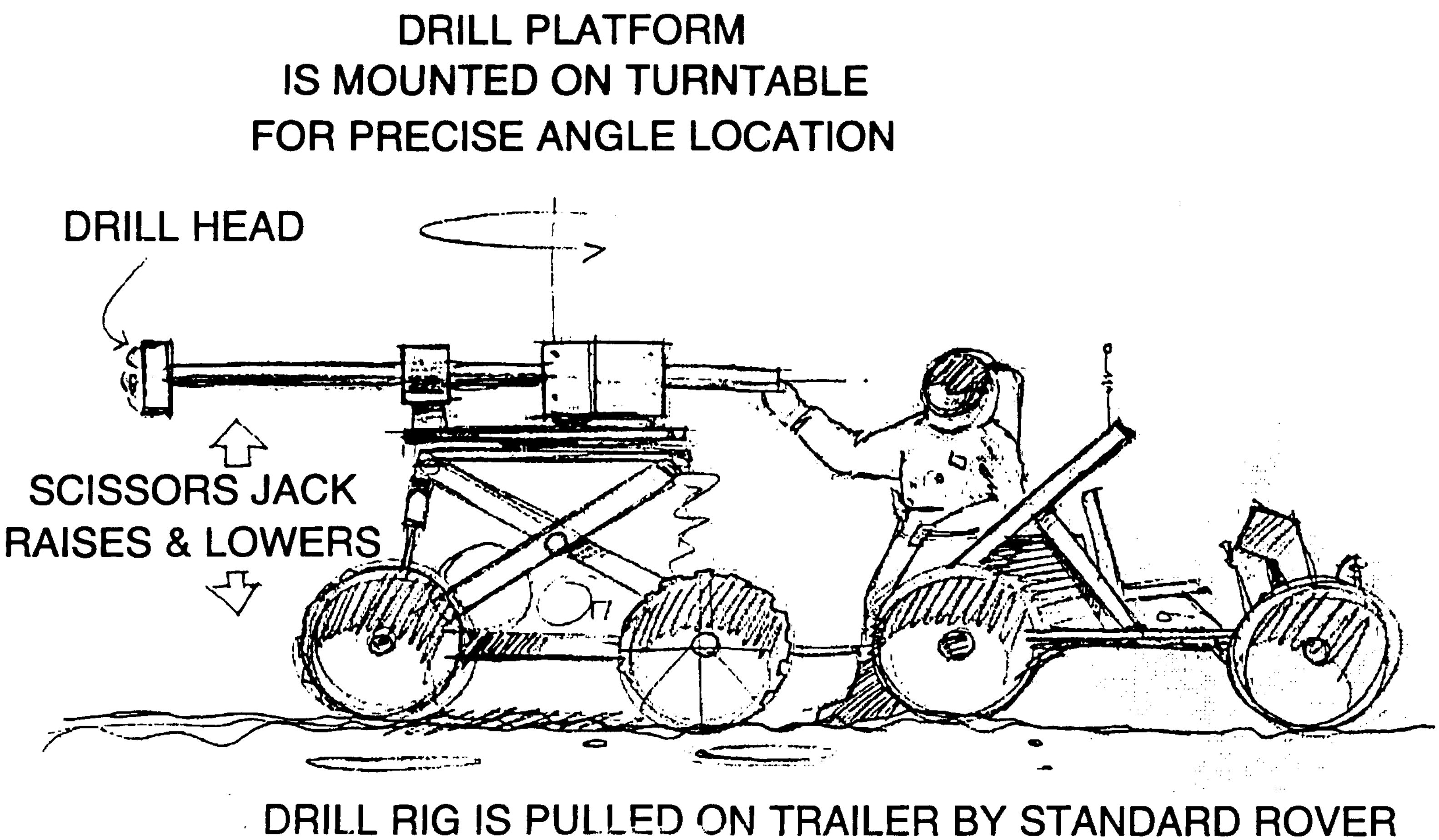

Figure 2.6.8. Horizontal Drill Rig.

4. Automated equipment must be operable remotely by humans, down to the surface level, and possibly by onboard humans.

5. The number of distinct machine types necessary to perform lunar surface operations should be minimized. Provide equipment depth by having an appropriate "fleet" of vehicles.

Table 2.6.3

Surface Mining Equipment Analysis

Equipment	Trenching	Leveling	Excavating	Covering	Comments
Backhoe	+	-	+	+	
Clamshell	0	-	+	+	
Bulldozer	0	-	+	+	
Ripper					Primarily used to loosen soil or soft rock
Front-end loader	-	+	+	+	
"Snow" blower	-	0	-	0	
"Weasel"	+				Form of ripper (cultivator)
Scraper	-	+	+	-	
Explosives	+	-	+	-	
Auger	-	-	-	+	
Disc					Form of ripper
Harrow	+				Form of ripper
Slusher	+	-	+	+	
Potato picker	+				Form of ripper
Cherry picker	-	-	-	+	
Bucket wheel excavator	+	-	+	0	
Wire brush	+	0	+	0	
Flail	+	-	+	0	

Notes: + = relatively better than other surface equipment for the identified task
0 = relatively equal to other surface equipment for the identified task
- = relatively worse than other surface equipment for the identified task

3 DESIGN STANDARDS AND CODES

3.1 Goals

The workshop goals of the Design Codes and Standards group (group D) were to: (a) develop a detailed outline showing the pertinent features needed to design a facility for the lunar and martian surfaces, (b) organize the outline in a logical, procedural way, and (c) provide brief descriptions for each listed major category.

The long-range goal is to develop a set of guidelines and reference material that will promote consistent, economical designs that can be easily reviewed by knowledgeable peers. This is not a checklist or cookbook approach that merely says "if your design satisfies the checklist, it's okay."

3.2 Discussions

Initial discussions centered around defining and clarifying "codes" and "standards." The group recognized the legal aspects of codes. Codes generally provide a minimum standard of design and represent a mature understanding of technology applied to known needs in known environments. A code is a distillation and collection of research results and experience.

R&D generally applies basic principles of science and engineering to projects that advance the state of the technology. The Apollo project is a classic example of a successful R&D effort. The next step in the evolution of technology after R&D is to broaden the user base. This results in the creation of design guidelines.

If there is an economic market for the researched product, associations are formed and research is sponsored and collated into standards. Eventually, if the market is large enough and the impact on society sufficiently great, codes evolve. The evolution of codes is generally a dynamic process involving tensions between practioners, and constructors, motivated by the potential for litigation. Consequently, the development of codes implies the existence of a funded organization with a vested interest in the development of a legal document.

The development of standards is often based on a large body of experimental data. This implies the need for test facilities. In addition to the development of the database needed to validate the design methodology, there is the need to develop tests to validate the construction or manufacturing process.

Codes endorsed by governmental agencies indirectly try to determine what a human life is worth. Standards created by associations try to define acceptable risk. Risks related to a lunar base include human risk, risk to mission completion, and risk to mission or architecture infrastructure.

3.3 Guidelines, Criteria, and Standards

The group decided there is a need for design criteria, guidelines, and standards.

The first attempt to define criteria produced the following categories:

1. Loads
2. Materials

3. Analytic methods (links loads to materials)
4. Environments
5. Equipment.

Designs are derived by a combination of principles and concrete constraints. Figure 3.3.1 suggests some of the factors that flow into a design. Figure 3.3.2 shows how a design is used in a mission.

Since earlier space missions (i.e., Viking) did not have standards and guidelines, there was some doubt as to whether they were needed for a lunar base. However, it is assumed that a lunar base would involve many firms and agencies in addition to NASA, and that some uniformity of approach among contractors will be desired if not required. The hope is for multiple facilities with components to be built over an extended period of time. This requires some standardization and/or documentation of approach. A manual of common practice or guidelines is thought to be preferable to each contractor developing a separate preliminary safety analysis and a final safety analysis detailing design assumptions and approach.

Discussion of standards centered on the need to adapt current standards rather than repeat previous work by devising new ones. Various standards are:

- ASTM
- ANSI
- MIL-STD's (Military Standards)
- NASA.

There was some debate about the cost effectiveness of MIL-STDs and NASA standards for constructed facilities. This discussion highlighted the different philosophies underlying codes and standards developed by government agency and those developed by commercial industry. For example, one group member thought it might be necessary to specify the correct functioning of a light switch (e.g., up for on); beyond that, an explanation of common practice would be sufficient to ensure that switches would be installed correctly. (The proper installation procedure for a three-way switch was not discussed.)

There was agreement that both awareness and reference to standards for ergonomics (human factors) were needed for operations that involved humans in unusual situations such as in space suits (thick gloves) or emergencies.

The group decided to rely on adapting current terrestrial standards to the lunar and martian conditions to work from the known to the unknown. Table 3.3.1 relates some existing codes and standards to the requirements they include.

Based on existing codes and standards, a number of questions were framed to help create, adapt, or adopt lunar and martian design criteria and standards:.

- How should standards be screened for reasonableness and applicability?
- What is missing (from the existing standards) for the design and construction of a lunar base?
- How should innovations, new materials or processes be accepted into the guidelines, standards and manuals?
- What is missing from existing standards?

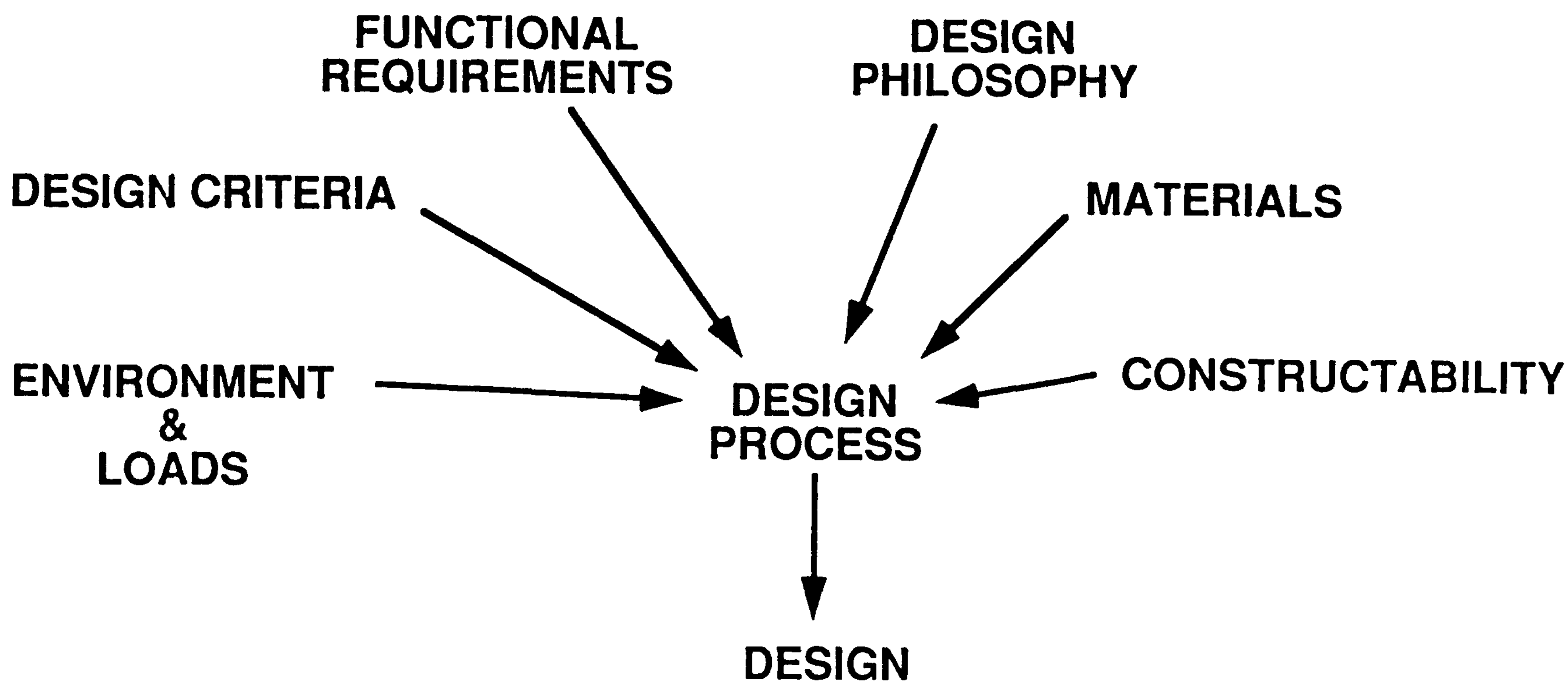

Figure 3.3.1. Sample Factors That Influence a Design.

National Goal

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Architecture for

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National Goal

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Facility Goal

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Functional
Requirements

.

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Design Philosophy
(Methodology)

.

.

Product Design

.

.

Product Construction

Figure 3.3.2. Hierarchical Breakdown of Uses by Design.

For example, missing factors might include:

1. Interface between flight vehicles/structures (cargo)

2. Interfaces between surface vehicles and facilities
   a. Treads
   b. Docking
   c. Weight or footprint pressures

3. Return periods for
   a. Solar flares
   b. Meteor showers (comets)

4. Eclipse thermal shock (see rate of change in loads)

5. Tool Specifications
   a. Need to address the lack of gravity
   b. Anchorage for operations in space
   c. Minimize number of tools
   d. Specialized tools required by transportation.

Table 3.3.1

Potential Applicability of Terrestrial Standards and Requirements

Code	Requirements						
	Functional Constraints	Environments and Loads	Materials	Methodology	Design Philosophy	Construct-ibility	Construction Requirements
American Concrete Institute (ACI) 318		Load comb.		yes			yes
American Institute of Steel Construction (AISC)		Load comb.	yes	yes			yes
Boiler and Pressure Vessel Code (B&PVC)		Load comb.		yes			yes
American Society of Mechanical Engineers (ASME)			yes				
ASTM			yes				
ANSI		yes		yes	yes		
Universal Building Code (UBC)	yes	yes		yes			yes
American Association of Under-ground Space Utilitization (AASU), Mining	Specification detailed in the Code of Federal Registry. Design is generally for a finite life; other underground construction such as water tunnels have a longer life specified for the design process.						

The Corps of Engineers has current design manuals and procedures for construction. These manuals could be used to model and to provide a starting point for creation of new manuals and procedures for the Moon and Mars. A generic model approach could be used; there is a databank (query/system) possibility for cross-referencing and finding manuals electronically.

3.4 Criteria Needs

The working group identified some of the reasons criteria and standards are needed. Tables 3.4.1 through 3.4.6 itemize the reasons and lists of contributors to consider. Note that these lists are not exhaustive and are intended to be representative only.

3.5 Design Standards and Codes Session Summary

The group concluded that there is a strong need for design criteria, guidelines, and standards for lunar and martian construction, mining and equipment. Further, there is a need to educate engineers in the use of this data.

A lingering question exists, however, over the responsibility for generating, maintaining, and enforcing the use of adopted standards. The answer was not clear but there was a feeling that the responsibility should be vested in a non-government entity (e.g., like one of the previously cited standards organizations) since the documents may tend to be complex and their maintenance very expensive. Clearly a group is needed to evaluate existing standards to determine exactly what is available and what is needed.

Table 3.4.1

Need for Criteria/Standards: Accident Conditions

Depressurization:
- Slow
- Rapid

Fire
Material failures
Radiation:
- Solar flares
- Steady states

GCR
Meteorite
Micro-meteorite
Thermal conditions:
- Long diurnal cycle
- Dust

Road/surfaces
Transportation modes
Blast effects
Vacuum conditions
Low gravity
Site layout/facility arrangement

Table 3.4.2

Need for Criteria/Standards: Design Philosophy and Constraints

Weight/cost (optimization)
Cost
Safety and safety factors:
- Life
- Mission
- Financial

Life cycle cost
- First vs. operating
- Facility/life time/decommissioning environmental concerns

Quality assurance level
- Consequence of failure
- Background
- Qualification testing
- Maintainability
- Repairability
- EVA labor
- Automation
- Facilities intelligence

Evolution and growth
Change of function
Degree of modularization
Failure mode
Constructibility program
Subsystems operational before whole system modular approach in order to start using system, for example: power, life support, waste handling
Off-the-shelf vs. new technology

Table 3.4.3

Need for Criteria/Standards: Environment and Load Considerations

Seismic
Radiation
- Recurrence period
- Galactic cosmic rays
- Solar flares
  - Steady state
  - Flares

UV
Meteorites
- Recurrence period
- Size
- Energy (velocity)
  - Secondary ejecta

Micrometeorites
- Recurrence period
- Size
- Energy (velocity)

Vacuum (moon) effects on materials
Winds (mars) need equivalent density for Mars atmosphere with dust in suspended state
Thermal (diurnal, eclipse)
- Range of temperature
- Difference
- Length
- Rate of change
- Light (intensity)
- Dust

Table 3.4.4

Need for Criteria/Standards: Constraints

Topography
Orbital mechanics (Delta V)
Site location versus delivery orbits from earth
Facility functional requirements:
- Lunar observatory
- Sunlight
- Resource richness
- Geographical location
- Weight
- Cost

EVA time/human factors
Level of technology at design freeze
Dimensions - shipping/surface handling
Levels of funding

Table 3.4.5

Need for Criteria/Standards: Constructibility/Maintainability

Costs	Labor needs
Safety	Automation
Lifetime	EVA time
Scheduling	Erectability
Reliability	Crew protection
Complexity	Interchangeability
Repair access	Consumables/tools
Modularization	Outfitting of interior
Maintainability construction	Waste and debris (reuse)
Loads construction access	Construction information
Power requirements	Documentation
Environmental impact	Availability
	Recall and ease of use

Material availability
Ground & site conditions
Design details (connections)
Expansion/growth capability (ease of)
Transportability (weight, size, volume)
Inflation & deflation techniques/technology
Training required to construct/repair/maintain
Robustness (alternatives to single points of failure)
Construction equipment needed to erect (availability)
Packaging for exit/egress through airlock
Material compatibility with environment
Minimization of parts/tools/methods
Assembly techniques (technology)

Table 3.4.6

Need for Criteria/Standards: Weight Considerations

Size
In-Situ construction materials
Energy constraints/modes
Energy supply
Soil mechanics
Topographic/metrology/surveying
Lava tubes
Use of craters (shielding for radiation)
Orbital mechanics (sitting as a function of minimizing energy)
Safety standards vs. Risk
- Life
- Mission
- Infrastructure

Creature comfort (human factors)
Standard of living expected/demanded a function of reason for being there. Salaried employees with no share in the profits will demand/expect better living conditions than the venture capitalists betting his own resources.

Psychology/human factors (Navy researchers have addressed this problem in severe terrestrial environments. NASA should really look at this data before attempting to duplicate it because it is not NASA data (editorial comment based on responses to questions at Case for Mars IV)

Construction limitations/constructibility
Economics
EVA

4 OPERATIONS AND PERFORMANCE

4.1 Goals

The Operations and Performance study group (group P) recognized the interdependence of operational needs and capabilities that must be provided. This group performed the hierarchal process of identifying major tasks, subdividing them into component subtasks, and attaching notional ways of performing the tasks.

Some basic ground rules were articulated as guidelines for developing later procedures. For example, one such rule of thumb was: "Anything that can be done to avoid lifting an object will reduce the likelihood of damage to that object." Another such rule stated that operations should be guided by a principle of simplicity; i.e., if two procedures achieve the same result, the simpler of the two is preferable.

4.2 Task Development

Together with the Construction and Mining Equipment group, this group developed a series of tasks and concepts for accomplishing them. Table 4.2.1 lists typical tasks and concepts.

Table 4.2.1

Operational Tasks Requiring Equipment

Site Analysis Task
- Remote sensing
- Surface geophysics
- Core sampling
- Sub-surface geophysics & testing
- Verify "excavatability"
- Sample analysis

Offloading Tasks
- Vehicles
- Habitats
- Logistics (supplies)
- Power units
- Crew

Science Equipment
- Generic
  (large & heavy vs. small & light)

Transportation Task
- Pallets
- Bulk cargo
- Liquid
- Loose
- Hard
- Lunar
- Lunar materials

Site Analysis Concepts
- Rover-based drilling
- Seismic/
  electromagnetics
- Trenching & scraping
- Telerobotic controls

Vehicles Concepts

Offloading & transportation
- Ramp
- Crane
  - kit
  - preassembled
- Winch
- Unloader
- Integrated w/lander (no equipment)
- Common modular vehicle
- Manipulator
- Multipurpose rover

Transportation Infrastructure
- Flatbed
- Conveyor
- Trajectory
- Cable-tram
- Tracks/monorail
- Piping
- Wheeled vs. track vs. hybrid walkers vs. cable

Table 4.2.1 (Cont'd)

Foundation/Stabilization
- Landing site
- Hab site
- Process plant
- Underground openings
- Towers/rigging
- Scientific instruments
- Roads
- Power plant
- Sintering
- Melting
- Vibration compaction geogrid
- Netting
- Expose bedrock
- Explosives
- Excavate/remove lose regolith
- Replacement
- Anchoring

Facility Assembly
- Underground excavation/hab
- Component/hab development
- Pressure seal & verify
- Construction
  - Lunar
  - Earth resources

Utility Emplacement
- Connections
- Surface, underground, overhead
- Protection, insulation
- Structural
- Power plant
- Fluids
- Electrical
- Gases
- Waste
- Communication

Excavating Trenching
- Backhoe
- Bulldozer
- Clamshell
- Ripper
- Front end loader
- Snow "blower"
- "Weasel"
- Scraper
- Explosives
- Traxcavator
- Auger
- Disc harrow
- Slusher
- Laser
- Potato picker
- Tunnel
- Bucket wheel

Excavating Trenching (cont'd)
- Melter
- Wire brush
- Benching
- Mobile miner
- Splitter
- Flail
- Drag line

Regolith Handling
- See excavation
- Regolith flow
- See transportation infrastructure
- Storage
- Direct dumping
- Dust control
- Hopper - vibrator
- Auger
- Conveyor

ISRU Operations
- Process list & tradeoffs
- See excavating
- See transportation
- Storage: equip, raw material, refined material
- By products
- Process monitoring (lab analysis)
- Environmental assessment
- Disposal/waste

ISRU Processes
Crushing, Screening
- Magnetic sep
- Gravity sep
- Magma electrolysis
- Hydrogen reduction

Material Manufacturing
ISRU
- Sintering blocks
- Casting (basalt)
- Concrete
- Quarry
- Glass/ceramic
- Metals
- Terrestrial raw material fabrication/manufacturing/machining

Maintenance/Repair -Equipment
- Modular replacement
- Welding/assembly
- Consumables
- Maintenance area/facility
- Artificial intelligence (monitoring, testing)
- Maintenance robots or humans
- Logistics
- Tool kit

4.3 Operations and Mining

The group developed a table relating operational cases for mining operations and rates to help define expected scales of productivity. Table 4.3.1 is the matrix supplied to the construction and mining equipment group.

4.4 Discussions

The Operations and Performance group concluded that development of the lunar outpost or base should be evolutionary, starting with completely ready deployable habitat modules and gradually progressing from simple to very complex construction using locally derived/developed materials. This may be regarded as adaptation based on experience.

The group raised many questions about what the "designers" needed from them. For example: do the operations planners or designers decide how to maintain a piece of equipment or monitor its condition during operation? Other uncertainties surrounded details of how to seal a leak in a habitat or gaps in radiation shielding. Should all equipment be wheeled? How location-tolerant should a habitat be? What should be included in an automated operations list? Questions like these will arise and must be addressed eventually.

The group discussed operations that should be automated, teleoperated, or performed by humans. They decided that automation is appropriate for long-term, highly repetitive tasks such as monitoring habitat conditions, mining with a prescribed set of motions, or hauling materials along a dedicated route from a mine to a processing plant. Teleoperation (remote control) should be used for dangerous tasks, to guide nonroutine actions, and to "train" automated systems. Humans in IVA or EVA should reconfigure systems, conduct very precise operations, and perform certain infrequent repair and maintenance procedures. Figure 4.4.1 shows a sample circumstance requiring EVA troubleshooting.

The equipment group expressed a need for a "shop" to do repair and maintenance operations. Equipment maintenance would probably be required from the project's outset, but the need for a shop would be determined by the number of pieces of equipment and the frequency of use. A shirt-sleeve environment would be preferred for other than quick-change modular replacement of components. The equipment group conceded that the provision of maintenance shop capabilities could evolve along with the development of the outpost/base.

Table 4.3.1

Operations Related to Mining

Operational Cases	Low	Medium	High
Production rate	5-100 t/yr	20-50 kt/yr	>100 kt/yr
Depth	Suggested: On-grade	Suggested: Shallow	Suggested: <3m for H2
Operations	Intermittent, Simple automation	Regular, Med automation	Continuous, Highly automated
Haul distance	Batch, medium	Batch, dedicated short haul	Dedicated, large or mobile miner/plant

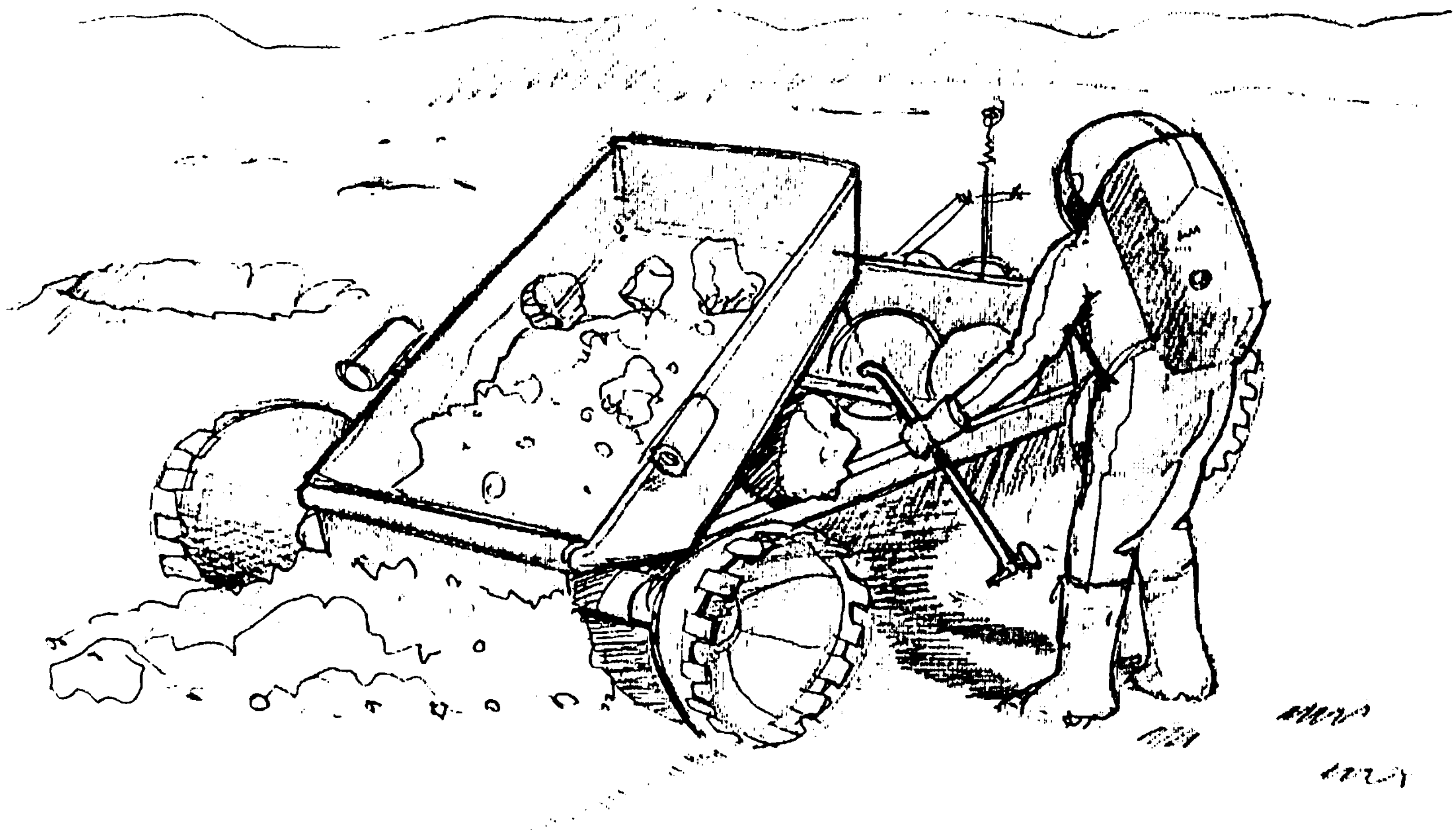

Figure 4.4.1. Manned Troubleshooting.

The operations group was concerned about habitats. Discussions with the other groups satisfied them with the progression of on-site operations complexities from space station derived habitats to building habitats using local materials. It was pointed out that base build up would probably involve attaching new structures to old and the overriding importance of providing an effective seal would be more important than precise alignment between adjacent sections. This discussion led to consideration of testing seal effectiveness, relevelling habitats, foundations, and relocating the habitat to other sites.

Other points of concern brought up by the operations group were:

- Type and location of utilities cables (burial, overhead, etc.)
- Relation between radiation protection and habitat access and/or airlock
- Kind of information and rates needed to assess operation and stability of equipment
- Method to train autonomous systems
- Suspension system/softness of ride on vehicles.

Some ideas were offered on each of these points but they were philosophical rather than prescriptive.

Finally the operations group conducted an open discussion on equipment design. The number of vehicles, for example, may possibly range from one multifunctional vehicle with multiple capabilities (Swiss Army knife, deluxe) to individual vehicles especially designed for specific functions. It was noted that a single vehicle may represent a single point failure and, because of this, should be avoided. The joint group guidance essentially distilled a philosophy of having the minimum number of types of vehicles, each highly standardized for reconfiguration redundancy, while still having the proper implement (tool) for a required specialized operation.

4.5 Operations and Performance Session Summary

Numerous operational tasks and concerns can be identified but without specific mission requirements and defined equipment/manpower, it is not practical to try to establish precise timelines and related productivities.

Much time can be spent in trying to imagine all of the possible operational difficulties that can arise in performing a task. This suggests that planning for the simplest possible operations and equipment should be the goal.

Needs must be stated as operational principles rather than as solutions to questions or problems. For example, in the operation of attaching two structures (e.g., habitat and laboratory modules) the essence of the problem is to achieve adequate sealing rather than precise alignment. Providing a suspension system for vehicles that offer a smooth ride is not an appropriate operational condition; protecting payload and personnel from transportation shock and vibration is an operational concern.

5 SUMMARY AND RECOMMENDATIONS

5.1 Construction and Mining Concepts and Equipment Design Session

5.1.1 Summary

- Mining and construction tasks were categorized into 11 primary functions, which were broken down into specific activities.
- Several equipment types and designs were reviewed for application to specific surface tasks, i.e., offloading, surface transportation, and construction activities.
- The relative merits of surface and underground mining were reviewed. Surface mining equipment may initially be used for construction operations in such tasks such as trenching, light excavation, and covering; dedicated equipment will be required once the mining quantity builds up. Underground mining excavation may provide space for protected habitat.
- Four ways to run utility lines were reviewed.
- Two in situ resource utilization (ISRU) concepts were examined, one involving a conventional mining technique, and the other involving a less conventional extraction process.

5.1.2 Recommendations

- Location of a lunar outpost site should be based on multiple coring samples that characterize the lunar regolith.
- Specific mission plans should be formed to narrow equipment options. The number of fleet vehicles should be kept to a minimum, and vehicle equipment should be designed to perform multiple/overlapping tasks so that no one piece of equipment will sit idle during any phase of activity.
- Construction activities must address the nature of the lunar regolith. In the initial phases of construction, habitat should be self-contained and modular. Later stages of construction may involve more complex construction. Once mining is under way, mining excavation may also serve to create the space needed for constructible underground habitat.
- Lunar construction and mining operations must be verified in a relevant earth test environment before lunar emplacement.

5.2 Standards and Codes Session

5.2.1 Summary

- Codes are legal standards dictated a governmental agency to assure safety and uniformity of practice. There is need to develop separate standards for extraterrestrial construction.

- Terrestrial analogs are a good starting point to identify the needed criteria and standards and adapt them to lunar and martian situations.

- The Corps of Engineers construction criteria and specifications is a good model, which furthermore may be automated for easy cross-referencing.

- Criteria and standards, once developed, need to be incorporated into a broad engineering curricula.

5.2.2 *Recommendations*

- Criteria and standards should be developed by an independent, nongovernment group to avoid the complexity typically associated with the bureaucratic process.

- Any new set of criteria and standards must be provided with a means to update the documentation.

- It follows that the creation of new criteria and standards will necessitate testing and proving facilities.

5.3 Operations and Performance Session

5.3.1 *Summary*

- A series of operational tasks and the concepts for accomplishing them were developed.

- Simplicity should be a key consideration in operations, at least until an experience base/level of expertise is developed.

- A central concern was the development of guidelines for habitat construction. Since base buildup would probably involve attaching new structures to old, an overriding inportance will be to provide an effective seal between adjacent sections.

5.3.2 *Recommendations*

- Mission plans should be formed as concretely as possible, including crew size and mission timetable, to help establish operations and performance criteria.

- A key operational principle is to progress from simple to complex. Any lunar base should begin construction with modular, self-contained units, and gradually progress to more complex construction using locally derived/developed materials.

- Operational scenario planning should continue in view of the fact that it may be significantly altered depending on mission architecture.

- Operations plans should indicate tasks and times and should avoid stating proposed methods.

- A future workshop on the subject should be broad rather than directed to a "baseline of the day."

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ABBREVIATIONS

ACI	American Concrete Institute
AI	Artificial intelligence
AISC	American Institute of Steel Construction
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BOM	Bureau of Mines
B&PVC	Boilder and Pressure Vessel Code
COE	Corps of Engineers
C/M	Construction and mining
CSM	Colorado School of Mines
DOD	Department of Defense
ERD	Exploration Requirements Documents
EVA	Extra-vehicular activity
FEL(s)	Front-End Loader(s)
GCR	Galactic Cosmic Radiation
hp	Horsepower
HQUSACE	Headquarters, U.S. Army Corps of Engineers
HVAC	Heating, Ventilation, and Air Conditioning
ISRU	In Situ Resource Utilization
IVA	Intra-vehicular activity
JSC	Johnson Space Center
kt	1000 tons
kW	Kilowatt

ABBREVIATIONS (Cont'd)

kWe	Kilowatt-electric
LEVPU	Lunar Excursion Vehicle Payload Unloader
MIL-STD	Military Standard
MT	Megaton
MW	Megawatt
MWe	Megawatt-electric
NASA	National Aeronautics and Space Administration
OEXP	Office of Exploration (NASA)
ppm	Parts per million
psi	Pounds per sq in.
PSS	Planet Surface Systems
PVA(s)	Photovoltaic Arrays
SEDS	Students for the Exploration and Development of Space
SEI	Space Exploration Initiative
t	metric ton
TBD	To be determined
UBC	Uniform Building code
UMP	Universal Mobile Platform
USACERL	U.S. Army Construction Engineering Research Laboratory
UV	Ultraviolet radiation

APPENDIX A: Workshop Participants

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APPENDIX B: Space Exploration Initiative

The Space Exploration Initiative

"Why the Moon? Why Mars?
Because it is humanity's destiny to strive, to seek, to find.
And because it is America's destiny to lead."

George Bush

The Space Exploration Initiative

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Fact Sheet -- Space Exploration Initiative (SEI)

WHAT IS SEI?

On July 20, 1989, the 20th Anniversary of the Apollo 11 Moon landing, President Bush announced a renewed commitment to expanding human presence beyond earth orbit and exploring the solar system. The President directed that the National Space Council determine the nature of this program, its costs and schedule and the possibilities for international cooperation.

- The Space Council recommended and the President approved a three to five year technology development program. Other than an expanded unmanned solar system probe program, no specific new starts were approved nor are any anticipated in the next several years.

- The Space Council recommended and the President approved a program to begin a dialogue with other space-faring nations concerning cooperation in exploration. Specific provisions are included for exploring possible cooperation with the Soviet Union.

- To provide overall focus for the program, the President set a goal of a manned mission to Mars by 2019 -- the 50th anniversary of the Apollo 11 Moon landing. This date was set to provide a concrete goal. All technical assessments have shown that this is an achievable goal. Moreover, this date goal will allow several years before any program development decisions need to be made. If technology develops as expected, it may be possible for future Presidents and Congresses to move the date forward.

WHY ARE WE EXPANDING SPACE EXPLORATIONS? WHAT'S IN IT FOR THE AMERICAN TAXPAYER?

There are many, interrelated reasons for a revitalized space program:

- Philosophical reasons -- the search for new knowledge, the expansion of mankind into the solar system, and the inspiration to our people. Exploration has traditionally brought out the best in the American people.

- Spinoff reasons -- in the past exploring space has produced new products, new services and technologies for the American people. These range from new medical treatments to electronics, to new materials.

- New space industries -- Space offers the potential of trillion dollar new industries including global cellular telephone services, medical products and treatments which could cure dreaded diseases, access to raw materials worth billions of dollars per year, and access to unlimited, safe, clean energy sources which could help solve the global environmental crisis.

These reasons can be summarized into two points: 1) Space is the key to our future economic competitiveness, and 2) Space can inspire our youth to excel in science and math. During the 1960s, the space program inspired a generation of students to enter and excel in these critical disciplines. Now, our production of scientists and engineers has dropped by almost 50%.

WHY PUSH SEI NOW? CAN'T WE WAIT A FEW YEARS?

With the reductions in our national security requirements, we must make decisions in the next few years as to where to devote our critical technological resources. Correspondingly, our economic competitors are targeting space as a key investment area of the 21st Century. The Japanese are particularly interested in space exploration, having sent the first probe to the Moon by any nation in 15 years and with many corporate design teams pressing lunar resource development. If we delay we may find that the potential of space has been realized by others, leaving us as the customer and not the purveyor.

Now is also a time with reduced international tensions to consider long-term cooperative space endeavors. The Soviet Union is a case in point. They have expressed an interest in cooperative space exploration and President Bush has approved a dialogue with them. The Soviets have key decisions facing them as well. If we delay, they may decide to dismantle or redirect their own space program and an opportunity for historic cooperation could be lost.

DOESN'T NASA HAVE A FULL PLATE WITH HIGHER PRIORITY SPACE PROGRAMS SUCH AS ENVIRONMENTAL MONITORING?

With NASA's development of the Space Station and expansion of other manned and unmanned missions, it is certainly true that NASA has numerous projects which demand attention. However, the entire manned program lacks a compelling rationale without the long-term goal of manned activities beyond earth orbit. This is particularly true of the Space Station. Much of the research rationale for the Station is to understand how man can live in operate in space for the long periods necessary for space exploration. The Station may even prove to be the most appropriate staging area for deep space missions. Now is the time to fully examine how the Station and Shuttle will evolve to best support our long-term space program. If we delay the in-depth exploration studies, we may well find we have locked in sub-optimum configurations of these other systems without understanding the long-term implications.

It is certainly appropriate to focus on current space requirements, but as with other things the nation does, we must also spend some resources on future needs and possibilities as well. The $188 million added to NASA's budget for SEI is about 1% of the agency's budget -- not an inordinate amount for NASA to spend on the future.

While NASA has other initiatives, such as Mission to Planet Earth to address environmental monitoring needs, these should not be regarded as a competitor to space exploration. In the long term, space exploration could well provide us the means, through possible unlimited clean energy sources for example, to fix the environmental problems the Mission to Planet Earth program enables us to understand. Moreover, much of the SEI research, for example closed loop life support system development, has direct applicability to solving global environmental problems.

HOW MUCH WILL SEI COST?

For FY 1991 the President has requested a total of $1.3 billion divided between the agency budgets of NASA, DOE and DOD. $1 billion of this is in the NASA budget (total NASA request for FY 1991 was $15.1 billion). In addition, $800 million of the NASA request was already programmed for needed technology development related to the whole range of U.S. commercial, national security and civil space programs. The actual Initiative thus comprises $188 million added to NASA's budget after the President's July 20, 1989 speech. This amount is divided between life sciences, expanded unmanned solar system missions, space power and propulsion development and mission studies. The mission studies amount, $37 million, is the heart of the program.

Over the next five years, the total amount of technology resources to be spent on SEI may rise to about $3 billion per year. Two thirds of this was already slated to be spent prior to the Initiative.

WHAT ABOUT THE $500 BILLION COST ESTIMATES WHICH HAVE BEEN TOSSED AROUND FOR SPACE EXPLORATION?

No one knows what specific missions will cost. The National Research Council recently underscored this conclusion. It is precisely the purpose of SEI to get good cost estimates and find ways to make exploration affordable before specific missions are planned and started.

It is important to place costs in context. If the nation moves out on specific exploration missions, the objective will be a continuing human presence in the Solar System. Costs will depend on how long one wishes to add them up for. The United States has spent $2.5 trillion on its road system -- an investment which appears enormous, but which has been repaid many times over in benefits. Considering the potential returns from space exploration, a continuing investment in space should be viewed much as we consider roads -- a vital infrastructure investment.

Historically, nations spend a few tenths to a few percent of their net wealth in exploration during periods of expansion. This was true of the great exploring powers of the 16th Century, and of this nation in the 19th Century. These investments were well repaid. The National Research Council suggests an exploration investment of a few tenths of one percent of our GNP. This is an amount considerably less than we spent on NASA in the 1960s, and one we can surely afford.

WHAT ABOUT THE INVOLVEMENT OF DOD AND DOE?

The President has decided that SEI will require the efforts of several agencies, while keeping NASA, as our civil space agency in charge of the overall effort. This approach will bring vital expertise from other agencies. Already, technologies and ideas from DOE and DOD promise greatly reduced cost, increased performance and lower risk in exploration missions.

The technologies to be developed for exploration have broad applicability to other U.S. space needs such as national security. It is thus appropriate and will save money if the technologies are developed in cooperation among agencies. One example of this broad space need is the multi-agency Advanced Launch System (ALS) development. ALS could lower costs to get to space by a large factor which will benefit all U.S. space programs.

Historically, the United States used varied elements of its infrastructure to assist in exploration. For example, the U.S. Navy supplies much of the logistics support to our antarctic exploration and scientific effort. This makes our antarctic program more efficient and does not hamper in any way cooperation among the many nations working in antarctica.

CAN'T SPACE EXPLORATION BE DONE CHEAPLY AND BETTER WITH UNMANNED MISSIONS?

Space exploration will have both human and unmanned components. Robots can best explore the most dangerous areas of a new planet such as Mars. Initial surveys and research with unmanned systems are a necessary and cost-effective first step to any exploration program. The SEI includes several such robotic missions to the Moon and Mars. It is these missions which will provide the first scientific returns from the program.

But, while unmanned systems can best survey a new environment, the in-depth exploration of an entire, complex planetary environment will have many surprises which require the flexibility of the human brain.

Why is it so hard to conduct exploration of a planet such as Mars remotely? Radio signals traveling at the speed of light (176,000 miles per second) take up to 40 minutes to travel to and from Mars (which is typically 100-200,000,000 miles away). A man or women sitting on earth would have to wait half an hour or more to find out whether a command radioed to an exploring craft on Mars was effective. There are many surprises waiting for us on a planet such as Mars. If it takes 40 minutes to react to these surprises, exploration can be far more costly and difficult. The only way to eliminate the 40 minute delay is to bring the human explorers to Mars to work "hand in claw" with the robots.

There are other reasons to work toward humans living and operating on the Moon and Mars. Since our ultimate objective is permanent occupation and use of other planets in the solar system, human presence on other planets is, by definition, a part of the program. In short, we will ultimately send humans because we are human -- if we were robots we would send only robots.

WHAT'S GOING TO HAPPEN IN THE NEXT YEAR ON SEI?

The key activity is the SEI outreach and synthesis. NASA has issued the call for new ideas and new technologies which can make exploration faster, cheaper, safer and better. This outreach is being conducted through professional aerospace associations such as the Aerospace Industries Association and the American Institute of Aeronautics and Astronautics, through an interagency search team, and through the RAND Corporation. The inputs will be submitted to a synthesis team chaired by former Apollo astronaut Tom Stafford. General Stafford's group will be external to NASA and will consist of the nation's top space experts. It will report its recommendations on technology development, near term milestones, and most importantly alternate exploration architectures. These architectures will be chosen to provide better performance, lower costs, better returns, etc. The National Research Council will also review the Stafford team recommendations. For the next several years, we plan on pursuing at least two alternative approaches so we can provide the President and Congress with the widest possible range of options when actual mission development decisions are made in a few years. For this reason, the resources to develop these alternate architectures have the highest priority within SEI.

Discussion of Space Exploration Initiative (SEI) Budget

The SEI budget consists of NASA, DOD and DOE space technology programs. In the case of NASA, the SEI comprises essentially all of the agency's advanced technology work.

NASA

National Aerospace Plane. The National Aerospace Plane or NASP is a joint effort of the DOD and NASA. The NASP has the potential of revolutionizing both intercontinental air transport and launch of payloads into space. In essence, NASP is an airplane which can fly people or cargo into space at a fraction of the cost and complexity of current launch vehicles. It could also make possible two hour flights to the orient. Both the Japanese and Europeans are developing their own versions of NASP. The objective of the program is to develop technology to the point that we could begin prototype NASP development in three years.

Space Research and Technology. There are a variety of elements in NASA's space technology development line. These include nuclear power and propulsion which could make Mars missions much faster and safer. The Pathfinder program comprises a whole range on new technologies such as new materials to make spacecraft lighter and more capable, and methods to extract fuel and oxygen from lunar material rather than having to bring it from Earth. The objective of this technology development is to demonstrate, in the laboratory, new technologies which could make missions to the Moon and Mars faster, cheaper, safer and better -- and to develop these technologies for other space and commercial spinoffs. Congress and outside experts have consistently urged a significant expansion of long-term technology investment.

Exploration Mission Studies. After President Bush announced the SEI, NASA and other groups proposed various ways to accomplish our space exploration goals. Some of the ways promise significantly cheaper, safer and better results. Former Apollo Astronaut Tom Stafford is chairing an external study group to identify two or more alternate approaches, "architectures," for accomplishing our exploration goals. For the next few years American industry will be asked to study and contrast these competing approaches so we can choose the best and cheapest approach when we decide to move forward to actual mission development (i.e. make a "new start" on specific hardware). This line will provide the funds -- $37 million -- to support these alternate architecture studies in FY 1991. This is the most important part of the Initiative.

Space Transportation Capability Development. Currently it costs between $3000-$5000 per pound to launch objects into earth orbit. If we are to accomplish space exploration affordably as well as maximize our use of space for commercial purposes, we must lower this cost. The primary government program to do this is the joint NASA/DoD Advanced Launch Technology development program which has as its objective lowering the cost of launch to orbit by a factor of from three to nine. A new launch system to replace existing systems could be developed by the end of the decade.

Life Sciences. Research on the Soviet Space Station, Mir, shows that humans will have considerable difficulty surviving in the weightless conditions necessary for a prolonged trip to Mars. In addition, we do not yet know whether long-term living at 1/6 gravity on the Moon will have harmful effects. NASA thus plans a series of experiments on board the Space Station and Space Shuttle to study these potential problems and devise solutions.

Space Station Freedom. Some approaches to exploration would expand upon the Space Station basic system to make it into a construction center and refurbishment port for missions to the Moon and Mars. All ideas will build upon the life sciences research to be done on board the station. In order to build upon the station's basic mission and capabilities, work must begin now to study how to expand it. Most important will be to develop ways to expand the amount of electrical power it can supply. Using sunlight to heat and power an electric generator is one very promising way to supply this electricity. These funds will allow NASA to begin work on this technology.

Unmanned Planetary Missions. Before we send men to Mars, or indeed back to the Moon we need much better information from unmanned probes about the surface dangers and optimum sites to land for both bodies. During the Apollo program, for example, we only mapped about 10% of the Moon. Because of the long lead times to develop planetary probes, the limited windows of opportunity to launch probes to Mars, and in some cases international opportunities to cooperate on unmanned missions, resources are needed now to continue development of these "precursors" to manned missions.

Facilities, Research and Program Management. Because of greatly reduced budgets during the 1970s and 1980s, the basic facilities and personnel programs of NASA have suffered. In order to proceed on an expanded program of space exploration, it is a high priority of NASA to update and upgrade these facilities.

DOD AND DOE.

The President mandated that both DOD and DOE would play major roles in technology development and architecture analysis for space exploration. Although NASA will be lead agency, these other agencies have outstanding facilities, expertise and programs which can help this effort and provide a fresh perspective on space problems. Advanced space launch capabilities which offer cheaper and better ways to get to space will help both our civil and national security space efforts. For this reason, the NASP and Advanced Launch System developments are joint NASA/DOD programs. Studies have also shown that solar power will not suffice for lunar bases since the Moon undergoes a "night" lasting 14 days. For this reason NASA has determined that nuclear power will be needed for the Moon. The joint NASA/DOD/DOE SP-100 program is developing this capability, and will demonstrate it in the late 1990s. Reliable nuclear power also has considerable relevance for other DOD and NASA space missions.

THE WHITE HOUSE

Office of the Press Secretary

For Immediate Release | July 20, 1989

REMARKS BY THE PRESIDENT
AT 20TH ANNIVERSARY OF
APOLLO MOON LANDING

The Steps of the Air and Space Museum
Washington, D.C.

10:30 A.M. EDT

THE PRESIDENT: Thank you all very, very much. And thank you, Mr. Vice President, for your introduction and for undertaking to head the National Space Council and for --already for demonstrating your skill for leadership there.

And thanks to all of you, who have braved the weather to join us today. Behind me stands one of the most visited places on Earth--a symbol of American courage and ingenuity. And before me stand those on whose shoulders this legacy was built--the men and women of the United States astronaut corps.

And we are very proud to be part of this unprecedented gathering of America's space veterans--and to share this stage with three of the greatest heroes of this or any other century--the crew of Apollo 11.

It's hard to believe that 20 years have passed. Neil and Buzz, who originated the moonwalk 15 years before Michael Jackson ever even thought of it.

And Michael Collins--former director of this amazing museum--and the brave pilot who flew alone on the dark side of the Moon, while Neil and Buzz touched down. Mike, you must be the only American over age 10 that night who didn't get to see the Moon landing.

And later this evening, after the crowd disperses and the sun goes down, a nearly full Moon will rise out of the darkness and shine down on an America that is prosperous and at peace. And for those old enough to remember that historic night 20 years ago--step outside tonight with your children or your grandchildren. Lift your eyes skyward, and tell them of the flag--the American flag--that still flies proudly in the ancient lunar soil.

And for those who were not yet born, or then too young to recall--you who are the children of the new century--raise your eyes to the heavens and join us in a great dream--an American dream--a dream without end.

Project Apollo. The first men on the Moon. Some called it quixotic, impossible--had never been done. But America dreamed it. And America did it. And it began on July 16th, 1969. The sun rose a second time that morning as the awesome fireball of the Saturn Five lifted these three pioneers beyond the clouds. A crowd of one million--including half of the United States Congress--held its breath as the Earth shook beneath their feet--and our view of the heavens was changed forevermore.

Three days and three nights they journeyed. It was a perilous, unprecedented, breathtaking voyage. And each of us remember the night.

Barbara and our daughter Dorothy were with me in our red brick house right here on the outskirts of Washington, where we moved up here to represent Houston in the United States Congress. Our 12-year-old kid, Marvin, was on a trip out West with family friends and remembers stopping at a roadside motel to watch. Second boy, Jeb, 16 that summer, teaching English and listening by radio in a small Mexican village, where electricity had yet to arrive.

The landing itself was harrowing. Alarms flashed--and a computer overload threatened to halt the mission where Eagle dangled thousands of feet above the Moon. Armstrong seized manual control to avoid a huge crater strewn with boulders. With new alarms signalling a loss of fuel--and the view now blocked by lunar dust--Mission Control began the countdown for a mandatory abort.

America--indeed the whole world--listened--a lump in our throat and a prayer on our lips. And only 20 seconds of fuel remained. And then out of the static came the words: "Houston. Tranquility Base here. The Eagle has landed.":

Within one lifetime, the human race had traveled from the dunes of Kitty Hawk to the dust of another world. Apollo is a monument to our nation's unparalleled ability to respond swiftly and successfully to a clearly stated challenge--and to America's willingness to take great risks for great rewards.

We had a challenge. We set a goal. And we achieved it.

So today is not only an occasion to thank these astronauts and their colleagues--the thousands of talented men and women across the country whose commitment, creativity, and courage brought this dream to life. It's also a time to thank the American people for their faith--because Apollo's success was made possible by the drive and daring of an entire nation committed to a dream.

In the building behind me are the testaments to Apollo and to what came before--the chariots of fire flown by Armstrong, Yeager, Lindbergh, and the Wrights. And in the National Archives--across the great expanse of grass--are preserved the founding documents of the idea that made it all possible -- the world's greatest experiment in freedom and diversity.

And here--standing between these twin legacies--is a fitting place to look forward to the future.

Because the Apollo astronauts left more than flags and footprints on the Moon. They also left some unfinished business. For even 20 years ago, we recognized that America's ultimate goal was not simply to go there and go back--but to go there and go on.

Mike Collins said it best: "The Moon is not a destination--it's a direction."

And space is the inescapable challenge to all the advanced nations of the Earth. And there's little question that, in the 21st century, humans will again leave their home planet for voyages of discovery and exploration. What was once improbable is now inevitable.

The time has come to look beyond brief encounters. We must commit ourselves anew to a sustained program of manned exploration of the solar system--and yes--the permanent settlement of space. We must commit to a future where Americans and citizens of all nations will live and work in space.

And today, yes, we are, the U.S. is the richest nation on Earth--with the most powerful economy in the world. And our goal is nothing less than to establish the United States as the preeminent spacefaring nation.

From the voyages of Columbus--to the Oregon Trail--to the journey to the Moon itself--history proves that we have never lost by pressing the limits of our frontiers.

Indeed, earlier this month, one news magazine reported that Apollo paid down-to-earth dividends--declaring that Man's conquest of the Moon "would have been a bargain at twice the price." And they called Apollo "the best return on investment since Leonardo da Vinci bought himself a sketch pad."

In 1961, it took a crisis--the space race--to speed things up. Today we don't have a crisis. We have an opportunity.

To seize this opportunity, I'm not proposing a 10-year plan like Apollo. I'm proposing a long-range, continuing commitment.

First, for the coming decade--for the 1990's--Space Station Freedom--our critical next step in all our space endeavors.

And next--for the new century--back to the Moon.. Back to the future. And this time, back to stay.

And then--a journey into tomorrow--a journey to another planet--a manned mission to Mars.

Each mission should will lay the groundwork for the next. And the pathway to the stars begins, as it did 20 years ago, with you--the American people. And it continues just up the street there--the the United States Congress--where the future of the space station--and our future as a spacefaring nation--will be decided.

And yes, we're at a crossroads. Hard decisions must be made now as we prepare to enter the next century.

As William Jennings Bryan said--just before the last turn of the century: "Destiny is not a matter of chance--it is a matter of choice. It is not a thing to be waited for--it is a thing to be achieved."

And to those who may shirk from the challenges ahead--or who doubt our chances of success--let me say this:

To this day, the only footprints on the Moon are American footprints. The only flag on the Moon is an American flag. And the know-how that accomplished these feats is American know-how. What Americans dream--Americans can do.

And 10 years from now--on the 30th anniversary of this extraordinary and astonishing flight--the way to honor the Apollo astronauts is not by calling them back to Washington for another round of tributes. It is to have Space Station Freedom up there, operational, and underway--a new bridge between the worlds--and an investment in the growth, prosperity and technological superiority of our nation.

And the space station will also serve as a stepping stone to the most important planet in the solar system--Planet Earth.

As I said in Europe just a few days ago, environmental destruction knows no borders. A major national and international initiative is needed to seek new solutions for ozone depletion, and global warming, and acid rain. And this initiative--"Mission to Planet Earth"--is a critical part of our space program. And it reminds us of what the astronauts remember as the most stirring sight of all. It wasn't the Moon or the stars, as I remember. It was the Earth--tiny, fragile, precious, blue orb--rising above the arid desert of Tranquility Base.

The space station is a first and necessary step for sustained manned exploration--one that we're pleased has been endorsed by Senator Glenn, and Neil Armstrong, and so many of the veteran astronauts we honor today. But it's only a first step.

And today I'm asking my right hand man, our able Vice President, Dan Quayle, to lead the National Space Council in determining specifically what's needed for the next round of exploration--the necessary money, manpower, and material--the feasibility of international cooperation--and develop realistic timetables, milestones along the way. The Space Council will report back to me as soon as possible with concrete recommendations to chart a new and continuing course to the Moon and Mars and beyond.

There are many reasons to explore the Universe, but 10 very special reasons why America must never stop seeking distant frontiers--the 10 courageous astronauts who made the ultimate sacrifice to further the cause of space exploration. They have taken their place in the heavens, so that America can take its place in the stars.

Like them, like Columbus, we dream of distant shores we've not yet seen.

Why the Moon? Why Mars? Because it is humanity's destiny to strive, to seek, to find. And because it is America's destiny to lead.

Six years ago, Pioneer 10 sailed beyond the orbits of Neptune and of Pluto--the first man-made object to leave the solar system. Its destination unknown. It's now journeyed through the tenures of five Presidents--four billion miles from Earth.

In the decades ahead, we will follow the path of Pioneer 10. We will travel to neighboring stars, to new worlds, to discover the unknown. And it will not happen in my lifetime, and probably not during the lives of my children, but a dream to be realized by future generations must begin with this generation. We cannot take the next giant leap for mankind tomorrow unless we take a single step today.

To all of you here, our able director of NASA and others who've served so well--to all of you here--and especially the astronauts--we wish you good luck in you quests, wherever that may take you. Godspeed to you, one and all. And God bless the United States of America.

Thank you all very, very much.

END

Office of the Vice President

Embargoed until 12:00 p.m May 1, 1990

PREPARED REMARKS OF THE VICE PRESIDENT TO THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

Thank you, Ed for those kind and generous words.

And thank you, members of the American Institute of Aeronautics and Astronautics for your leadership in charting an exciting future in space.

And congratulations to Dick Truly and NASA on another successful Shuttle flight and Hubble Space Telescope deployment...a scientific instrument which will look back to the beginning of time.

Your theme, "Global Aerospace: On the Threshold of Tomorrow" is certainly an appropriate topic. For President Bush and I believe that today we are on an important threshold. As a nation we need to decide whether we will hesitate, or step boldly in space exploration.

You know which course of action I favor and let me take a few minutes today to explain why we should step boldly.

There are times when seemingly small decisions reverberate through the centuries. Now is such a time. The decisions we make in this decade for space will set the nation's course for decades, if not centuries to come. The legacy we leave to future generations may well be decided in these next few years.

In the 15th Century, China may well have been the most technologically and culturally advanced state on Earth. She owned great fleets of large oceangoing ships. In 1433 a fleet of Chinese ships sailed all the way to Africa, trading, exploring, and advancing Chinese culture. But the Ming Empire had other priorities -- problems at home, pressing needs elsewhere. They recalled the fleet -- and then they burned it. They wanted to bring an end to "wasteful" exploring. And they also wanted to ensure that Chinese explorers would not even be tempted to venture forth again for a long, long time.

At about the same time that China was burning its fleet, a small European nation's foresighted leader, Prince Henry of Portugal --now known as Henry the Navigator -- sent ships up and down the coast of Africa. Soon another European nation, Spain - just emerging from centuries of war and turmoil -- also began an exploration program. For a time Portugal and Spain competed to explore and use the new world that Spain discovered.

Portugal did not completely abandon exploration, as China did. But she soon lost out to Spain through gradual loss of sea-exploration capabilities. Spain went on to reap the harvest of two continents -- ushering in a golden age for her people which was to last almost two centuries.

The question now facing the United States in space is which path to take with regard to the "oceans" of the 21st Century - space?

Before I sketch out my answer, let me review the space plans of a modern nation known for investing in the future -- Japan.

Japan has, of course, a good record of investing in the future. Consumer electronics is an example. In the early 1960s "Consumer Electronics" consisted of black and white television sets and 45 RPM record players. Japan invested heavily in research and development of integrated circuits. Today, Japan owns the majority of the world's huge market in integrated circuits.

Japan has targeted space as the electronics industry of the future. She is increasing her investment in space significantly. Japan has shown special interest in unmanned and manned exploration the Moon. She recently launched the first probe to that body in 15 years.

What's in space for the Japanese -- and for us?

Consider the successful launch of Pegasus a few weeks ago -- made possible by a strong government - private sector partnership. We are all familiar with the success of the satellite communications industry. Soon, small commercial satellites will open a trillion dollar industry supplying additional new information services from space -- services such as cellular telephones, world-wide TV and computer services and much more. Think what this could mean to a developing nation. It could skip the entire cost of stringing wires and other infrastructure expenses, and still develop state of the art communications services.

In the next century, space will be providing even more valuable products and services. New medicines and medical understanding from research and manufacturing in space could cure dreaded diseases and extend life. Material from the Moon could enable us to supply many of the earth's energy needs safely and cleanly from space. Space exploration could give us access to precious metals of various sorts -- the equivalent of finding whole new continents on earth.

There are other reasons to be initially concerned about our Solar System. As the AIAA has pointed out in a position paper released at this meeting, those same asteroids which promise material riches can be a threat as well. For example, in 1965 a small asteroid exploded high over Canada with a force equivalent to an atomic bomb. It would certainly benefit all nations to know when such a natural event might occur, warn those who could be affected, and maybe, someday, even affect whether and where such an event might happen.

Furthermore, investing in space is especially important in light of the decline in our military spending. In the past much of our investment in military research and development has had civilian benefits. In addition to directly assuring our national security, military research led to competitive new industries and products in fields such as microelectronics and many others.

I hope and trust that in the decades ahead we will continue a vigorous defense research and development program. Our investment in national security preserved peace and fostered the cause of freedom.

Thanks to the promising trend toward a more peaceful and less threatening world, it does appear our defense spending will decline. To ensure that we continue to benefit from research and development in advanced technologies, we therefore need to continue and expand our investment in space-related research and development.

The President is committed to bringing the benefits of space development to the American people.

The National Space Council has developed and put in place a comprehensive five part strategy to advance our space endeavors.

First, we will develop our space infrastructure -- the equivalent of the roads and bridges program of the 20th Century to get us to space in the 21st.

Second, we will open the frontiers of space through manned and unmanned programs. The launch of the Hubble Space telescope last week was a fitting signal that America leads the world in space exploration once more.

Third, we will use space to solve problems on Earth. Our Mission to Planet Earth Program will give us the information to understand the causes of current environmental problems. Perhaps space could then allow us, by providing a clean inexhaustible source of energy, to correct these problems and prevent future ones.

Fourth, we will use space to foster our economic well being--to make sure that space is developed to its full commercial potential. The best way to guarantee that America benefits from developing the space frontier is to unleash the forces of the marketplace.

Finally, we must ensure the freedom to operate in space. to explore and develop, for ourselves and for other nations.

For our part, the Administration is committed to building a space program which leads the world in all facets of space use. This morning President Bush and I met with the leaders of Congress for the first Congressional leadership meeting on space at the White House in 15 years. We explained our strategy for space and the top priority it has for this Administration. President Bush told the Congressional leaders that a key part of our investment in our space future is his Space Exploration Initiative -- setting us on a course back to the Moon to stay and then on to Mars.

We are now asking Congress for modest resources for the next few years so that we can answer the President's charge to figure out how to implement this important Initiative.

For the next several years we will be evaluating alternate ways to do the job. We will be developing new technologies which will enable us to accomplish our objectives faster, cheaper and better. As the National Research Council reported, there are many potential approaches and architectures for accomplishing the President's space exploration goals. NASA will soon be calling on you for these new ideas and new technologies. When they cast their net widely, I trust you will be there with new ideas.

But your ideas will do little good without adequate Congressional support.

Let me emphasize -- what we are asking for is simply modest funds to answer the President's, the American peoples' and Congress, questions about when, how, and how much it will take to accomplish our goals. In a few years, when we have the answers to our questions and have chosen a specific path, a specific plan, then and only then will we ask Congress for the money to build the great ships to the future.

If Congress is afraid even to ask the questions of when, how and how much, we will have made an important and fateful decision -- and I think, a deeply misguided one. We need to move ahead so we can make an informed decision later on how to proceed and at what pace. For we all will be held accountable for that decision.

And it is to America's youth that we must ultimately answer. What will we say to the young man I met at the U.S. Space Camp a few months ago who told me he wanted to plant the American flag on Mars? What will we say to our students who dream of shores unseen and vistas unknown? Will we tell them we were afraid even to take the first step-?

America has been given an opportunity which may not come our way again. This nation has risen to the challenge before. Soon after we first became a nation, we doubled our land area at a cost many said we could not afford. The next decades proved the wisdom of our investment.

In this century we built a road system at a cost of over $2.5 trillion. When we began that road system early in the century many argued that we could neither afford it nor needed it. They were wrong.

We begin now on the road system of the 21st Century -- the road system into the solar system. Untold wealth and an unlimited future awaits us. As in the past, let us prove to the nay-sayers that it can be done. Let us prove to the nay-sayers that challenging this new frontier will be worthwhile. And let us prove to the nay-sayers once again bold initiatives are required for a nation that prides itself as the leader of the free world.

In addition to serving as Chairman of the Space Council, I chair the Competitiveness Council. Our future competitiveness will depend on developing advanced technology. It will depend on educating our young people for excellence in math and science. And the space program is a sound investment in ensuring that these key aspects of American competitiveness are there when we need them.

We need your help now. Help us convince Congress that investment in space is key to our nation's future. Help us in explaining space potential to our people. Help us to develop the new technologies to make these possibilities real. And help us think of new ways to do it faster, safer, cheaper and better.

Thank you and God bless you.

APPENDIX C: Option 5a Reference Architecture

REFERENCE ARCHITECTURE

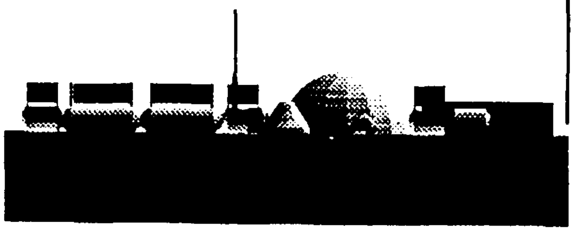
Option 5a (Option 5 with ISRU Emphasis)

Release 90 - 2
May 1990

National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center
Houston, Texas

Planet Surface Systems Office



REFERENCE ARCHITECTURE DESCRIPTION

OPTION 5a

(Option 5 with ISRU Emphasis)

PSS Reference Architecture Document 90-2

Planet Surface Systems Office

Distributed at

Interim Review

May 22 - 24, 1990

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Reference Architecture Description

for the

Lunar/Mars 90 Day Study Period

Option 5a (Option 5 with ISRU Emphasis)

1.0 INTRODUCTION

1.1 Purpose.

This document provides the reference architecture for Planet Surface Systems (PSS) lunar and martian sites developed during the 90 Day Study Period for Option 5, with ISRU emphasis. This is one of five options studied, of which only Options 1 and Option 5 were studied in detail by PSS. Option 5 reduces the scale of lunar outpost activity by using only a human-tended mode of operation and limiting the flight rate to the Moon to one mission per year. Option 1 involves permanent habitation and development of lunar resources with a flight rate of 2 to 3 lunar missions per year and has been covered in another document, PSS Reference Architecture Document 90-1(LESC Document No. 27922), published in January, 1990.

This option reflects adding, to the baseline Option 5, a lunar oxygen production capability of 5 t/yr. This rate is sufficient for the LEV ascent needs in view of the 1 flight/yr rate. The emplacement phase and early consolidation phase are basically identical to the baseline option 5. Changes become evident with flight 10 in the later part of the consolidation phase, where a cargo flight to deliver power, mining, and LLOX elements has been inserted. Due to space basing of the LEVs, there is a resulting 5 t increase in cargo capacity of landers.

1.2 Overview.

This document describes the reference architecture developed and used during the 90 Day Study Period for Option 5, with ISRU emphasis.

Section 2 provides a background for understanding the reference architecture concept and the terminology used. This section also describes the three phases of development (Emplacement, Consolidation, and Operations/Demonstration) and the top level mission objectives of each. The methodology of the approach is also described.

Section 3 describes the specific baseline reference architectures for both the lunar and martian outposts. This section details the mission elements delivered and the resulting layout of these elements on the surface.

A detailed manifest is included in Appendix A and includes figures for mass. Volume, and power requirements are included (if known, in the Lunar Cargo List). The information provided reflects version 90.1 of the Element/Subsystems Data Base with the elements referenced by their associated IDs.

2.0 REFERENCE ARCHITECTURE CONCEPT

2.1 Background.

2.1.1 Taxonomy

The Planet Surface Systems Office has developed the following terminology to describe the various aspects of planetary surface systems. This taxonomy includes the terms element, subsystem, functional area, and architecture. These terms are defined as follows :

> *Element* - Refers to the major hardware items such as rovers, habitat modules, and power plants. An element may share in the accomplishment of several functions.
>
> *Subsystem* - Refers to the major functional systems that perform a specific operation for an element. Examples of subsystems of a habitat module would be the life support system and thermal control system.
>
> *Functional Area* - Refers to a group of elements and activities with related functions and attributes. Functions may be distributed among several elements. For the 90 day study PSS identified 5 functional areas which are discussed in Paragraph 2.1.3.
>
> *Architecture* - Refers to the overall system structure of the planetary surface systems. Reference architecture includes site layouts and interfaces between different elements and functional areas.

This taxonomy was chosen to correspond with National Space Transportation System (NSTS) terminology where an orbiter is an element and each orbiter component, such as communications, is a subsystem. Note however, in NSTS terminology, a "system" would correspond to the Integration Agent (IA) organizational term "functional area."

2.1.2 Lunar/Martian Development Phases.

For the 90 day study period, Mission Analysis and Systems Engineering (MASE) developed a Lunar and Martian Program Mission Statement, *Human Exploration Study Requirements*, for the development of the Moon and Mars outposts in three phases : Emplacement, Consolidation, Operations/Demonstration.

Please note that this document will describe the Mars outpost reference architecture layout through the Emplacement Phase only. The 90 day study did not address the Consolidation and Operational Phase. The objective of the Mars Emplacement Phase is to establish a manned presence on Mars using the experience base gained in the lunar outpost during its development phases.

Emplacement Phase.

The Lunar Emplacement Phase will be used as a testbed to develop the techniques required to set-up and operate an outpost in a non-terrestrial environment. Although experience from terrestrial conditions that may be analogous to lunar or martian conditions will assist in preparing for this phase, the Emplacement Phase allows the opportunity to apply techniques and technologies developed for a planetary surface. The Mars Emplacement Phase will use the concepts and procedures developed during the deployment of the lunar outpost as a basis for establishing a permanent habitat on Mars. The goals for the Lunar Emplacement Phase are to:

- Assure permanent habitation using a habitat that is completely self-contained.

- Develop operations for local surface activities.

Consolidation Phase.

During the Lunar Consolidation Phase activities will center on:

- Learning to construct prefabricated habitation facilities.

- Developing technologies for the use of lunar and martian resources. Testing and evaluating systems and operations on the lunar surface for eventual application to Mars missions.

- Expanding the outpost's area of influence.

Operations / Demonstration Phase.

The Lunar Operations / Demonstration Phase objective is to achieve a steady state operation of the lunar outpost and to use local resources to help sustain the outpost and make the launch and landing operations more efficient with the utilization of lunar LOX.

2.1.3 Functional Areas.

As in Option "A", Planet Surface Systems identified five functional areas for the purpose of the Lunar/Mars 90 Day Study. Table 2.1.3-I shows the five functional areas and supporting activities of each. The lunar/martian outpost site layout concepts developed during this 90 day study period satisfy the requirements specified, either stated or implied, by the individual activities within each of the functional areas. The following summarizes the functional areas.

PSS FUNCTIONAL AREA	RELATED ACTIVITIES
HUMAN SYSTEMS	Life Support Systems Crew Systems Shelter EVA Systems IVA Systems
SUPPORT AND UTILITIES	User Accommodations Telecommunications, Navigation, & Information Mgmt. Energy
SURFACE VEHICLES	Construction Mining Crew & Materials Transport
IN-SITU RESOURCE UTILIZATION	Beneficiation Processing Storage Distribution
LAUNCH AND LANDING	Ascent / Descent Operations Payload Integration / Deintegration Servicing / Fueling Storage Distribution Environmental Protection

Table 2.1.3-1 PSS Functional Areas with Related Activities.

Functional Area 1 - Human Systems.

Human systems encompass areas that relate directly to the crew, either by providing for their well-being or by enabling crew operations. This includes the following categories : Life Support Systems, Crew Systems, Shelters, and EVA and IVA Systems.

Life Support Systems. Life support systems include items that are available in habitats, rovers, and other applicable surface elements providing for the protection and support of crew members. These items would include water, gases for atmosphere regeneration, and food for crew members for specific tours of duty at the outpost. Closure targets mean closed with respect to resupply from Earth. Resupply categories include water, gases, food, crew items (e. g., garments, personal hygiene), and filters and expendables for life support systems.

Crew Systems. Crew systems include the items needed to provide crew comfort and well-being. Showers, beds, hygiene and health maintenance facilities are examples of crew systems

Shelters. Shelters include fixed structures for providing a suitable environment (e. g., protection from solar and cosmic radiation and other environmental hazards such as vacuum and chemicals) for crew members. Shelters may be permanent or temporary; man-tended or permanently manned.

Extra-vehicular Activity (EVA) Systems. EVA systems provide equipment and techniques for human operations outside of pressurized, life-supporting environments. EVA systems include Extravehicular Mobility Units (EMUs), mobility aids, and other associated equipment.

Intra-Vehicular Activity (IVA) Systems. IVA systems provide the equipment and techniques for human operations within pressurized, life-supporting environments. Examples of IVA operations include housekeeping, laboratory analyses and operations, and supervisory and remote control of surface operations.

Functional Area 2 - Support and Utilities.

Support and utilities encompass all elements installed, constructed, and/or fabricated for basic support of outpost activities. This includes the following areas: User Accommodations, Telecommunications, Navigation and Information Management (TNIM), and Energy.

User Accommodations. User accommodations pertain to elements and operations that do not directly support outpost development and operation activities. This includes science such as Astrophysics, Planetary Science, Life Science, and Applications Research. Astrophysics refers to astronomy that involves sensing of distant objects and signals. Typical elements include radio telescopes, optical monitoring telescopes, or low frequency (LF) arrays. Planetary science refers to the study of the planetary body on which the surface systems are deployed. Typical elements include seismic arrays and meteorological stations. Life science includes biological, biomedical, physiological, and psychological research. Other science includes scientific disciplines not listed in the above categories. Applications research efforts includes user conducted research or demonstrations with an applied objective in mind. An example of an applications research effort would be to determine the effects of combining terrestrial and planetary chemicals or a propellant plant demonstration.

Telecommunications, Navigation, and Information Management (TNIM). TNIM covers all telecommunications to include data processing, navigation and tracking elements, and facilities which support all outpost operations and activities. Telecommunications include internal communications (analog, digital, voice, and message) and associated interfaces in support of all surface activities. PSS concerns are limited to internal communications, i.e. those means and networks established to support surface (local) activities. Navigation and tracking include the elements and facilities supporting surface system operations involved with guidance, navigation and control. As required, telecommunications and data systems provide support to navigation and tracking activities. Data systems include those elements which provide data processing for surface systems. The exchange of data among surface data processing systems or elements is provided by internal communications means and networks. Information management is comprised of actions taken to define what data or information are needed; where they are needed; and how, in what form, how frequently, and by which means they will be distributed to the user. The user may be a person or a machine.

Energy. The energy functional area provides for the generation, conversion, storage and transmission of power and energy. The surface systems major energy needs for fixed or mobile applications are typically mechanical, electrical, and thermal. Generation provides sources of energy in the amounts and levels required by surface systems. Conversion provides for transformation of one form of energy into another. Storage provides for storing energy for later use. Transmission provides for the conditioning and routing of energy. Management and distribution provides for transmission conditioning, switching, and conservation control of energy. Thermal management provides for dissipation of wasted heat and control of surface systems temperatures within acceptable ranges.

Functional Area 3 - Surface Vehicles

The surface vehicles functional area includes all rovers and other types of vehicles that facilitate movement on the surface. The activities involve the following: Crew Transport and Transfer, Construction, Mining, and Materials Transport.

Crew Transport and Transfer. This includes the pressurized transfer of crew between the flight vehicles and habitat. It also involves the unpressurized transportation of crew to various locations on the surface.
Construction. Construction operations may include site preparation, excavations, foundations, anchoring, and backfilling. Operations which involve minimal processing of native materials (e. g., regolith) are considered part of construction.
Mining. Mining refers to the extraction of the raw feedstock from the planet surface.
Materials Transport. Materials transport is the function of moving input materials between the various processing steps following initial extraction.

Functional Area 4 - In-Situ Resource Utilization(ISRU).

ISRU refers to operations and elements that do more than minimal processing of native planet materials (e. g., bagged regolith, regolith mounds). They may include propellant production, cast basalt, sintered blocks, and other processes. The products of these operations are generally simple: liquid oxygen, argon gas, metals, ceramic blocks. The following are part of ISRU: Beneficiation, Processing, Storage, and Distribution.

Beneficiation. Beneficiation is the refinement or enhancement of input materials.
Processing. Processing is the conversion of beneficiated inputs to refined output.
Storage. Storage includes those elements and facilities that store the output materials before final distribution of their use (e.g., tanks and refrigeration for liquid oxygen).
Distribution. Distribution is moving of the output products to their final destination.

Functional Area 5 - Launching and Landing Operations.

Launching and landing operations encompass landing or launching and servicing activities for Excursion Vehicles (EVs), e. g., Lunar Excursion Vehicles (LEVs) and Mars Excursion Vehicles (MEVs). Launch and Landing includes: Ascent/Descent Operations, Payload Integration/Deintegration, Servicing/Fueling, and Storage.

Ascent/Descent Operations. Ascent/descent operations include the activities associated with landing and launching EVs. Countdown operations are included.

Payload Integration/Deintegration. Payload integration and deintegration (segregation) encompass activities, facilities, and equipment that involve the interfaces between payloads and EVs. This includes loading and offloading.

Servicing/fueling. Servicing and fueling activities involve maintenance and fueling support for the EVs to include auxiliary power, thermal control, and like items.

Storage. Storage includes the elements and facilities that store (e. g. tanks and refrigeration for liquid oxygen) the materials needed by the EVs.

2.2 Methodology.

As in Option "A", the methodology used to determine the lunar and martian outpost reference architecture began with an analysis of requirements and elements lists provided by the PSS program office. Table 2.2-I summarizes the contents of these PSS lists by functional area for the lunar and martian programs. An asterisk ("*") denotes an element considered a major "architectural element" - a structure, vehicle, or support equipment that remains stationary in its placement on the surface.

	Functional Area	Element	
LUNAR	HUMAN SYSTEMS	Initial Habitat Module	*
		Airlock	*
		EMU	
		Hab/Lab Module	*
		Constructible Hab/Lab	*
		Logistics Module	*
	SUPPORT AND UTILITIES	Logistics Pallet	
		Payload Unloader	
		TNIM Equipment	
		Excavation Pyrotechnics	
		Power System (25/12.5 kW)	*
		Thermal System	
		Power Module (100 kW)	*
		LLOX Fueling Pallet	
		Nuclear Power Plant (550 kW)	*
	SURFACE VEHICLES	Unpressurized Robotic/Manned Rover	
		Pressurized Manned Rover (Science dedicated)	
		Excavator/Loader	
		Regolith Hauler	
	IN-SITU RESOURCE UTILIZATION	Lunar Oxygen Demonstration	
		Integrated LLOX Demonstration	
		LLOX Production Plant (5t /yr)	*
	LAUNCH AND LANDING	LEV Servicer	*
		Pressurized Transport Module	*
		Pads	*
MARS	HUMAN SYSTEMS	Initial Habitat Module	*
		Airlock	*
		EMU	
		Hab/Lab Module	*
		Constructible Hab/Lab	*
		Logistics Module	*
	SUPPORT AND UTILITIES	Logistics Pallet	
		Payload Unloader	
		TNIM Equipment	
		Excavation Pyrotechnics	
		Power System (25/12.5 kW)	*
		Thermal System	
		Power Module (100 kW)	*
	SURFACE VEHICLES	Unpressurized Robotic/Manned Rover	
		Pressurized Manned Rover (Science dedicated)	
	IN-SITU RESOURCE UTILIZATION	ISRU Demonstrator (future)	*
	LAUNCH AND LANDING	MEV Servicer	*
		Pads	*

Table 2.2-I PSS Lunar and Mars Outpost Element List grouped by Functional Area

The required functions and elements which would satisfy those selected were determined using the functional area grouping methodology illustrated in the previous table 2.2-I.

Grouping elements and activities into functional areas was useful in identifying functional interfaces between various elements and components of the outpost.

To consider the placement of these elements and the site layout of the outpost, an *activity zone* approach was used. Given the selection of elements to meet mission requirements, major activities requiring proximity were identified and grouped together. These groupings provided the basis for partitioning the outpost planet surface into distinct zones. The activities occurring in each zone are specific in nature, but demand effective interaction for safe and efficient operations at the outpost. This interaction is facilitated by *linkages*, or circulation patterns. Figure 2.2-I illustrates the methodology used to determine the zones and linkages.

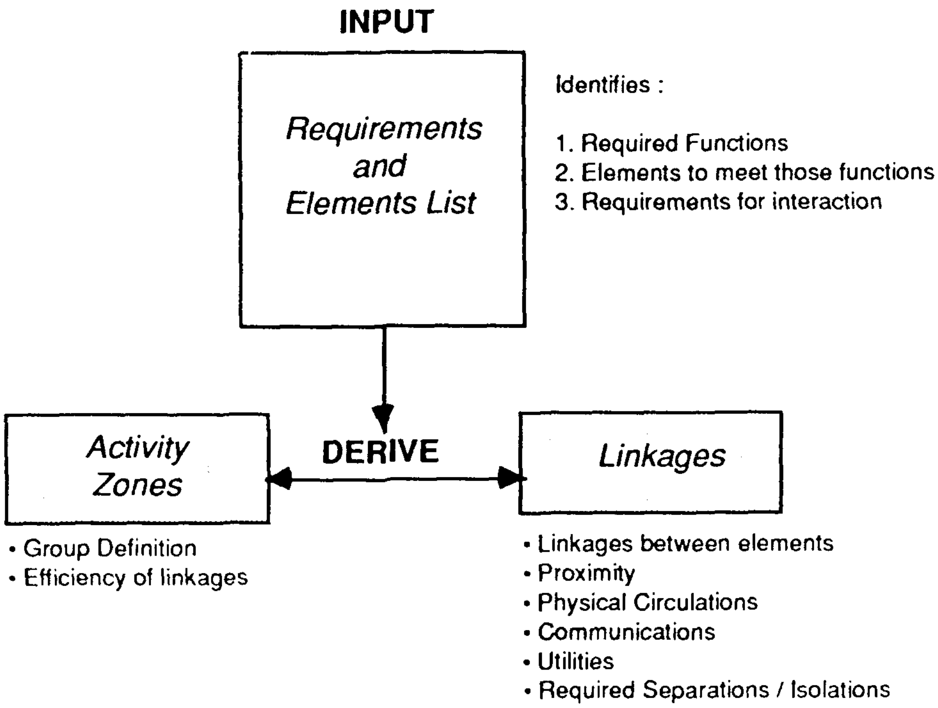


Figure 2.2-I Methodology

Five zones were established as follows:

Zone 1 - Crew Habitation
Zone 2 - Science Users
Zone 3 - In-Situ Resource Utilization (ISRU)
Zone 4 - Launch and Landing
Zone 5 - Power Production

Zone 1 - Crew Habitation exists as the central hub of all crew activities. The pressurized facilities are the focus of this zone.

Zone 2 - Science Users area is dedicated to the science community and provides an unobstructed surface for deploying passive science equipment independent of site requirements.

Zone 3 - The In-situ Resource Utilization area is an isolated area where the demonstration of material processing of local resources can occur.

Zone 4 - The Launch and Landing area provides the capability for the outpost to sustain the use of reusable flight vehicles, as well as payload delivery and unloading.

Zone 5 - Power Production is an area that would be isolated and would contain the primary nuclear energy sources for the outpost.

The main linkages between these zones are identified in terms of movement:

Movement of crew
Movement of Logistics
Movement of Utilities
Movement of Communications

Movement of Crew - Once the initial habitat is in place, circulation of the crew takes place by two means : 1) by foot, internal and external to the habitat, and 2) by surface transportation vehicle, unpressurized vehicles for short traverses and pressurized vehicles for long-distance traverses or extended surface activities.

Movement of Logistics - The moving of crew resupply items is an ongoing activity. These materials and supplies must be unloaded once delivered to the surface. They must then be moved to the required storage. Perishable items need pressurized storage and other items may be stored external to the habitat.

Movement of Utilities - The movement of utilities refers to the transfer of electric power from the power source to the end user. Options for utility routing include : elevated above grade, exposed at grade, through conduit at grade, or buried below grade.

Movement of Communications - The equipment required to move initial communication is minimal and is integrated into the first LEV. As activities expand, the crew will need the ability to stay in constant contact with the central ground station.

The specific description and discussion of these zones and linkages as they pertain to the Lunar / Mars 90 Day Study occurs in Section 3.0.

3.0 OUTPOST BASELINE REFERENCE ARCHITECTURES

3.1 Development Concept

The reference architectures for both the lunar and martian outposts were developed using the methodology described in paragraph 2.2. The reference architecture, or site layout, resulted from the placement of the five activity zones linked in the most efficient manner. Figure 3.1-I graphically illustrates the zone layout for the lunar and martian outposts and the linkages between them. The primary linkages occur between the Crew Habitation - Zone 1 and the other zones distributed peripherally. These linkages involve crew movement and distribution of utilities. Secondary linkages involve transport of locally produced material such as lunar liquid oxygen (LLOX) and science distribution activities.

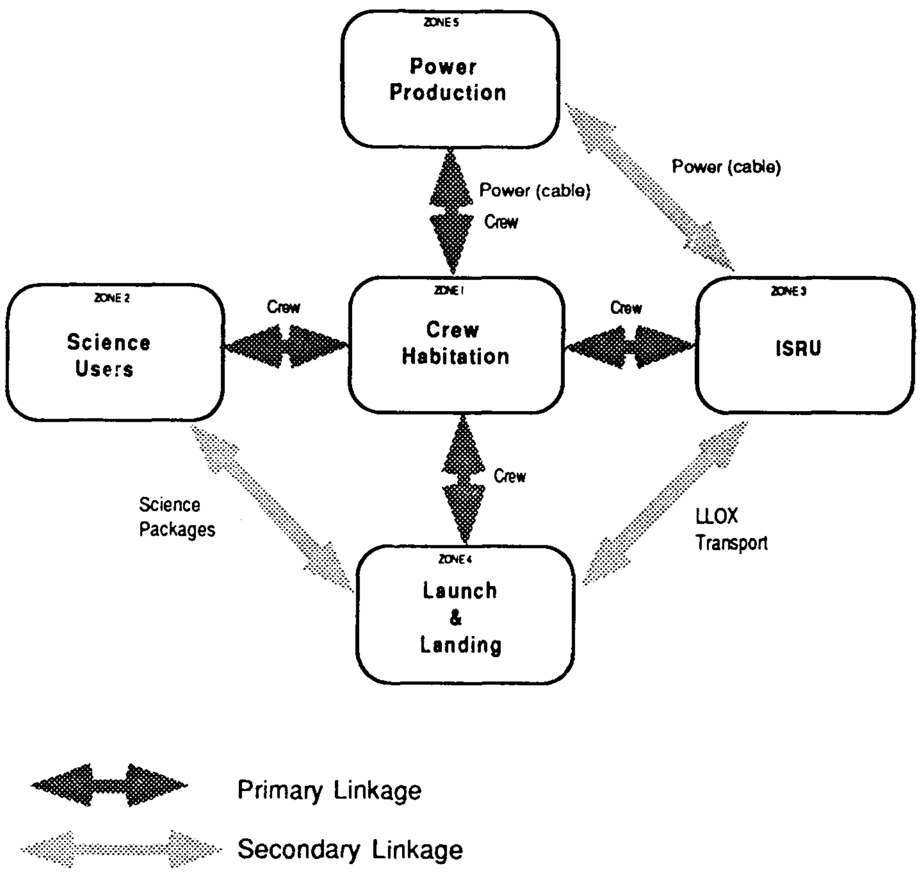


Figure 3.1-I Zone Layout & Linkages, Lunar and Mars Outposts

The actual site layout that resulted is shown in Figure 3.1-II and covers an area 2.5 kilometers by 2.0 kilometers. This site would be applicable to both the Moon and Mars.

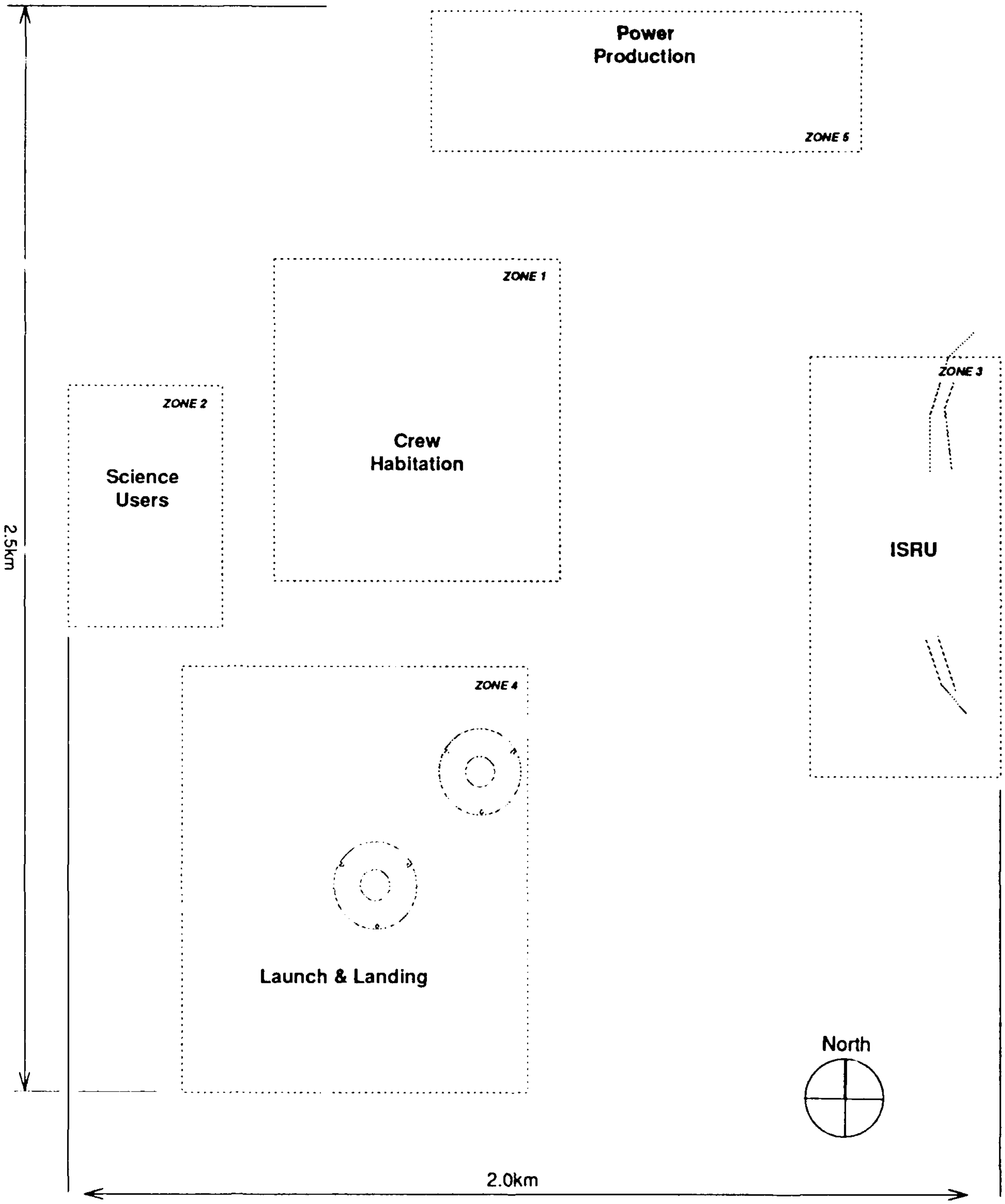


Figure 3.1-II Outpost Site Layout

3.1.1 Key Features.

The baseline reference architecture for the lunar and martian outposts was determined using the following concepts:

•Habitats are operations centers which provide:

Command, control, and communications.

Laboratories, workshops, and pressurized storage.

Living quarters, medical facilities, dining areas, and hygiene facilities for the well-being and safety of the crew members.

•Rovers and EVA systems can be regenerated at habitats. Rovers will provide umbilicals/recharge for EVA elements.

•Energy management is achieved through:

Centralized power plants with utility distribution.

Backup and emergency power for habitats.

•TNIM links outpost activities with central control from habitats and auxiliary control from local stations (e. g., rovers, landers, survey parties).

•User accommodations requirements are satisfied as follows:

Habitats provide the laboratories.

Mobile facilities for analysis and data collection are provided in rovers.

Deployment of distributed science equipment is supported within normal outpost operations and available surface vehicles.

3.2 Lunar Outpost Layout - Option "5a"

3.2.1 Lunar Outpost Development Overview

The resulting Lunar Outpost is shown in Figures 3.2.1-I, 3.2.1-II, and 3.2.1-III. These plans show the outpost at the end of the three phases - Emplacement, Consolidation, and Operation/Demonstration, respectively.

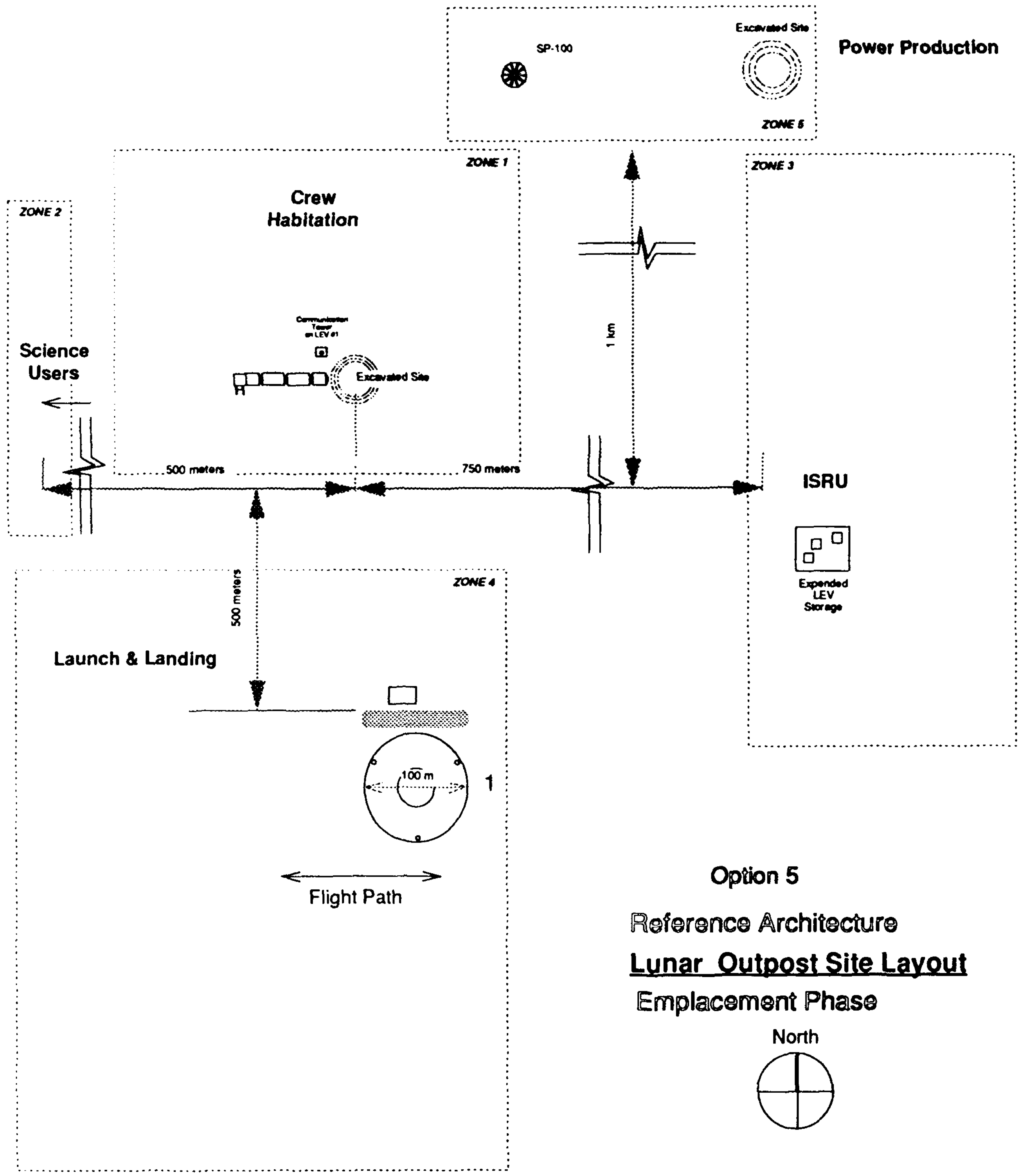


Figure 3.2.1-I Lunar Outpost Layout - Emplacement Phase

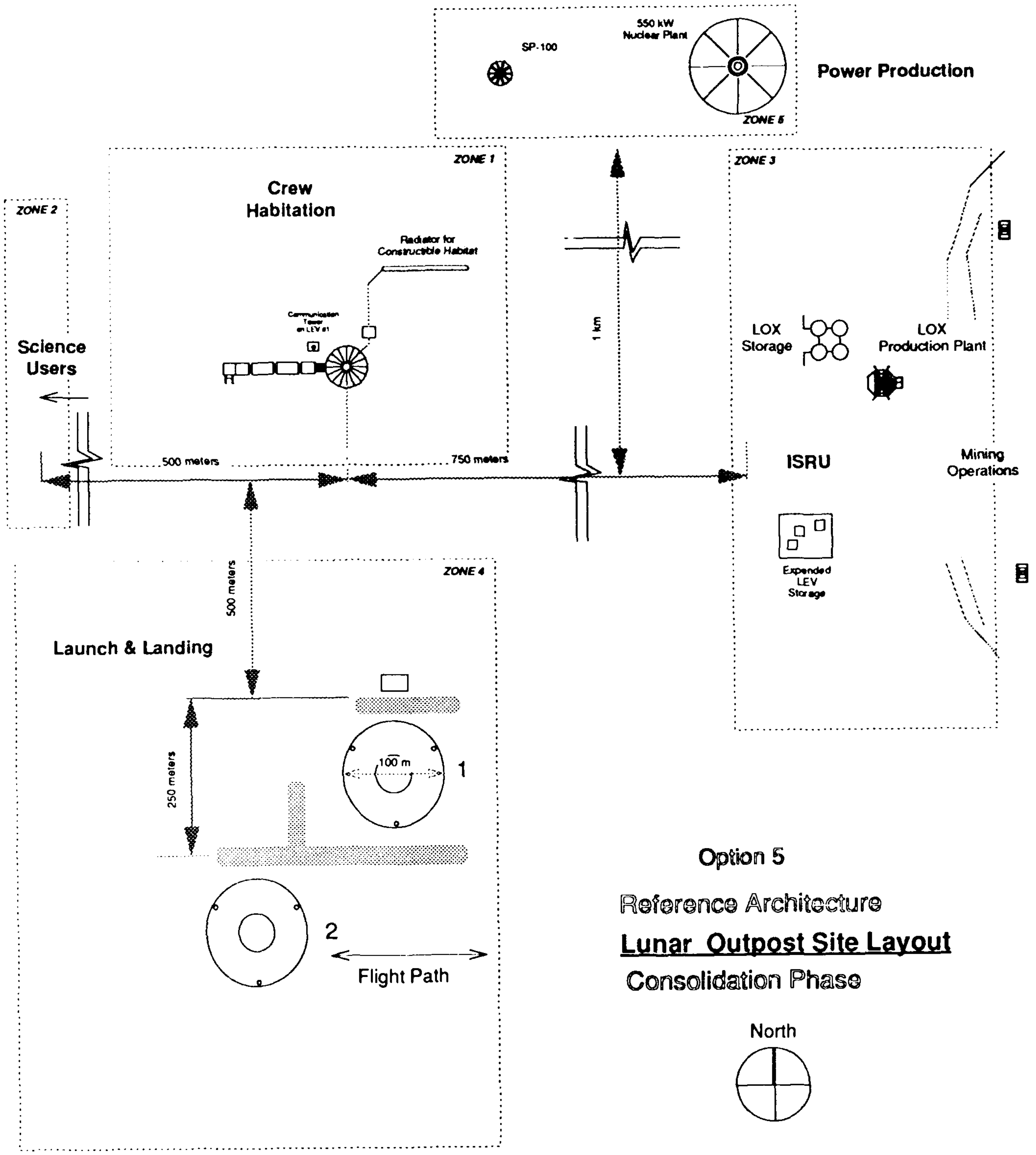


Figure 3.2.1-II Lunar Outpost Layout - Consolidation Phase

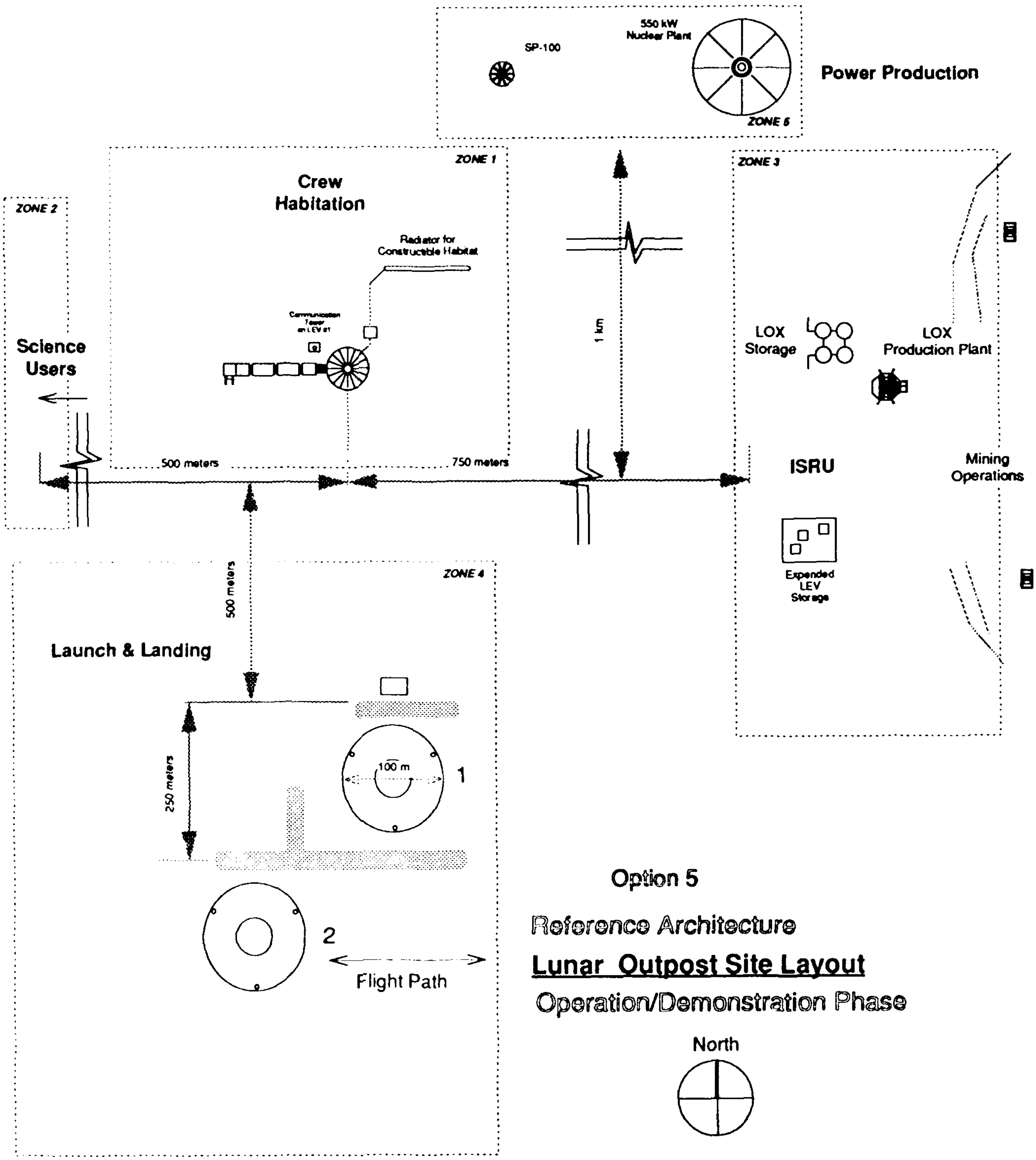


Figure 3.2.1-III Lunar Outpost Layout - Operation/Demonstration Phase

3.2.2 Rationale.

The lunar outpost will be divided into five activity zones previously described; Crew Habitation (Zone 1), Science Users (Zone 2), In-Situ Resource Utilization (Zone 3), Launch and Landing (Zone 4), and Power Production (Zone 5). Zoning allows consolidation of activities and performance of these activities within a particular area. The rationale for zoning in the locations as shown was based on satisfying a number of considerations which were divided into two categories; overall outpost considerations and considerations specific to each zone. These considerations were then used as the guidelines for outpost evolution planning.

Overall Outpost Rationales.

Overall outpost zoning is driven by concerns for crew safety, and isolation of clean areas from dust-creating operations

(1) Crew safety entails the isolation of the main crew quarters from hazardous activities such that:

a. The habitat is isolated from the cryogenic storage needed to fuel the landers. This is because of the possibility of explosion present with these materials.

b. The habitat is at least 500 meters from any launch and landing pad to provide protection from any possible aborted landings. Also, this distance isolates the habitat from landing ejecta.

c. Nuclear power plants must be located at least 1 km from crew living and working areas. This is to isolate the crew from possible radiation hazards.

(2) Isolation of dust-creating operations requires:

a. The isolation and separation of the Science Users Zone from ISRU (mining & processing operations) and Launch and Landing Zones (ejecta from LEVs).

b. The isolation and separation of the Crew Habitation Zone with its photovoltaic arrays and radiators from the ISRU (mining & processing operations) and Launch and Landing Zones (ejecta from LEVs).

c. The separation of the Power Production Zone with its radiators from the ISRU (mining & processing operations) and Launch and Landing Zones (ejecta from LEVs).

The outpost layout shown in Figures 3.2.1-I through 3.2.1-III accommodates considerations for crew safety and the separation of clean areas from dust-creating operations.

Zone - Specific Rationale

The rationale unique to each zone are as follows:

Zone 1 - Crew Habitation:

a. The crew quarters must be the safe haven of the outpost. However, the crew must support and have access to all activities at the outpost. The functions of the habitat area include the actual crew living accommodations, life support system, and thermal control system.

b. There must be immediate access to pressurized and non-pressurized surface vehicles to provide emergency exits in the event of a hazardous situation in the habitat and to reduce the EVA time needed for going from the habitat to the vehicle.

c. The initial outpost communications elements, ground station and communications tower, are located to provide immediate access by crew members - preferably IVA.

d. The initial landing pad will be located in Zone 4, Launch and Landing, no less than 500 meters from the habitat. Precautions will be taken to protect reflective and optical surfaces on outpost equipment in Zone 1 from possible blast ejecta. This distance will require a 2 to 5 minute rover trip at speeds of 10 to 15 km per hour between this landing pad and the habitat. Therefore, routes planned between this and a subsequent landing pad and the habitat should allow the crew to safely walk back to the habitat in the event a rover fails.

Zone 2 - Science Users

a. Access to the Science Users Zone will be provided by an unobstructed stabilized circulation path that is a minimum of 25 meters wide.

b. The Science Users Zone is a dedicated area west of and approximately 500 meters from Zone 1 (Habitat). This area must provide an unobstructed, dust-free surface for deploying telescopes and other passive science equipment.

Zone 3 - ISRU

a. Zone 3 will be dedicated to mining operations, raw feedstock processing, and product storage facilities.

b. Zone 3 must have access to Zone 1 (Habitation) and Zone 4 (Launch and Landing) because crew personnel must be moved to and from Zone 1 to conduct Zone 3 operations and because Zone 3 is required to support LEV refueling operations in Zone 4.

c. Mining operations will be disruptive to the surface. Therefore, the mining area is to be on the outer fringes of the ISRU zone; a minimum of 30 meters from the process plant. This approach also allows for future mining activities.

d. Tailings must be collected by a hauler and deposited in a tailings discharge area adjacent to the mining operation.

e. Buried liquid hydrogen tanks are located immediately adjacent to the main roadway to ease transfer activities.

f. The liquefied oxygen product is stored in insulated tanks to minimize boil-off. An oxygen loading station must be be located adjacent to the tanks. This station should include pumping equipment and a flexible hose for loading the oxygen into transfer vehicles and/or equipment, such as the LEV servicer.

Zone 4 - Launch and Landing

a. During the early part of the Lunar Emplacement Phase, landing facilities will be coupled with overall outpost operations; primarily in the habitat area. EVA will be needed to get crews and payloads to the outpost until pressurized transfer from vehicle to outpost becomes available in the Lunar Consolidation Phase. The initial launch and landing pad will be located 500 meters from the habitat area. One additional pad will be located to the south of pad #1, spaced a minimum of 250 meters apart.

b. The landing pads need to be aligned in a north-south orientation to accommodate flight paths from the east to west.

c. The landing pads must be relatively flat, leveled, stabilized surfaces each with a 50 meter radius and separated by 250 meters to limit possible damage to an adjacent pad from ejecta. Blast barriers would provide additional protection and allow equipment such as the LEV Servicer to be located 100 meters from the pad.

d. Three pad markers are placed on the perimeter of each pad.

e. An LEV servicer is located in close proximity to one of the pads.

f. The initial launch and landing zone will be located 500 meters from the habitat zone and ISRU zone. This distance accommodates safety and navigation error and is within a 5 minute EVA walk to the habitat module should a surface vehicle fail. This time is based on a typical EVA walking speed of 3 to 5 km per hour. While the initial pad is located 500 meters away, a subsequent pad #2 would each be located nominally 250 meters more remote. The exact distance of pad #2 from the habitat would be determined after assessing launch and landing effects from initial landings on pad #1.

Zone 5 - Power Production

The energy requirements of the lunar and martian outposts need to be satisfied by power sources as follows.

a. The initial power source for the habitat module must be a nuclear SP-100 power module located in Zone 5. This type of power is needed in Zone 1 (Habitat) to provide a consistent source of energy.

b. When a larger habitat is deployed and the LLOX Production Plant is delivered, power requirements will be satisfied by the delivery and installation of a 550 kW Nuclear Power Plant. If possible, the nuclear plant will be located in a crater to provide nuclear shielding. The location of these two nuclear power plants constitute Zone 5 (Power Production and Distribution).

c. Shielding for the nuclear sources is assumed to be such as to require the location of Zone 5 a minimum of 1 kilometers away from Zone 1 (Habitat) and Zone 2 (ISRU).

3.2.3 Lunar Outpost Element Delivery and Set-Up Sequence.

This section describes the lunar outpost element delivery and set-up sequence. Each phase is broken down and key elements are listed by delivery on certain flights. This will illustrate the characteristics of the buildup of the outpost.

The Lunar Emplacement Phase.

The Lunar Emplacement Phase is initiated with Flight 0. The Payload Unloader, with attachments, is delivered. This will be the main piece of equipment used in cargo unloading and surface construction activities. Activities occurring during this flight involve site surface preparations and the use of excavation pyrotechnics that have been delivered on Flight 0. The communications tower and ground station are also delivered on this flight and deployed. The resulting reference architecture is shown in Figure 3.2.3-I.

Flight 1 is the first actual cargo flight. It emplaces the initial habitation module and associated airlock with a dustoff area. An SP-100 nuclear power module is deployed in the Power Production area away from the habitat.

Flights 2 and 3 are the initial flights that deliver crew to the surface for 30 day stay times. The Lunar Oxygen Demo is delivered and set up in Zone 3 and another Unpressurized Manned/Robotic Rover is delivered on Flight 3

Flight 4 delivers a laboratory module with Health Maintenance Facility (HMF) and airlock used for expanded science activities. Flight 5 delivers the LEV Servicer used in the Launch and Landing Zone for maintaining an LEV in that area. Figure 3.2.3-II depicts the outpost layout after Flight 5. Figure 3.2.3-III is an enhanced view of the Zone 1 Crew Habitation area after this flight. The Lunar Emplacement Phase is finished with Flight 5.

Table 3.2.3-I lists the major elements/subsystems delivered during the Emplacement Phase and summarizes the set-up sequence discussed above.

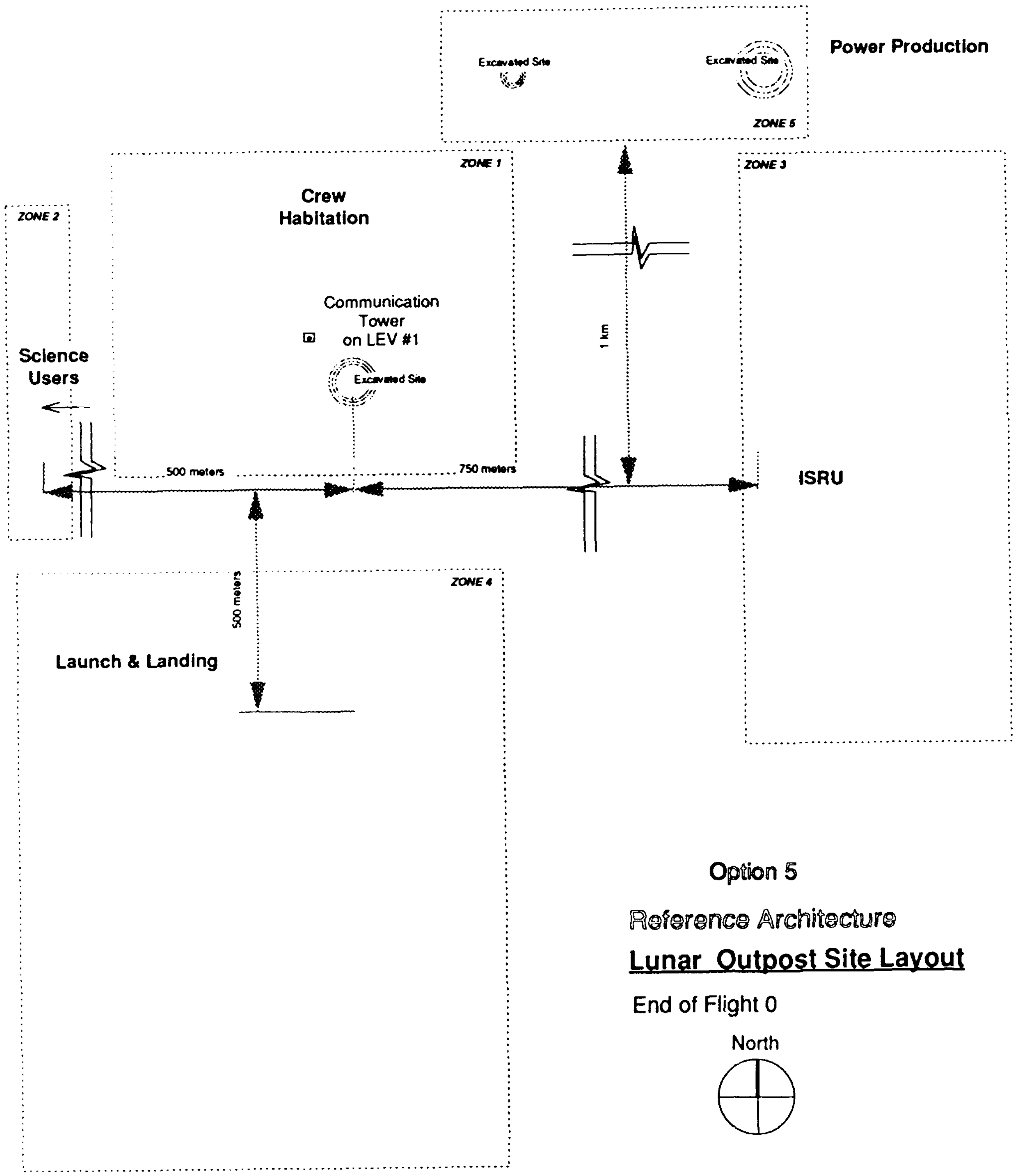


Figure. 3.2.3-I Lunar Outpost Site Layout - Emplacement Phase, End of Flight 0

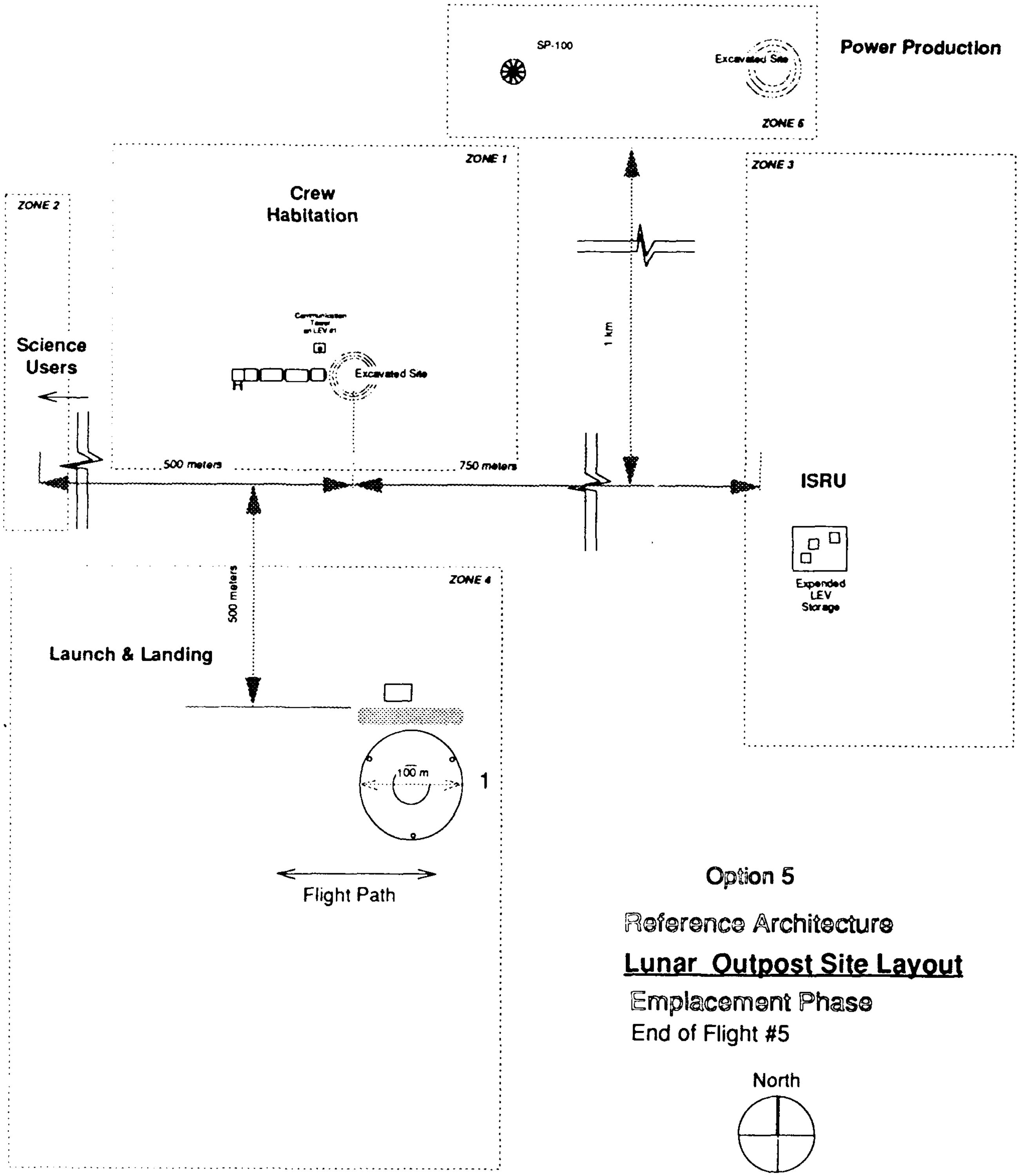
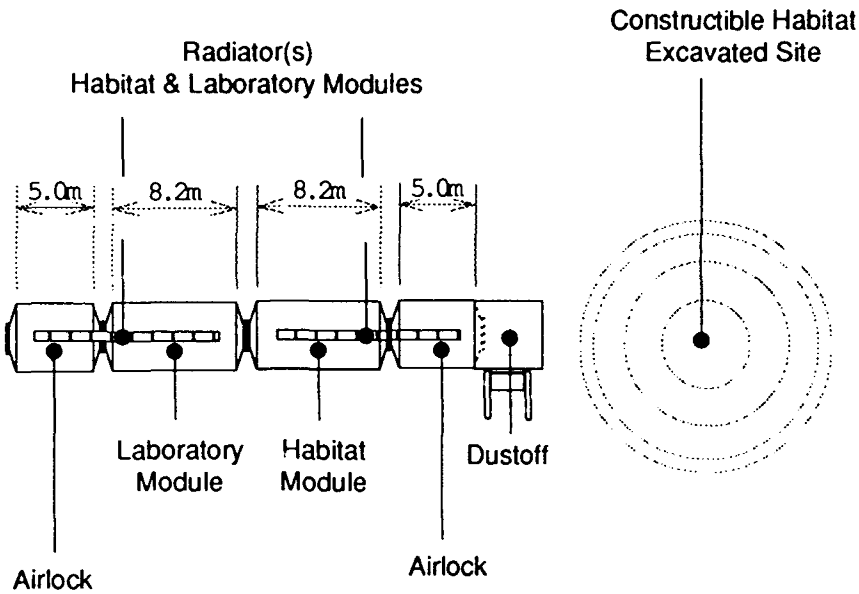


Figure 3.2.3-II Lunar Outpost Site Layout - Emplacement Phase, End of Flight 5



Reference Architecture

Lunar Outpost Site Layout

Zone 1 - Crew Habitation Area

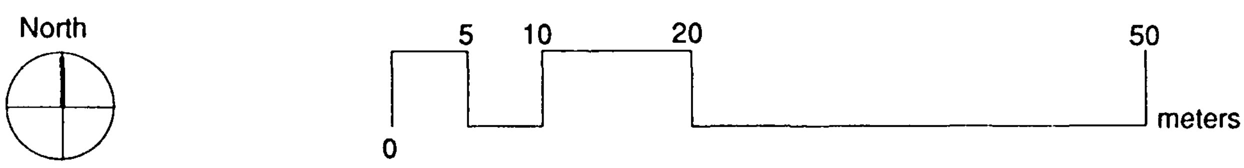


Figure 3.2.3-III Lunar Outpost Site Layout - Zone 1, Crew Habitation Area End of Flight 5

Activity	Element	Function
Flight 0	Payload Unloader	Accommodate Payload unloading from LEV. Transport habitat, associated equipment & exploration and scientific equipment from LEV to required sites.
	TNIM	Provides communications for the outpost.
	Unpressurized Manned/Robotic Rover	Provides site selection verification and means to obtain and return samples of 150 kg to 100 km.
	Excavation Pyrotechnics	Prepares site to allow Constructible Hab & Power Plant construction during later phases without disturbing ongoing outpost activities.
Flight 1	Initial Hab Module	Permanent habitable facility to support 4 crew for 30 days.
	Airlock #1 w/Dustoff	Required to transfer crew into hab from LEV & provides EVA capability.
	Power Module , SP-100	Provides 100 kW power to outpost.
Flight 2	EMUs	Required to transfer crew into hab from LEV & provides EVA capability.
	Lunar Oxygen Demonstration	Initial processing evaluation of feasibility of producing useful product from the lunar regolith.
Flight 3	EMUs	Required to transfer crew into hab from LEV & provides EVA capability.
	Unpressurized Manned/Robotic Rover	Provides means to obtain & return samples of 150 kg to 100 km.
Flight 4	Lab Module	Upgrades permanent habitat facility to support 4 crew / 90 days. Provide capability to perform science/lab functions in habitat (IVA). Provides Health Maintenance Facility (HMF).
	Airlock #2	Required to transfer crew into hab from LEV & provides EVA capability.
Flight 5	LEV Servicer	Provide capability to store and maintain 1 LEV including power, thermal protection, & heat rejection, and reliquefaction of O2 and H2.
	EMUs	Required to transfer crew into hab from LEV & provides EVA capability.

Table 3.2.3-1 Major Elements / Subsystems - Lunar Emplacement Phase

The Lunar Consolidation Phase.

The Lunar Consolidation Phase starts with Flight 6 with the delivery of another unpressurized rover. A pressurized manned rover is delivered on Flight 7. This rover is dedicated to science and provides a range up to 500 km. On Flight 8 the constructible habitat - structure, outfitting, and life support systems are delivered along with a Logistics Module for the constructible. An area has been dedicated to expended logistics modules. Figure 3.2.3-IV is an enhanced view of Zone 1 - Habitation Area at the end of Flight 8.

Flight 9 is a piloted flight and involves a surface stay of 180 days for the crew of (4). Flight 10 is a cargo flight and delivers the LLOX Production Plant capable of 5 t/yr. This flight also delivers and deploys the Nuclear Power Plant in Zone 5, and delivers a LLOX Fueling Pallet used in refueling landers. (2) Regolith Haulers and a Mining Excavator/Loader are delivered and used in Zone 3 in conjunction with the LLOX Production Plant.

Flight 11 ends the Consolidation Phase with the crew of (4) staying 600 days simulating a Mar's mission timeline. Figure 3.2.3-V illustrates the Lunar Outpost after Flight 11.

Table 3.2.3-II lists the major elements/subsystems delivered during the Consolidation Phase and serves to summarize the set-up sequence discussed above.

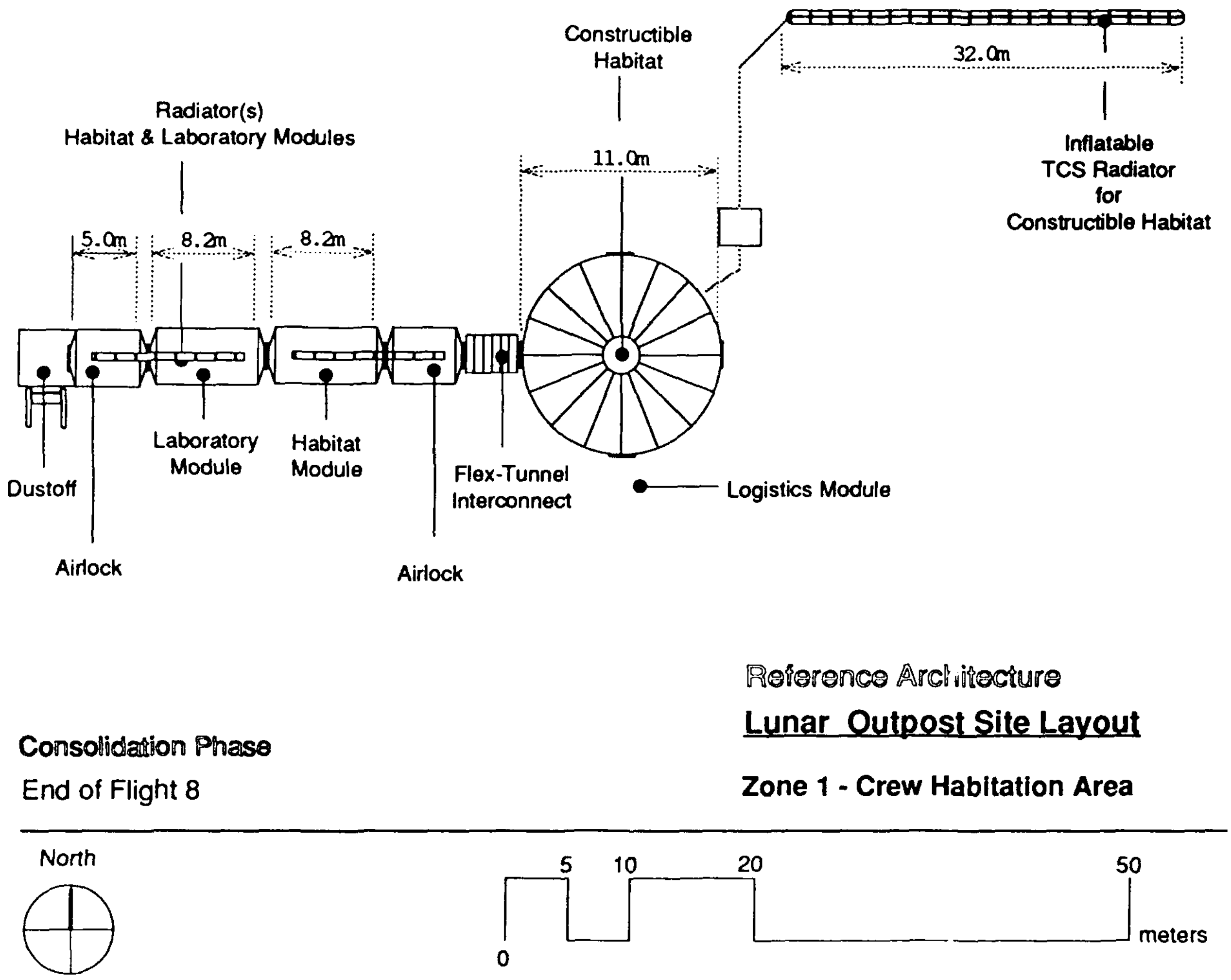


Figure 3.2.3-IV Lunar Outpost Site Layout - Zone 1, Crew Habitation Area End of Flight 8

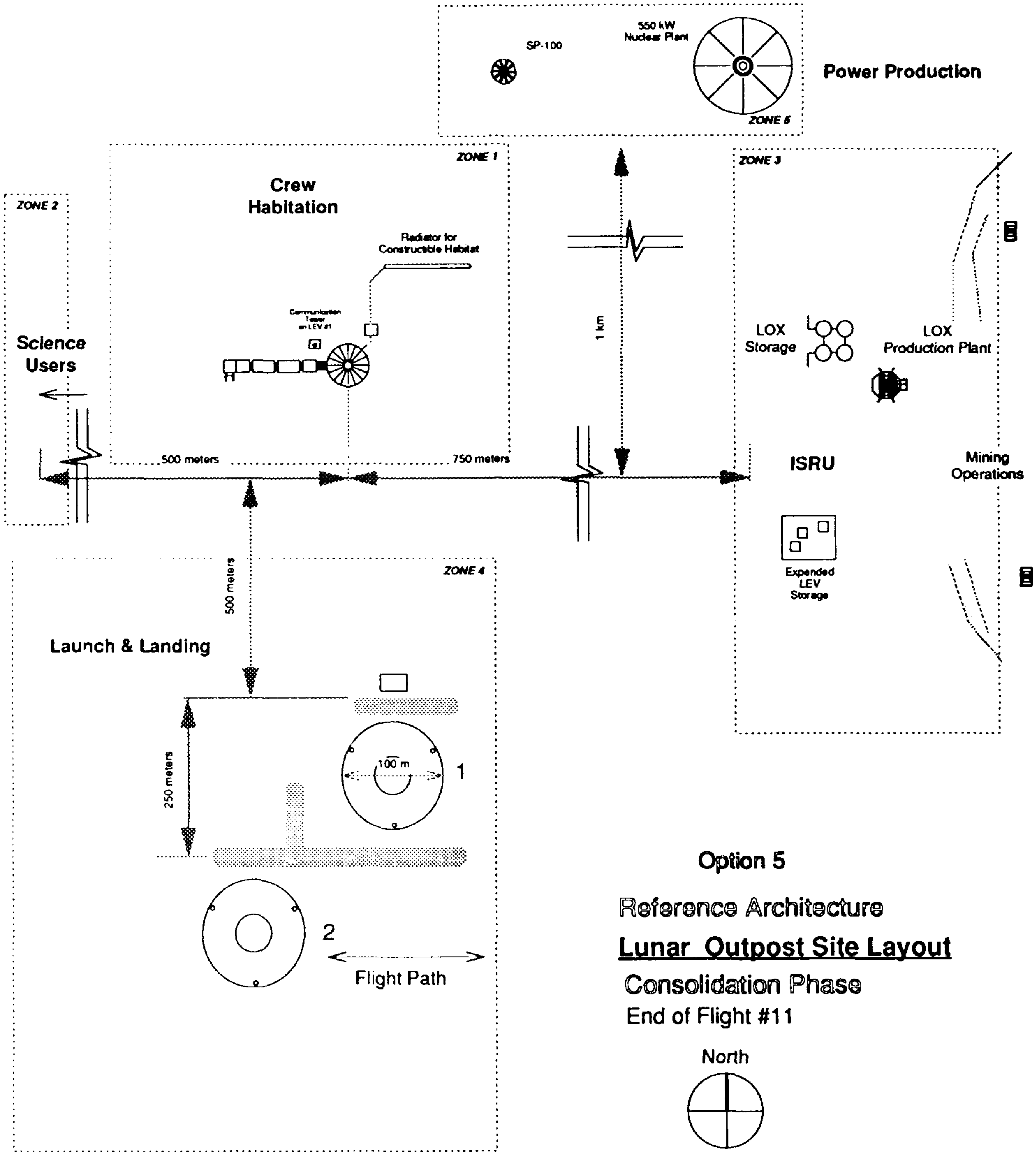


Figure 3.2.3-V Lunar Outpost Site Layout - Consolidation Phase, End of Flight 11

ACTIVITY	ELEMENT	FUNCTION
Flight 6	Unpressurized Rover	Provides unpressurized means of surface transportation for crew.
Flight 7	Pressurized Manned Rover	Provides capability of IVA surface sorties of 500 km.
Flight 8	Constructible Hab Outfitting	Provides interior furnishings capable of supporting 4 crew.
	Constructible Hab TCS	Provides means of rejecting waste heat in supporting 4 crew.
	Constructible Hab Air Supply	Provides means of supplying atmosphere in supporting 4 crew.
	Constructible Hab LSS	Provides means for life support in supporting 4 crew.
	Constructible Tunnel	Provides pressurized access between initial hab module and constructible habitat.
	Airlock #3	Required to transfer crew into hab from LEV & provides EVA capability.
	Constructible Logistics Module	Provides consumables, constructible Hab/Lab outfitting equipment, and spares necessary to support the Consolidation Phase.
Flight 9	No Cargo	
Flight 10	Nuclear Power Plant (550 kW)	Provides additional power required for LLOX production.
	LLOX Production Plant	Produces and stores 5 metric tons of LLOX per year for use in LEVs.
	LLOX Fueling Pallet	Enables the transfer of lunar-derived liquid oxygen from the production facility to the launch and landing area.
	Mining Excavator/Loader	Provides a means for excavating and loading regolith into regolith haulers.
	Regolith Hauler	Provides a means to transport regolith from mining area to processing plant.
Flight 11	No Cargo	

Table 3.2.3-II Major Elements / Subsystems - Lunar Consolidation Phase

The Lunar Operation / Demonstration Phase.

The Operation / Demonstration Phase commences with Flight 12. Science is strongly accommodated during this phase. A Pressurized Transport Module is delivered on Flight 14 to assist in IVA transfer of crew from landers to the habitat. The main element deployed during this phase is the ISRU Demonstration brought up on Flight 16. It is located in the ISRU Zone. Flight 20 is a flight direct to the lunar farside and is the last flight of this phase.

Figure 3.2.3-VI depicts the reference architecture at the end of the Operation / Demonstration Phase with 360 day crew stay times.

Table 3.2.3-III lists the major elements/subsystems delivered during the Operation / Demonstration Phase and serves to summarize the set-up sequence discussed above.

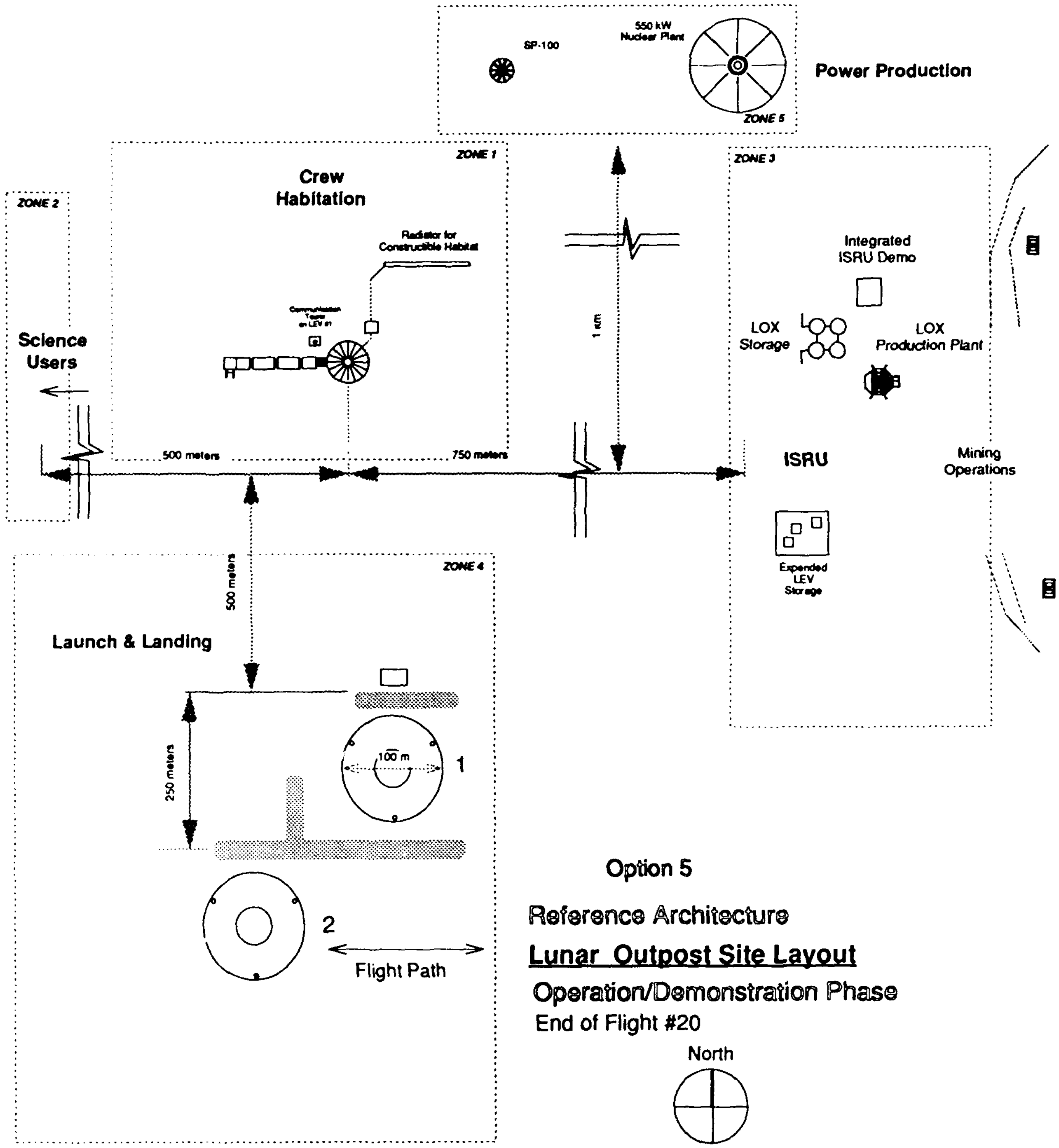


Figure 3.2.3-VI Lunar Outpost Site Layout - Operation / Demonstration Phase, End of Flight 20

ACTIVITY	ELEMENT	FUNCTION
• ***Flight 14***	Pressurized Transport Module	Provides means of transfering crew in a pressurized environment from LEVs to the habitat.
Flight 16	ISRU Integrated Demonstration	Provides means of actually demonstrating the production and use of locally produced materials.
•		

• **No major Cargo on Piloted Flights 15, 17, 18, 19, 20**

Table 3.2.3-III Major Elements / Subsystems - Lunar Operation/Demonstration Phase

3.3 Mars Outpost Layout.

3.3.1 Mars Outpost Development Overview

This section describes the Mars outpost layout through the Emplacement Phase only. The objectives of the Mars Emplacement Phase are to establish a manned presence on Mars, based on the experience gained during the lunar outpost development phases. This accounts for the repetitive nature of the information presented. Environmental conditions will differ and subsequent differences between lunar and martian systems elements will likely arise in future studies. The Mars Emplacement Phase outpost site layout is shown in Figure 3.3.1-I.

3.3.2 Rationale.

The rationale for zoning the Mars outpost site layout are the same as for the lunar outpost. The rationale provided in Paragraph 3.2.2 are applicable to the Mars outpost site layout.

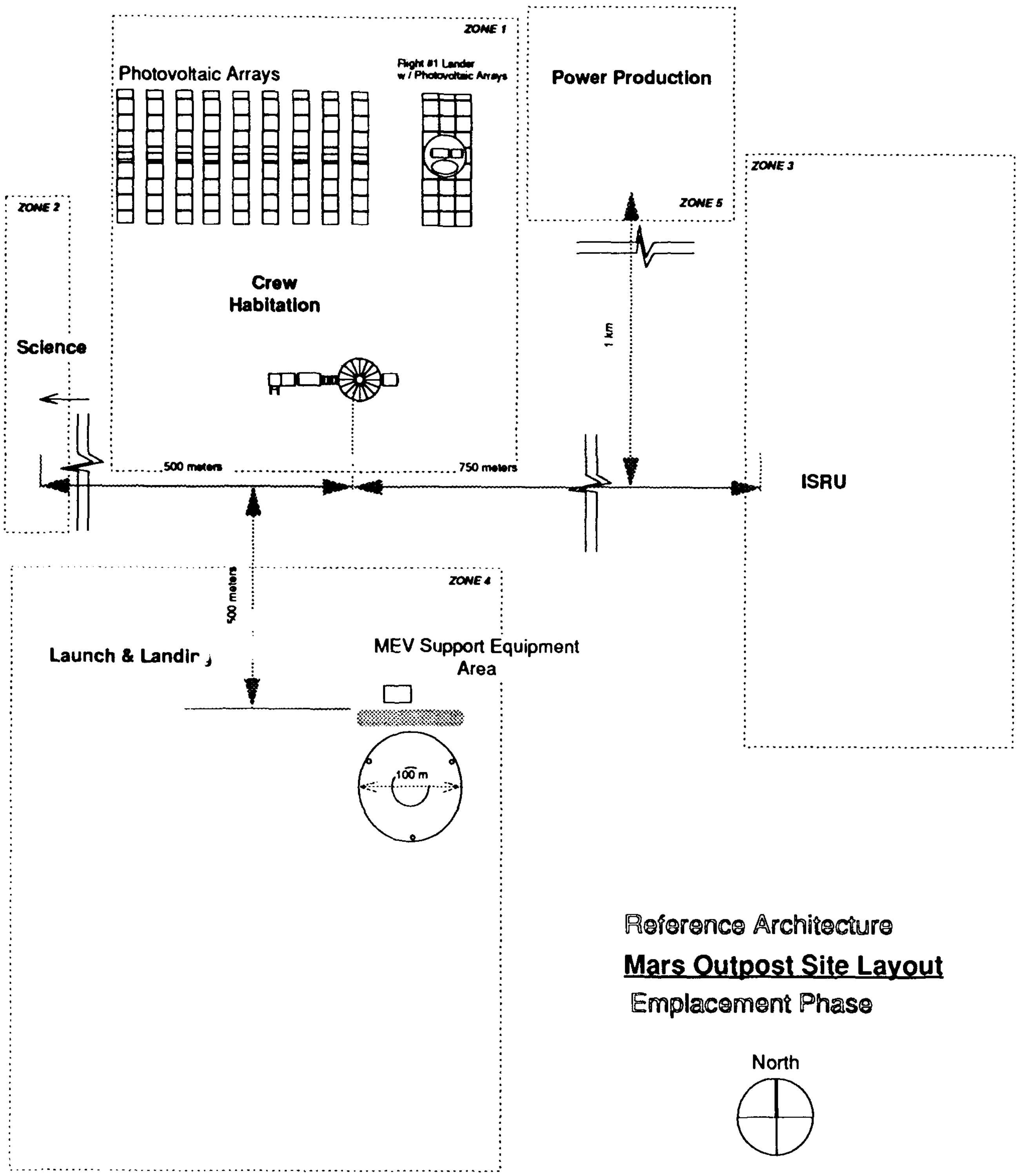


Figure 3.3.1-I Mars Outpost Layout - Emplacement Phase

3.3.3 Mars Outpost Element Delivery and Set-Up Sequence.

This section describes the Mars outpost element delivery and set-up sequence for the Emplacement Phase. The delivery and set-up sequence runs through the fourth flight to the surface of Mars and is presented in that manner.

Flights 1 through 3

Flights 1 through 3 are piloted and mainly expedition class missions. A habitat module and airlock are delivered but remain on the Mars Excursion Vehicle (MEV). A 25 kW PVA/RFC Power System also deploys from the MEV. These missions deal with site selection and an excavation (if a crater is not used) made for the future constructible habitat. Figure 3.3.3-I shows the Mars reference architecture at the end of Flight 3 at the selected site.

Flight 4

Flight 4 is a cargo flight and delivers the initial surface habitat module with airlock, the constructible habitat with airlock and logistics module, a 75 kW PVA/RFC Power System, and an MEV Servicer. These elements are deployed by the next crew mission arriving on Flight 5. Figure 3.3.3-II shows the Mars Outpost after Flight 5.

Table 3.3.3-I lists the major elements/subsystems delivered during the Mars Emplacement Phase and serves to summarize the set-up sequence discussed above.

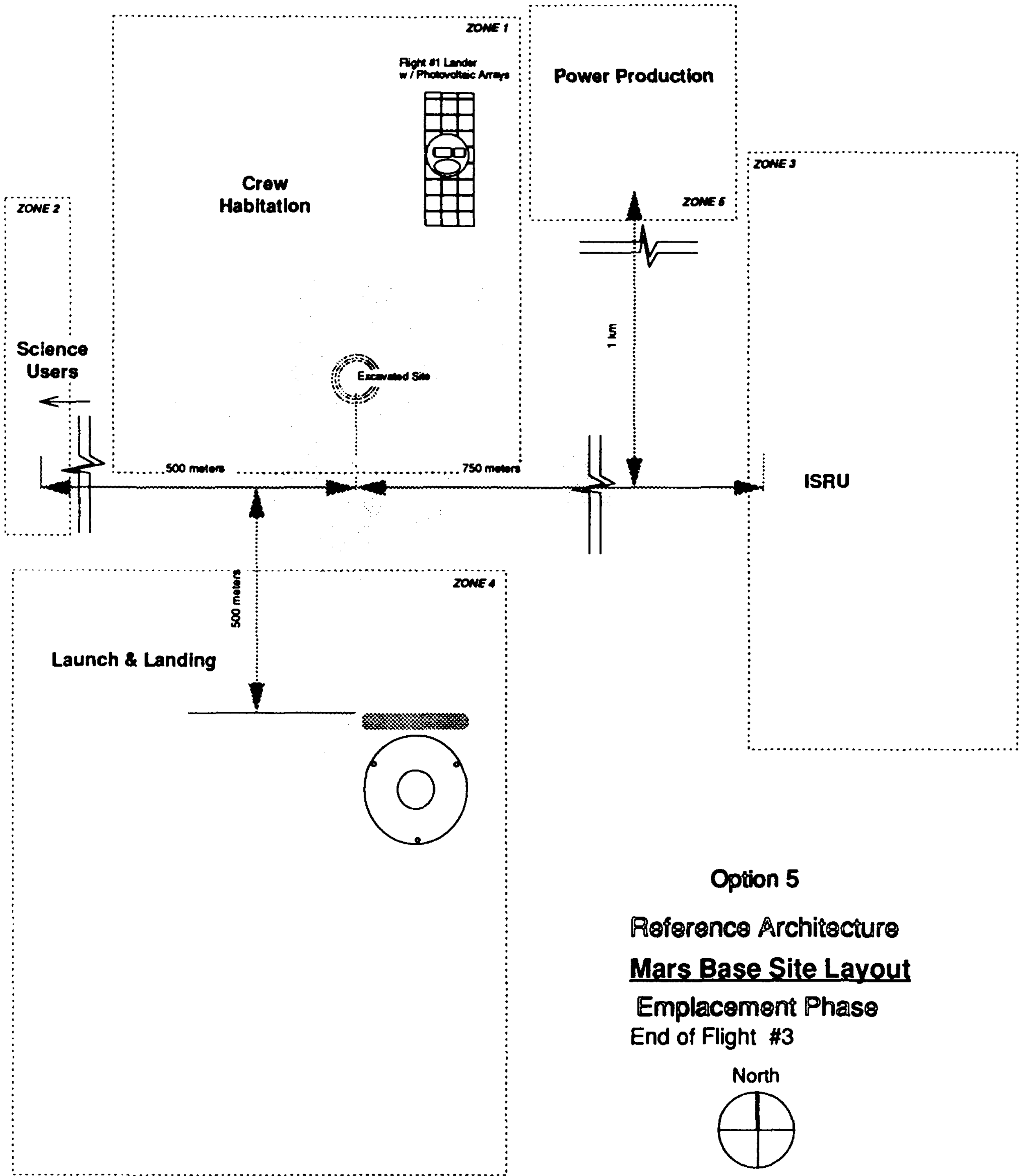


Figure 3.3.3-I Mars Outpost Site Layout - Emplacement Phase, End of Flight 3

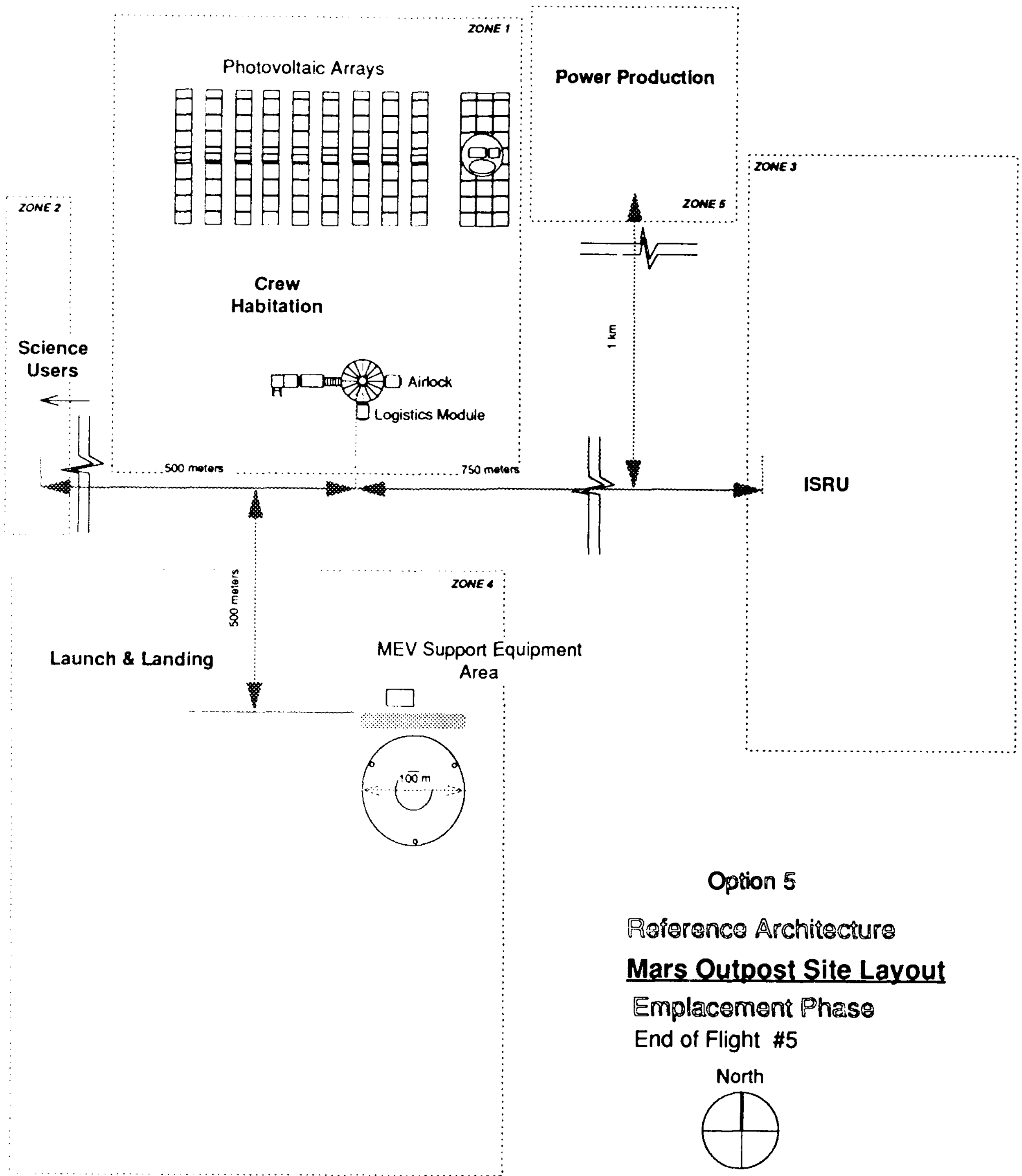


Figure 3.3.3-II Mars Outpost Site Layout - Emplacement Phase, End of Flight 5

ACTIVITY	ELEMENT	FUNCTION
Flight 1-3	Initial Hab Module on MEV	Permanent habitable facility to support 5 crew for 50 days.
	Airlock w/Dustoff on MEV	Required to transfer crew into hab from MEV & provides EVA capability.
	EMUs	Required to transfer crew into hab from MEV & provides EVA capability.
	Unpressurized Rover	Used for site certification. Provides capability for manned geological/geophysical traverses up to 50 km. In combination with robotic package, provides crew rescue capability for >10 km manned traverses.
	Power System (25/12.5 kW) on MEV	Provides power to hab on MEV.
Flight 4	Power System (75/37.5 kW)	Provides adequate power to allow completion of Emplacement Phase and steady state operations.
	Payload Unloader	Accommodates payload unloading from MEV. Transports habitation equipment, exploration and scientific equipment from MEV to required sites.
	Hab Module	Provides a permanent habitat facility to support 5 crew / 50 days. Provides capability to perform science/lab functions in habitat (IVA).
	Constructible Hab/Lab	Upgrades permanent habitat facility to support 5 crew / 600 days. Provide capability to perform more extensive science/lab functions in habitat (IVA).
	(2) Airlocks	Required to transfer crew into hab from MEV & provides EVA capability.
	Constructible Logistics Module	Provides crew consumables and equipment necessary to allow crew stay of 600 days.
	MEV Servicer	Provide capability to store and maintain 1 MEV including power, thermal protection, & heat rejection, and reliquefaction of O_2 and H_2.
	Excavation Pyrotechnics	Prepares site to allow constructible Hab/Lab and power module construction.
	TNIM	Provides communication for outpost.

Table 3.3.3-I Major Elements / Subsystems - Mars Emplacement Phase

Annex A

Detailed Manifest by Flight

A detailed manifest is included in Appendix A and includes figures for mass. Volume, and power requirements are included (if known in the Lunar Cargo List). The information provided reflects version 90.1 of the Element/Subsystems Data Base with the elements referenced by their associated IDs.

Emplacement Phase

Qnty	E/SDB	Element	type	mass		
Flight	**0**	**Jul-02**	**C**		**22.42**	**t**
#	***ID***	***Name***				
1	CCL	Payload Unloader		10.00		
1	CCLatt	Attachments for Payload Unloader		6.33		
1	CXL	Lunar Excavation Pyrotechnics		3.68		
1	UTL	Communication Equipment		0.94		
1	RUL	Unpressurized Manned/Robotic Rover		1.47		
		Includes safe haven supply				
Flight	**1**	**Jul-03**	**C**		**25.34**	**t**
#	***ID***	***Name***				
1	HMLhab	Initial Habitat Module		12.00		
1	HXLalk	Lunar Airlock		3.00		
1	UPL100	Power Module (100 kW)		6.56		
1	HSLi46	Initial 4 crew / 6 mo supply		2.28		
6	xs	Spares		1.50		
		Stay limited by hab facilities				
Flight	**2**	**Jul-04**	**P (30d)**		**6.04**	**t**
#	***ID***	***Name***				
1	CTG	Tools & Implements		0.29		
5	EEL	Lunar Surface EMU		0.88		
0.2	HSL46r	4 crew / 6 mo resupply + half pallet		0.62		
12	xs	Spares		3.00		
1	IPLdem-x	Lunar Oxygen Demo		1.00		
1	zel-02	Geologic Exp Equipment		0.10		
1	zel-03	Geophysical Station		0.10		
1	zel-04	Laser Retroreflector		0.05		

Next Science requires lab facility

Flight 3 **Jul-05** **P (30d)** **8.47 t**

#	***ID***	***Name***	
5	EEL	Lunar Surface EMU	0.88
0.2	HSL46r	4 crew / 6 mo resupply + half pallet	0.62
14	xs	Spares	3.50
1	RUL	Unpressurized Manned/Robotic Rover	1.47
1	zel-05	Portable Geophysical Package	0.50
1	zel-06	Optical Telescope ("Crater")	0.50
1	zel-11	UV-Visible Interferometer Elts	1.00

Includes safe haven supply

Flight 4 **Jul-06** **C** **23.28 t**

#	***ID***	***Name***	
1	HXLalk	Lunar Airlock	3.00
1	HMLlab	Lab Module	12.00
1	HSLi46	Initial 4 crew / 6 mo supply	2.28
12	xs	Spares	3.00
		n/a	0.00
1	zel-07	Biomedical Lab Instruments	0.50
1	zel-08	Analytical Science Lab Instruments	0.50
1	zel-09	Particles & Field Instruments	1.00
1	zel-11	UV-Visible Interferometer Elts	1.00

Flight 5 **Jul-07** **P (90 day)** **9.93 t**

#	***ID***	***Name***	
6	EEL	Lunar Surface EMU	1.05
0.5	HSL46r	4 crew / 6 mo resupply + half pallet	1.56
12	xs	Spares	3.00
1	LSL	LEV Servicer	2.07
1	zel-12	Biostack, Aseptic Samplers	0.05
2	zel-10	Geophysical Stations	0.20
2	zel-11	UV-Visible Interferometer Elts	2.00

Consolidation Phase

Qnty	E/SDB	Element	type	mass		
Flight	**6**	**Jul-08**	**P (90 day)**		**10.43**	**t**
#	***ID***	***Name***				
4	⊞L	Lunar Surface EMU		0.70		
0.5	HSL46r	4 crew / 6 mo resupply + half pallet		1.56		
10	xs	Spares		2.50		
1	zcl-01	Geologic Science Resupply		0.10		
2	zcl-04	Submillimeter (IR) Interf Elts		4.00		
1	zel-10	Geophysical Stations		0.10		
1	zel-01	Unpress Manned/Teleoperated Rover (science)		1.47		
		Next science requires lab				
Flight	**7**	**Jul-08**	**P (90 day)**		**10.44**	**t**
#	***ID***	***Name***				
4	⊞L	Lunar Surface EMU		0.70		
0.5	HSL46r	4 crew / 6 mo resupply + half pallet		1.56		
12	xs	Spares		3.00		
		n/a		0.00		
1	zcl-11	Pressurized Manned Rover (500 km)		5.18		
		n/a		0.00		
		n/a		0.00		
Flight	**8**	**Jul-10**	**C**		**26.04**	**t**
#	***ID***	***Name***				
2	xs	Spares		0.50		
1	HXLalk	Lunar Airlock		3.00		
1	HIL-x1	Enhanced Habitation Structure		2.95		
1	HIL-x2	Enhanced Habitation Outfiting		5.99		
1	HIL-x3	Enhanced Habitation LSS		4.21		
1	HIL-x4	Enhanced Habitation TCS		1.55		
1	LLL	Constructible Logistics Module		3.00		
1	HIL-x6	Enhanced Habitation Air Supply		3.45		
1	HILtun	Enhanced Habitation Tunnel		0.39		
1	zcl-05	Experimental Plant/Animal Lab		0.50		
1	zcl-06	Biomedical Lab Instruments		0.50		

Complete Constructible; Begin 180 d stays.

Flight	**9**	**Jul-11**	**P (180 da)**	**10.32 t**
#	***ID***	***Name***		
4	EEL	Lunar Surface EMU	0.70	
1	HSL46r	4 crew / 6 mo resupply + half pallet	3.12	
18	xs	Spares	4.50	
		n/a	0.00	
2	zcl-03	UV-Visible Interferometer Elts	2.00	
		n/a	0.00	

Deliver LLOX plant, power plant

Flight	**10**	**Jul-12**	**C**	**27.47 t**
#	***ID***	***Name***		
1	UPL550	Power Plant - 550 kW	16.60	
1	IPLp5	LLOX Plant (5 t/yr)	5.00	
1	LFL	LLOX Fueling Pallet	1.27	
1	CEL	Mining Excavator/Loader	2.60	
2	CHL	Regolith Hauler	2.00	
		n/a	0.00	

Start 4 crew for 600 day Mars Mission Sim

Flight	**11**	**Jul-13**	**P (600 da)**	**10.38 t**
#	***ID***	***Name***		
4	EEL	Lunar Surface EMU	0.70	
2.3	HSL46r	4 crew / 6 mo resupply + half pallet	7.18	
10	xs	Spares	2.50	
		n/a	0.00	

Operation/Demonstration Phase

Qnty	E/SDB	Element	type	mass	
Begin	***Operation/Demonstration***				

Complete 600 day Mars Mission Sim.
**Resupply only. No crew transfer.*

Flight	**12**	**Jul-14**	**P (0* day)**	**10.34 t**
#	***ID***	***Name***		
2	HSL46r	4 crew / 6 mo resupply + half pallet	6.24	
12	xs	Spares	3.00	
1	zcl-03	UV-Visible Interferometer Elts	1.00	
1	zxx-x	PI Science	0.10	

Begin usage of LLOX

Flight	**13**	**Jul-15**	**P (180 day)**	**14.39 t**
#	***ID***	***Name***		
4	EEL	Lunar Surface EMU	0.70	
1	HSL46r	4 crew / 6 mo resupply + half pallet	3.12	
14	xs	Spares	3.50	
1	zcl-04	Submillimeter (IR) Interf Elts	2.00	
1	zcl-04	Submillimeter (IR) Interf Elts	2.00	
1	zel-01	Unpress Manned/Teleoperated Rover (science)	1.47	
3	zcl-07	Particles & Fields Stations	0.60	
1	zcl-03	UV-Visible Interferometer Elts	1.00	

Flight	**14**	**Jul-16**	**P (180 day)**	**14.39 t**
#	***ID***	***Name***		
4	EEL	Lunar Surface EMU	0.70	
1	HSL46r	4 crew / 6 mo resupply + half pallet	3.12	
12	xs	Spares	3.00	
1	LHL	Pressurized Transport Module	2.30	
1	zcl-08	Cosmic µWave Background Obstry	0.10	
1	zcl-09a	Laser Gravity Interferometer Exp (1)	1.00	
1	zel-01	Unpress Manned/Teleoperated Rover (science)	1.47	
7	zxx-x	PI Science	0.70	
1	zcl-09b	Laser Gravity Interferometer Exp (2)	2.00	
		n/a	0.00	

Flight 15 **Jul-17** **P (360 day)** **14.61 t**

#	ID	Name	
4	⊞L	Lunar Surface EMU	0.70
2	HSL46r	4 crew / 6 mo resupply + half pallet	6.24
12	xs	Spares	3.00
2	zcl-02	Geophysical Stations	0.20
1	zel-01	Unpress Manned/Teleoperated Rover (science)	1.47
1	zcl-09c	Laser Gravity Interferometer Exp (3)	2.00
1	zul-05	Animal/Microbe Lab Instruments	1.00

Flight 16 **Jul-18** **P (360 day)** **14.74 t**

#	ID	Name	
4	⊞L	Lunar Surface EMU	0.70
2	HSL46r	4 crew / 6 mo resupply + half pallet	6.24
12	xs	Spares	3.00
3	zcl-02	Geophysical Stations	0.30
1	zul-02a	Gamma Ray Observatory (p1)	2.50
1	IXLdem	ISRU Integrated Demonstration	2.00

Flight 17 **Jul-19** **P (360 day)** **14.69 t**

#	ID	Name	
4	⊞L	Lunar Surface EMU	0.70
2	HSL46r	4 crew / 6 mo resupply + half pallet	6.24
13	xs	Spares	3.25
1	zul-02b	Gamma Ray Observatory (p2)	2.50
1	zul-04	Submillimeter (IR) Interf Elts	2.00
		n/a	0.00

Deliver last identified Science P/L

Flight 18 **Jul-20** **P (360 day)** **11.94 t**

#	ID	Name	
4	⊞L	Lunar Surface EMU	0.70
2	HSL46r	4 crew / 6 mo resupply + half pallet	6.24
16	xs	Spares	4.00
1	zul-03	UV-Visible Interferometer Elts	1.00
		n/a	0.00

Steady State Example

Flight 19 **Jul-21** **P (360 day)** **9.94 t**

#	ID	Name	
4	EEL	Lunar Surface EMU	0.70
2	HSL46r	4 crew / 6 mo resupply + half pallet	6.24
12	xs	Spares	3.00
		n/a	0.00
		n/a	0.00

Direct to farside. Less supply.

Flight 20 **Jul-22** **P FS(30 day)** **10.39 t**

#	ID	Name	
4	EEL	Lunar Surface EMU	0.70
0.2	HSL46r	4 crew / 6 mo resupply + half pallet	0.62
2	xs	Spares	0.50
1	zulf-10	Low Frequency Radio Array	0.50
1	zel-01	Unpress Manned/Teleoperated Rover (science)	1.47
1	zulf-08	Geologic Exploration Eqpt	0.10
1	zulf-09	Geophysical Station	0.10
64	zxx-x	PI Science	6.40

Lunar Cargo Items
Listed by E/SDB ID

ID	Name	FltMass	Mass	Vol	kWd
CCL	Payload Unloader	10.00	10.00	240.0	3.0
CCLatt	Attachments for Payload Unloader	6.33	5.50	32.0	
CEL	Mining Excavator/Loader	2.60	2.60	*21.0*	40
CHL	Regolith Hauler	1.00	1.00	*25.0*	15.0
CHLlfa	LFA Construction Machine	2.76	2.40	*15.0*	
CTG	Tools & Implements	0.29	0.25	*1.5*	
CXL	Lunar Excavation Pyrotechnics	3.68	3.20	1.8	
EEL	Lunar Surface EMU	0.18	0.18	0.6	0.1
engrp-x1	Power Capability of Rover				5.0
HIL	Constructible Habitat, 16 m Diameter	40.70	40.70	380.00	100
HIL-x1	Enhanced Habitation Structure	2.95	2.95	33.10	
HIL-x2	Enhanced Habitation Outfiting	5.99	5.99	42.40	
HIL-x3	Enhanced Habitation LSS	4.21	4.21	50.00	
HIL-x4	Enhanced Habitation TCS	1.55	1.55	8.40	
HIL-x6	Enhanced Habitation Air Supply	3.45	3.45		
HILtls	Constructible tools	0.14	0.14		
HILtun	Enhanced Habitation Tunnel	0.39	0.39	14.0	
HMLhab	Initial Habitat Module	12.00	12.00	150.00	25
HMLlab	Lab Module	12.00	12.00	150.00	25.0
HSL46r	4 crew / 6 mo resupply + half pallet	3.12	3.12		
HSL86r	8/6 resupply + pallet	7.16	6.76		
HSLi46	Initial 4 crew / 6 mo supply	2.28	2.28		
HSLils	Init LSS Supplies	1.46	1.46		
HXLalk	Lunar Airlock	3.00	3.00	85.0	10.0
IPL	LLOX Pilot Plant (60 t/yr)	24.60	24.60	*150.0*	300
IPLdem	Oxygen Extraction Demonstration	1.50	1.50	*3.0*	10
IPLdem-x	Lunar Oxygen Demo	1.00	1.00	*3.0*	2
IPLp5	LLOX Plant (5 t/yr)	5.00	5.00	*18.8*	25
IPLpil	LLOX Pilot Plant (12 t/yr)	8.00	8.00	18.80	45
IXLdem	ISRU Integrated Demonstration	2.00	2.00	*12.0*	2
LFL	LLOX Fueling Pallet	1.27	1.10	8.0	40.0
LHL	Pressurized Transport Module	2.30	2.00	12.0	
LLL	Constructible Logistics Module	3.00	3.00		
LSL	LEV Servicer	2.07	1.80	20.00	9.0
RPL	Pressurized Manned Rover w/ Drills	5.18	4.50	144.00	1.9
RUL	Unpressurized Manned/Robotic Rover	1.47	*1.28*	*11.0*	*0.7*
UPL100	Power Module (100 kW)	6.56	*5.70*	*411.0*	*100.0*
UPL25	Power System (25/12.5)	8.40	*8.00*	*60.0*	*25.0*
UPL550	Power Plant - 550 kW	16.60	*15.00*	*190.0*	*850.0*
UPM25	P\'A Power System (25/0)	2.50	*2.50*	*5.0*	*25.0*
UTL	Communication Equipment	0.94	*0.82*	*14.0*	*0.9*
xs	Spares	0.25			
zcl-01	Geologic Science Resupply	0.10	*0.10*		
zcl-02	Geophysical Stations	0.10			
zcl-03	UV-Visible Interferometer Elts	1.00			

zcl-04	Submillimeter (IR) Interf Elts	2.00	*2.00*		
zcl-05	Experimental Plant/Animal Lab	0.50			
zcl-06	Biomedical Lab Instruments	0.50			
zcl-07	Particles & Fields Stations	0.20			
zcl-08	Cosmic µWave Background Obstry	0.10			
zcl-09a	Laser Gravity Interferometer Exp (1)	1.00			
zcl-09b	Laser Gravity Interferometer Exp (2)	2.00			
zcl-09c	Laser Gravity Interferometer Exp (3)	2.00			
zcl-10	Materials Processing Lab Experiments	2.00			
zcl-11	Pressurized Manned Rover (500 km)	5.18	4.50		
zel-01	Unpress Manned/Teleoperated Rover (science)	1.47	1.28		
zel-02	Geologic Exp Equipment	0.10	0.10	*0.6*	
zel-03	Geophysical Station	0.10	0.10	*0.6*	
zel-04	Laser Retroreflector	0.05	0.05	*0.3*	
zel-05	Portable Geophysical Package	0.50	0.50	*3.0*	
zel-06	Optical Telescope ("Crater")	0.50	0.50	*2.0*	*0.5*
zel-07	Biomedical Lab Instruments	0.50	0.50	3.0	1.0
zel-08	Analytical Science Lab Instruments	0.50	0.50	3.0	1.0
zel-09	Particles & Field Instruments	1.00	1.00	6.0	0.1
zel-10	Geophysical Stations	0.10	0.10	0.6	
zel-11	UV-Visible Interferometer Elts	1.00	1.00	6.0	0.5
zel-12	Biostack, Aseptic Samplers	0.05	0.05	0.3	
zel-13	Geologic Exploration Equipment	1.00	1.00	6.0	
zel-14	Submillimeter (IR) Interf Elts	2.00	2.00	100.0	0.5
zul-01	Geophysical Stations	0.10			
zul-02a	Gamma Ray Observatory (p1)	2.50			
zul-02b	Gamma Ray Observatory (p2)	2.50			
zul-03	UV-Visible Interferometer Elts	1.00			
zul-04	Submillimeter (IR) Interf Elts	2.00			
zul-05	Animal/Microbe Lab Instruments	1.00			
zul-06	Science Resupply	0.50			
zulf-07	Unmanned local rover	1.47	1.28		
zulf-08	Geologic Exploration Eqpt	0.10			
zulf-09	Geophysical Station	0.10			
zulf-10	Low Frequency Radio Array	0.50			
zxx-x	PI Science	0.10			

APPENDIX D: Plenary Talk Storyboard

NASA

Themes

- Mars Expedition
- Lunar / Mars Exploration
- Evolution Emphasis
- Expanding Human Presence

Planet Surface Systems

Presentations/L.D Toups/C & M Workshop --8/6/90-1

Mars Expedition

NASA

Mars Expedition

Overall

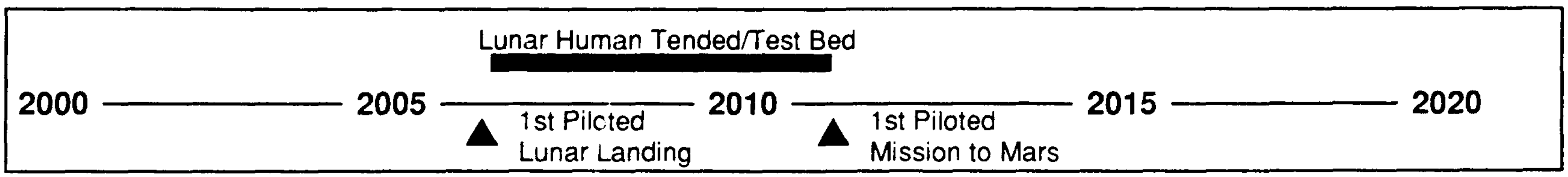
- Low Cost "Apollo style", reduce Mission cost by avoiding unproven technology and complex operations
- Establish human tended lunar outpost as an engineering and operational testbed for Mars
- Design transportation and surface systems for Mars missions, Prove systems at lunar surface
- Enable suite of Mars missions with lunar testbed support and near term technology

Moon

- Moon serves as engineering and operational testbed for Mars "*Expedition*"

Mars

- "*Expedition*" supported by habitat lander (with high level of surface commonality with Moon)



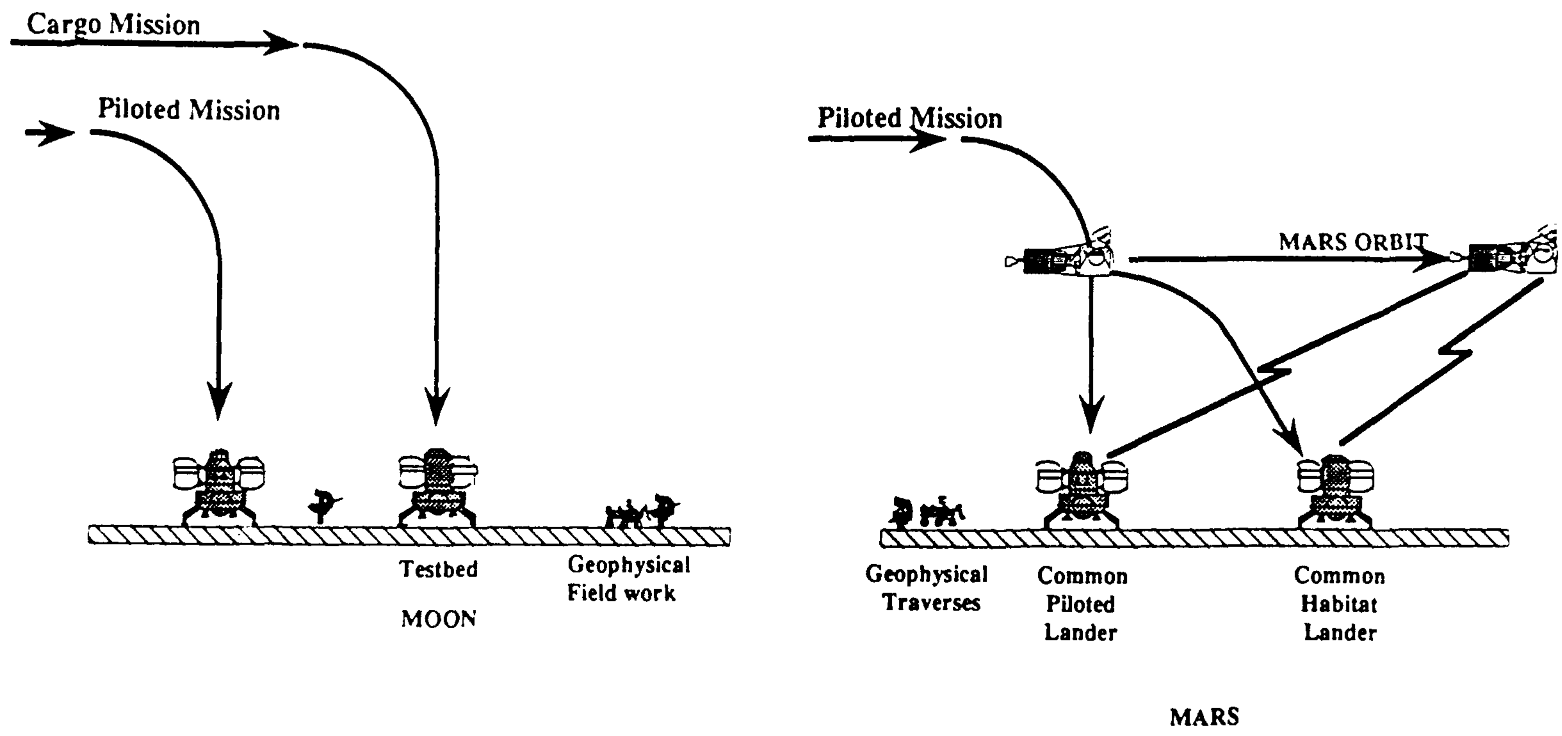
Planet Surface Systems

Presentations/LD Toups/C & M Workshop --8/6/90-3

NASA

Mars Expedition

"Surface Mission Profile"



Planet Surface Systems

Presentation ...) Toups/C & M Workshop --8/6/90-14

NASA

Construction & Mining Task Requirements

Mars Expedition

"Flags and Footprints"

- No significant construction on surface of Moon or Mars (deployment of science packages)

- No mining activities on either Moon or Mars

NASA

Lunar / Mars Exploration

NASA

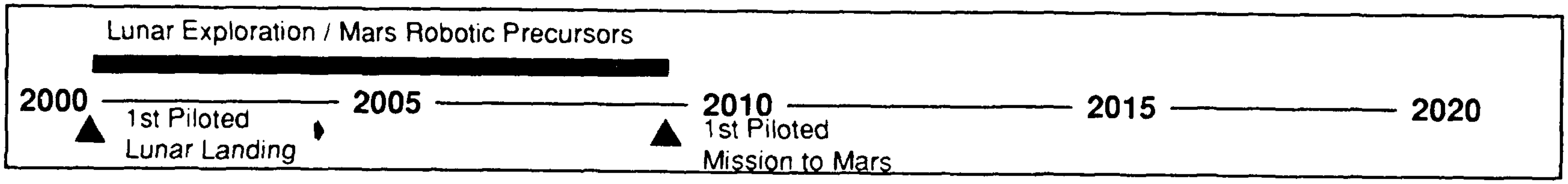
Lunar / Mars Exploration

Overall

- Exploration Intensive - **not** - Outpost Emplacement Intensive
- **Lunar Mission precedes Mars Mission**
- **Minimal surface systems & crew size**
  Maximize amount of scientific equipment emplaced
- **Develop expendable systems which can evolve into reusable systems**
  i.e. reusable crew cab could provide basic building block for habitation module
- **Emphasizes a few robust modular elements rather than a variety of optimized, specialized elements**
- **Emphasis on exploration and science**
- **ISRU Demonstrations**

Moon & Mars

- **No emplaced surface infrastructure; crew lives out of lander**

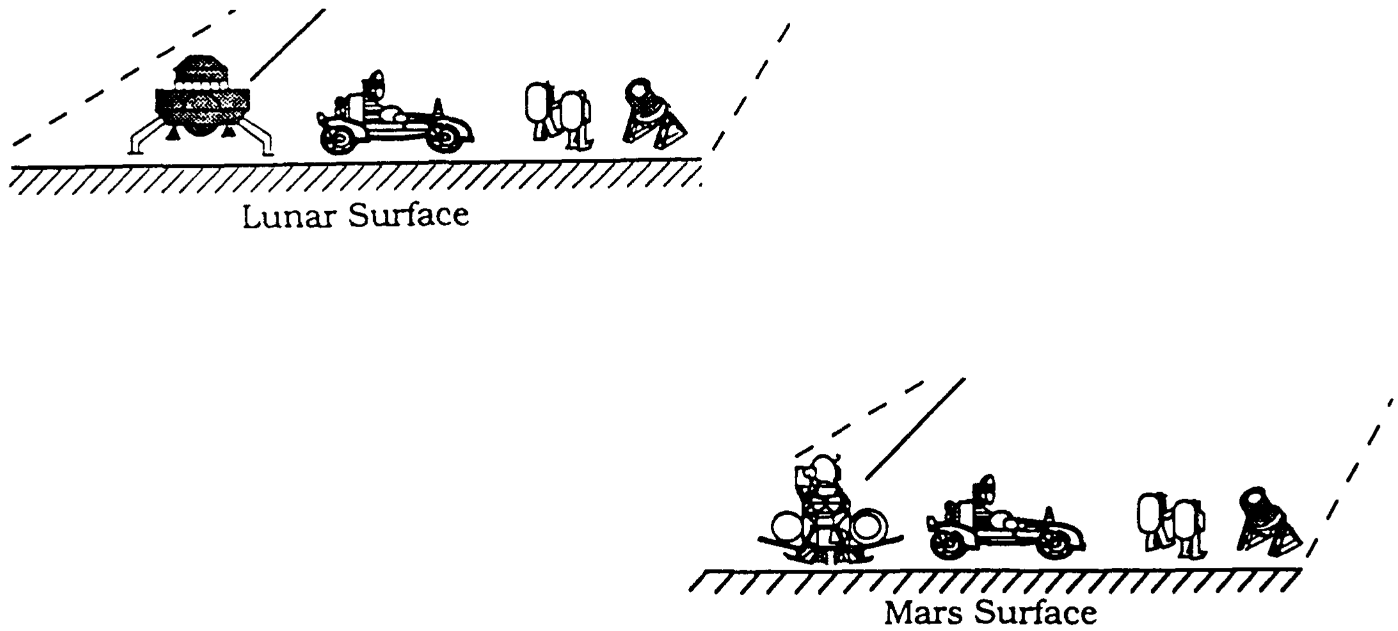


Presentations/L.D Toups/C & M Workshop --8/6/96-6

Planet Surface Systems

NASA

Lunar / Mars Exploration
"Surface Mission Profile"



Planet Surface Systems

Presentations/LD Toups/C & M Workshop --8/6/90-15

NASA

Construction & Mining Task Requirements

Lunar / Mars Exploration

- Light construction and mining on Moon
  Lift/Place, Move Regolith

Decision Point • 2005 - 2007

- Demonstration of utilization of lunar indigenous resources
- Payload unloading/loading on Moon

Decision Point • 2009 - 2011

- Significant mining activities
- Construction of lunar ISRU Demo

Decision Point • 2010 - 2012

- Demonstration of utilization of martian indigenous resources
- Payload unloading/loading on Mars

NASA

Evolution Emphasis

Planet Surface Systems

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Evolution Emphasis

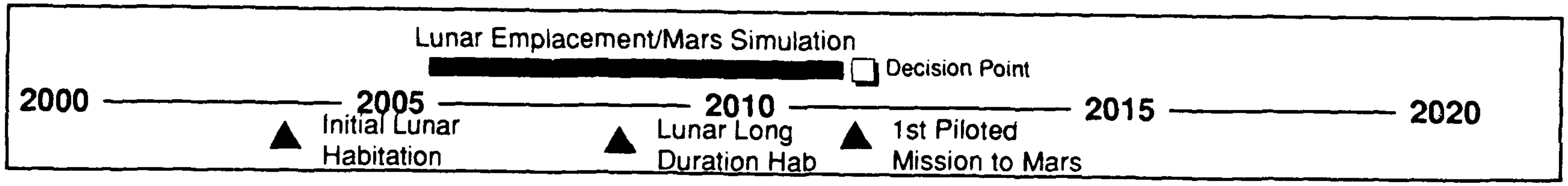
Moon

- Lunar systems evolve into systems with demonstrated reliability and long operational life ⟶ applied to Mars
- Lunar outpost serves as a testbed and a center for learning to live and work on an extra-terrestrial body

  Develop techniques for cargo offloading, construction, operations, logistics

Mars

- Long duration "research outpost"emplaced on Mars each flight (more than one flight)



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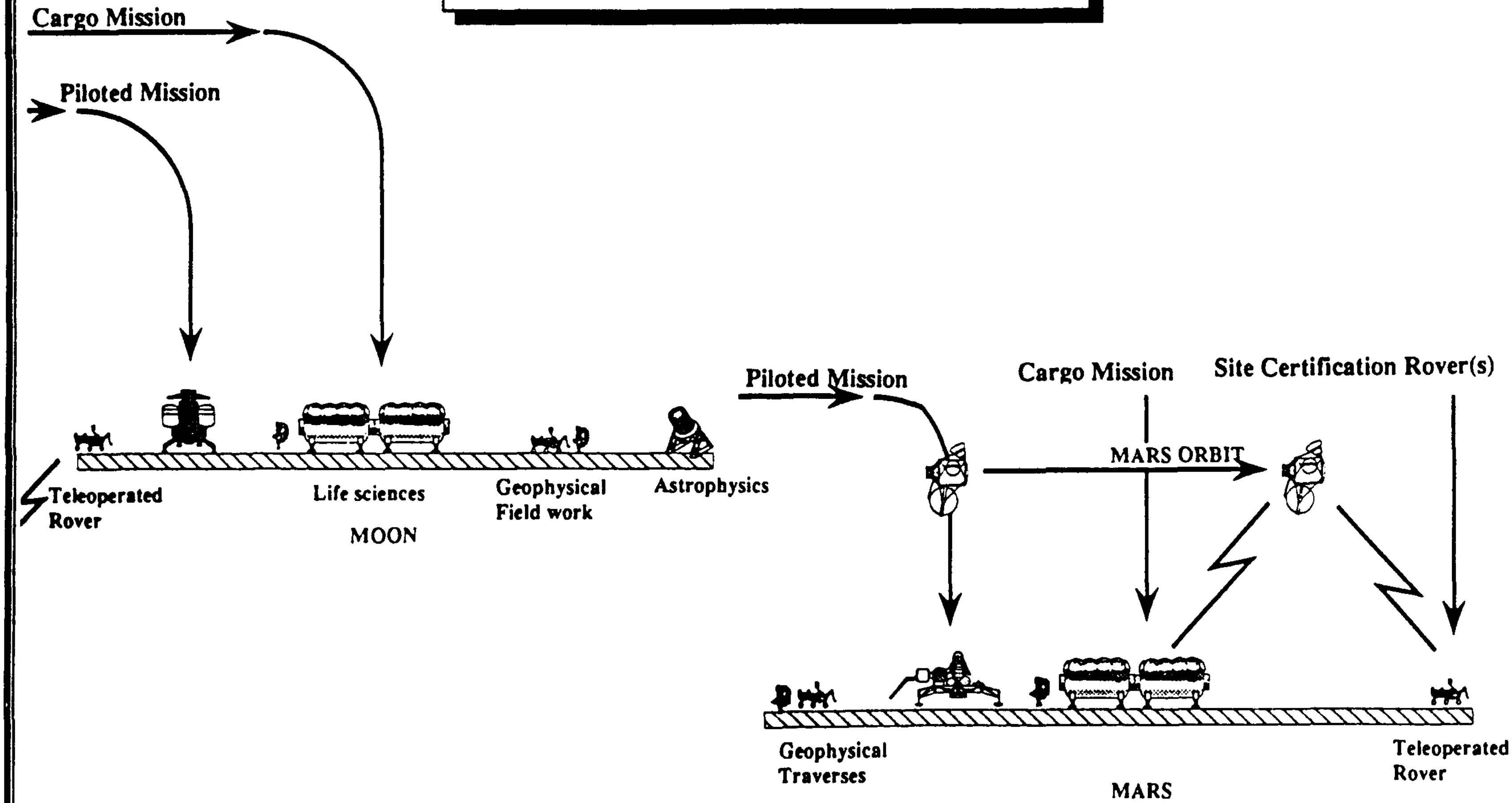
Evolution Emphasis

"Surface Mission Profile"



Planet Surface Systems

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Construction & Mining Task Requirements

Evolution Emphasis

- Unloading of payloads up to 20 t off landers
- Moving regolith (to cover habitat)

Decision Point • 2008 - 2010

- Significant mining activities associated w/ producing lunar ISRU products

Decision Point • 2018 - 2020

- Significant mining activities associated w/ producing martian ISRU products

Expanding Human Presence

NASA

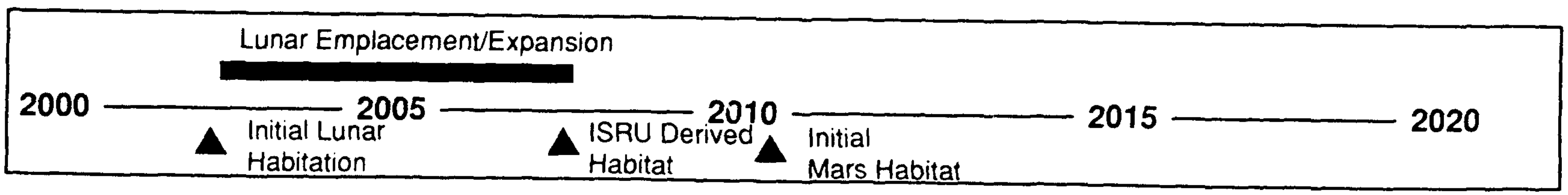
Expanding Human Presence

Overall

- Emphasis on outpost self-sufficiency (as quickly as possible)
- Robust ISRU
- Grand-scale sciences

Moon & Mars

- Develop extensive outpost facilities and capabilities utilizing many crewmembers (4 ➧ 20 or more)
- Aggressive ISRU
  Habitats, life support, support infrastructure
- Initial hab modules followed by locally manufactured pressurized facilities



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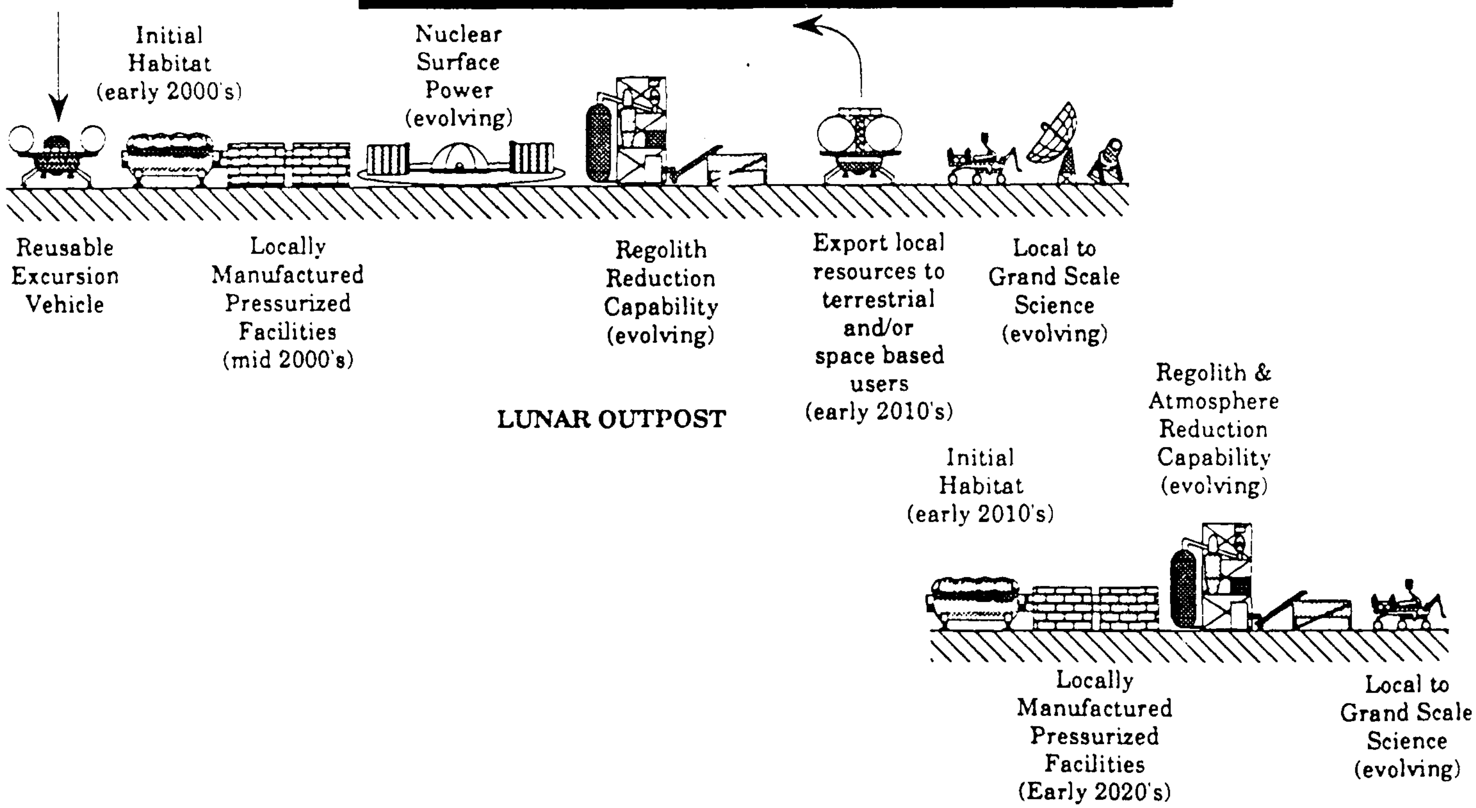
Expanding Human Presence

"Surface Mission Profile"



Planet Surface Systems

Presentations/LD Toups/C & M Workshop --8/6/90-17

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Construction & Mining Task Requirements

Expanding Human Presence

- Unloading of payloads up to 20 t off landers on Moon
- Moving payloads on surface of Moon
- Moving regolith (to cover habitat) on Moon
- Demonstration of utilization of lunar indigenous resources
- Construction of prototype pressurized ISRU facility on Moon

Decision Point • 2006 - 2008

- Construction of ISRU Habitat
- Significant mining activities associated w/ producing lunar ISRU products for local, space, and terrestrial use

Decision Point • 2017 - 2019

- Significant mining activities associated w/ producing martian ISRU products for local, space, and terrestrial use

TASK REQUIREMENTS

1. SITE SELECTION AND MAPPING
2. SITE SURVEYING, SUBSURFACE ANALYSIS
3. UNLOADING CONSTRUCTION EQUIPMENT FROM LANDER
4. ROAD BUILDING
5. SITE LEVELLING, LANDING PAD PREPARATION
6. EXCAVATION AND TRENCHING
7. OFFLOADING CARGO FROM LANDER
8. TRANSPORTING CARGO ON SURFACE
9. EMPLACING ELEMENTS ON SURFACE
10. DEPLOYING ELEMENTS (PVA, RADIATORS)
11. ELECTRICAL AND FLUID CONNECTIONS
12. CHECKOUT, TROUBLESHOOTING AND REPAIR
13. REGOLITH SHIELDING HABITATS
14. LANDER SERVICING
15. NUCLEAR REACTOR DEPLOYMENT
16. SCIENCE PACKAGE TRANSPORT AND DEPLOYMENT
17. REMOVAL OF EXPENDED LANDERS
18. ISRU PLANT DEPLOYMENT
19. MINING - EXCAVATING AND HAULING
20. ISRU OPERATIONS
21. MODULAR HABITAT CONSTRUCTION
22. ISRU-DERIVED HABITAT CONSTRUCTION

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SURFACE CONSTRUCTION REQUIREMENTS

1. SITE SELECTION AND MAPPING

- ORBITAL INFORMATION - SLOPES, TOPOGRAPHIC INFORMATION TO 20cm RESOLUTION, REGOLITH CHARACTERISTICS (SPECTROMETER DATA). WILL ALLOW THE SELECTION OF A NUMBER OF CANDIDATE SITES.

2. SITE SURVEYING AND SUBSURFACE ANALYSIS

- MEASURED FROM A GROUND-BASED UNIT (SUCH AS A ROBOTIC ROVER) - DETAILED SLOPES AND TOPOGRAPHY FOR FINAL SITE SELECTION. SUBSURFACE DRILLING AND TESTING FOR DETAILED DATA. ANALYSIS OF SOIL MINERALOGY.

3. UNLOADING CONSTRUCTION EQUIPMENT FROM LANDER

- SITE SURVEYING EQUIPMENT AND SOME CONSTRUCTION EQUIPMENT MAY PRECEDE ALL OTHER EQUIPMENT TO THE SURFACE - MUST BE SELF-DEPLOYING FROM THE LANDING VEHICLE

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SURFACE CONSTRUCTION REQUIREMENTS

4. ROAD BUILDING

- LEVEL PATHWAYS WILL OPTIMIZE TRANSPORT OF CARGO AND CREW. FILLING CRATERS, SMOOTHING BUMPS AND ELIMINATING ROCKS WILL GREATLY IMPROVE VEHICLE SPEEDS. HARDENING THE SURFACE, SUCH AS BY MICROWAVE SINTERING, WILL REMOVE DUST CONTAMINATION PROBLEMS IN BEARINGS AND WEARING SURFACES.

5. SITE LEVELLING, LANDING PAD PREPARATION

- LEVEL SITES IN THE HABITATION, POWER AND LAUNCH/LANDING AREAS WILL IMPROVE OPERATIONS IN THOSE AREAS. SIMILAR TO ROAD BUILDING, LEVELLING AND GRADING OFFER IMPROVED MOBILITY, BUT HARDENED SURFACES PROVIDE MAXIMUM BENEFITS

6. EXCAVATION AND TRENCHING

- TRENCHING REQUIRED FOR UTILITIES. EXCAVATION REQUIRED FOR HABITAT EMPLACEMENT, NUCLEAR REACTOR EMPLACEMENT, BERMS AT LAUNCH/LANDING AREAS AND REGOLITH SHIELDING FOR HABITATS.

SURFACE CONSTRUCTION REQUIREMENTS

7. OFFLOADING CARGO FROM LANDER

- CARGO WILL BE DELIVERED ON LANDERS IN ANY NUMBER OF CONFIGURATIONS - ATOP LANDER (FLATBED CONCEPT), ON FIXED SIDE CARGO PLATFORMS, OR ON CARGO PLATFORMS WHICH CAN BE LOWERED TO THE SURFACE. CARGO MASSES FROM 50 KG TO 15 MT MUST BE ACCOMMODATED, AND COULD POSSIBLY BE AS HIGH AS 5M ABOVE THE FOOTPADS

8. TRANSPORTING CARGO ON SURFACE

- OFFLOADED CARGO MUST BE TRANSPORTED TO IT PLACE OF USE. CURRENT DESIGNS INDICATE A MAXIMUM TRAVEL DISTANCE OF 2KM. (NUCLEAR PLANT ELEMENTS).

9. EMPLACING ELEMENTS ON SURFACE

- DELIVERED ELEMENTS MUST BE PROPERLY POSITIONED AND ALIGNED (eg, THERMAL RADIATOR PACKAGES MUST BE PLACED ON AN EAST-WEST AXIS, AND PVA's MUST BE PLACED ON A TRUE NORTH-SOUTH AXIS)

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SURFACE CONSTRUCTION REQUIREMENTS

10. DEPLOYING ELEMENTS

- ONCE POSITIONED CORRECTLY ON THE SURFACE, MANY OF THE SURFACE ELEMENTS REQUIRE DEPLOYMENT:
  - PHOTOVOLTAIC ARRAYS
  - NUCLEAR REACTORS
  - THERMAL RADIATORS
  - COMMUNICATION TOWERS
  - LAUNCH PAD MARKERS

11. ELECTRICAL AND FLUID CONNECTIONS

- ELECTRICAL AND FLUID LINES WILL BE PLACED IN A TRENCH FOR THERMAL STABILITY. CONNECTIONS MUST BE MADE FROM THE POWER GENERATION EQUIPMENT TO HABITATS, ISRU FACILITIES, SCIENCE PACKAGES, AND ALL OTHER ELEMENTS REQUIRING POWER. THERMAL FLUID CONNECTIONS AND COMMUNICATION EQUIPMENT CONNECTIONS ARE MADE LIKEWISE.

12. CHECKOUT, TROUBLESHOOTING AND REPAIR

- ONCE THE SYSTEMS ARE INTERCONNECTED, THEY MUST BE CAPABLE OF BEING TESTED AND REPAIRED

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SURFACE CONSTRUCTION REQUIREMENTS

13. REGOLITH SHIELDING OF HABITATS

- TO PROVIDE THE PROPER AMOUNT OF RADIATION SHIELDING TO THE CREW, THE HABITATS MUST BE SHIELDED IN APPROXIMATELY 1M OF REGOLITH. THE REGOLITH CAN BE BERMED AGAINST THE HABITATS, PLACED ON A STANDOFF STRUCTURE, OR PLACED IN BAGS WHICH SHROUD THE HABITAT. THE REGOLITH MUST BE EXCAVATED TRANSPORTED TO THE HABITAT SITE AND EMPLACED TO SUFFICIENT DEPTH AND COMPACTION.

14. LANDER SERVICING

- FOR CREW SURFACE STAYS EXCEEDING 30 DAYS, THE LANDING VEHICLE MUST BE SERVICED ON THE SURFACE TO PROVIDE ELECTRICAL POWER CONDITIONING, THERMAL CONTROL, MICROMETEORITE PROTECTION, AND CRYOGENIC FUEL CONDITIONING.

15. NUCLEAR REACTOR DEPLOYMENT

- NUCLEAR REACTORS ARE DELIVERED IN PACKAGES WHICH MUST BE ASSEMBLED. THE REACTOR CORE IS PLACED IN A HOLE EXCAVATED IN THE PLANET SURFACE, AND THE THERMAL CONTROL SYSTEMS AND POWER MANAGEMENT SYSTEMS ARE DEPLOYED NEARBY.

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SURFACE CONSTRUCTION REQUIREMENTS

16. **SCIENCE PACKAGE TRANSPORT AND DEPLOYMENT**

- SCIENCE PACKAGES ARE OFFLOADED FROM THE LANDER AND TRANSPORTED TO THE SCIENCE AREA OF THE OUTPOST. SCIENCE PACKAGES CAN RANGE FROM 50 KG SELF-CONTAINED RETROREFLECTORS TO 2MT TELESCOPE ASSEMBLIES.

17. **REMOVAL OF EXPENDED LANDERS**

- LANDERS ARE DESIGNED EITHER TO BE EXPENDABLE OR TO BE REUSED FOR A SPECIFIC NUMBER OF MISSIONS. THE LANDER WHICH ARE EXPENDED ON THE SURFACE MUST BE TRANSPORTED OFF THE LAUNCH/LANDING PAD AREA TO AN AREA WHERE THEIR COMPONENTS CAN BE RE-USED. AN EXPENDED LANDER COULD BE IN THE RANGE OF 10 MT.

18. **ISRU PLANT DEPLOYMENT**

- LIKE THE NUCLEAR PLANT, THE FACILITY FOR PRODUCING USEFUL PRODUCTS FROM PLANETARY RESOURCES WILL BE DELIVERED IN PARTS AND CONSTRUCTED, EARLY ISRU (IN-SITU RESOURCE UTILIZATION) FACILITIES MAY MANUFACTURE LIQUID OXYGEN (FOR LIFE SUPPORT AND TO FUEL LANDERS) FROM REGOLITH. A BY-PRODUCT OF THE HIGH-TEMPERATURE MELTING PROCESS MAY BE CAST BASALT STRUCTURAL ELEMENTS OR PAVERS.

SURFACE CONSTRUCTION REQUIREMENTS

19. MINING - EXCAVATING AND HAULING

- DIFFERENT ISRU PROCESSES REQUIRE VARYING AMOUNTS OF FEEDSTOCK. THE PRODUCTION OF A MINIMUM OF 5 MT OF LLOX PER YEAR COULD CONSUME 30 TO 1500 MT OF REGOLITH PER YEAR. THE PRODUCTION OF A SINGLE MT OF 3He WOULD REQUIRE THE MINING OF 75,000,000 MT OF REGOLITH.

20. ISRU OPERATIONS

- THE REGOLITH MUST BE EXCAVATED AND TRANSPORTED TO THE ISRU FACILITY. THE BY-PRODUCTS OF THE PROCESS MUST BE EITHER STOCKPILED OR RETURNED TO RECLAIM THE EXCAVATION SITE.

21. MODULAR HABITAT CONSTRUCTION

- IN ORDER TO GAIN SIGNIFICANT LIVING VOLUME WITH MINIMUM MASS AND VOLUME DELIVERED TO THE SURFACE, MODULAR CONSTRUCTIBLE HABITATS WILL BE CONSTRUCTED. CONSTRUCTIBLE HABITATS MAY BE PANEL CONSTRUCTION OR INFLATABLE TECHNOLOGY, BUT MUST BE ERECTED ON SITE USING EARTH-FABRICATED MATERIALS. THE HABITATS MUST PROVIDE A PRESSURE SHELL, RADIATION PROTECTION AND ENVIRONMENTAL CONTROL, AND MAY BE INTERNALLY OUTFITTED IN SHIRT-SLEEVES AFTER THE PRESSURE SHELL IS CERTIFIED

SURFACE CONSTRUCTION REQUIREMENTS

22. ISRU-DERIVED HABITAT CONSTRUCTION

- ONCE ISRU OPERATIONS HAVE BEEN PROVEN AND ISRU-DERIVED MATERIAL PROPERTIES ASSESSED, CONSTRUCTION MAY COMMENCE ON STRUCTURES WHICH UTILIZE ISRU-DERIVED STRUCTURAL MEMBERS, PANELS, etc. INITIAL ISRU-DERIVED STRUCTURES WILL BE NON-CRITICAL BUILDINGS SUCH AS STORAGE FACILITY OR VEHICLE GARAGES. ONCE PRESSURE CERTIFICATION CAN BE MADE, A LOW PRESSURE STRUCTURE SUCH AS A GREENHOUSE CAN BE CONSTRUCTED. FINALLY, A FULL-PRESSURE HABITAT CAN BE CONSTRUCTED USING INDIGENOUS MATERIALS.

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