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OPTIONS FOR A LUNAR BASE SURFACE ARCHITECTURE

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Abstract

The Planet Surface Systems Office at the NASA Johnson Space Center has participated in an analysis of the Space Exploration Initiative architectures described in the Synthesis Group report. This effort involves a Systems Engineering and Integration effort to define point designs for evolving lunar and Mars bases that support substantial science, exploration, and resource production objectives. The analysis addresses systems-level designs; element requirements and conceptual designs; assessments of precursor and technology needs; and overall programmatic and schedules.

This paper focuses on the results of the study of the Space Resource Utilization Architecture. This architecture develops the capability to extract useful materials from the indigenous resources of the Moon and Mars. On the Moon, a substantial infrastructure is emplaced which can support a crew of up to twelve. Two major process lines are developed: one produces oxygen, ceramics, and metals; the other produces hydrogen, helium, and other volatiles. The Moon is also used for a simulation of a Mars mission. Significant science capabilities are established in conjunction with resource development. Exploration includes remote global surveys and piloted sorties of local and regional areas. Science accommodations include planetary science, astronomy, and biomedical research. Greenhouses are established to provide a substantial amount of food needs.

The following identifies the major phases of development, the systems and elements involved, and the physical layout and evolution of the base. Significant alternatives and options are also discussed.

Introduction

For the past eight years, NASA has been, once again, examining the options and alternatives for the surface systems that reside on the surface of the Moon. These studies have range of goals and objectives for surface activity that range from minimum local science experiments to significant bases capable of independent operation for extended periods of time without Earth support. *Figure 1* displays the surface system architectures that have been studied over this period of time. The figure illustrates the scope and scale of each architecture in general, and somewhat arbitrary, terms. The two major categories classify the architectures into those that are resource scarce, "Mission Push", and those that are resource rich, "Mission Pull". The Mission Pull category is the collector of those architectures having only the minimum set of surface assets necessary to accomplish the specific objectives of a predetermined set of missions; that is, the mission objectives 'push' the need for the specific assets. The latter category, Mission Push, is the collector of architectures that are focused on the development of surface capabilities which, in turn, will enable missions; that is, the capabilities provided by the surface assets 'pull' or define and enable the missions.

ARCHITECTURES STUDIED TO DATE	MISSION PUSH		MISSION PULL	
	Expeditions	R&D Outposts	Self- Sustaining	Self- Sufficient
1984 JSC Lunar Base Studies _____		✓	✓	✓
1986 NASA/Los Alamos Mars Studies _____	✓			
PSSMAT, AMWG Studies _____	✓	✓	✓	✓
NCOS _____			✓	
Ride _____	✓	✓		
FY 88 OEXP Case Studies				
◦ Phobos Exploration _____	✓			
◦ Mars Expedition _____	✓			
◦ Lunar Observatory _____		✓		
◦ Lunar-to-Mars Evolution _____			✓	
FY 89 OEXP Case Studies				
◦ Mars Expedition _____	✓			
◦ Lunar Evolution _____			✓	
◦ Mars Evolution _____				✓
90-Day Study _____		✓		
Post 90-Day "White Papers"				
◦ Expedition _____	✓			
◦ Exploration _____	✓			
◦ Evolution _____		✓		
◦ Expanding Human Presence _____			✓	
Synthesis Group Architectures				
◦ Mars Exploration _____		✓		
◦ Resource Utilization _____				✓
◦ Science Emphasis for Moon and Mars _____	✓			
◦ Moon to Stay, and Mars Exploration _____			✓	

Figure 1. Architectures studied to date.

The subcategories provide some finer gradations to help in characterizing the architectures. The subcategories of "Expedition" and "Research and Development Outposts" are self-explanatory, however the other two require some additional explanation. "Self-Sustaining" is that set of architectures that have an end goal of being able to survive for long periods of time without Earth support. "Self-Sufficient" is that set of architectures that can not only survive but can grow without Earth support. The locations of the check marks are no more than relative judgements of scale between architectures.

Many different surface system assets have been conceptualized over this period of time. *Figure 2* is a partial listing of those assets studied. Many of the more mature elements and systems are further defined in the "Planet Surface System Elements and Systems Data Base".

Surface Systems

- °Mass Drivers
- °Tether Slings
- °Rock-melter Tunneling Devices for Hab Volumes
- °Inflatable Habitats
- °Lava Tubes for Hab Volumes
- °Mars Airplanes
- °Locally Produced Propellants
 - Many different chemical fuels from lunar soil
 - Mars chemical fuels from atmosphere, or Martian moons
- °Nuclear Power
- °Solar Dynamic Power
- °Beamed Power
- °Communications Architectures Using Halo Satellites in Libration Points
- °Lunar Volatile Collectors Including ^3He for "Safer" Fusion
- °Building Materials from Ceramic Plant Concepts
- °Lunar Concrete and Lunar Fiberglass Demos
- °Lunar Hoppers
- °Lunar Based Solar Power for Earth
- °Geo Solar Power Satellite System from Lunar Materials

Figure 2. Summary of systems studied to date.

It would be impossible to discuss every option in detail, therefore only one was chosen for further discussion in the sections to follow. Since there are so many similarities between each architecture, particularly in the early phases, the discussion of one architecture of somewhat aggressive capability, should yield an understanding of all. The one chosen is the latest work done by the Space Exploration Team and is from the NASA Synthesis Group recommendations. This particular architecture has been labeled "Space Resource Utilization". It is divided into phases of Initial Operational Capability (IOC), and Next Operational Capability (NOC) -1, -2 and so on.

Planetary Surfaces Systems Overview

The Space Resource Utilization Architecture focuses on developing the capability to extract useful materials from the resources of the Moon. On the Moon, a substantial infrastructure is emplaced which can support up to 12 crew. Two major process lines are developed, one which produces oxygen, ceramics, and metals, and another which produces hydrogen, helium, and other volatiles.

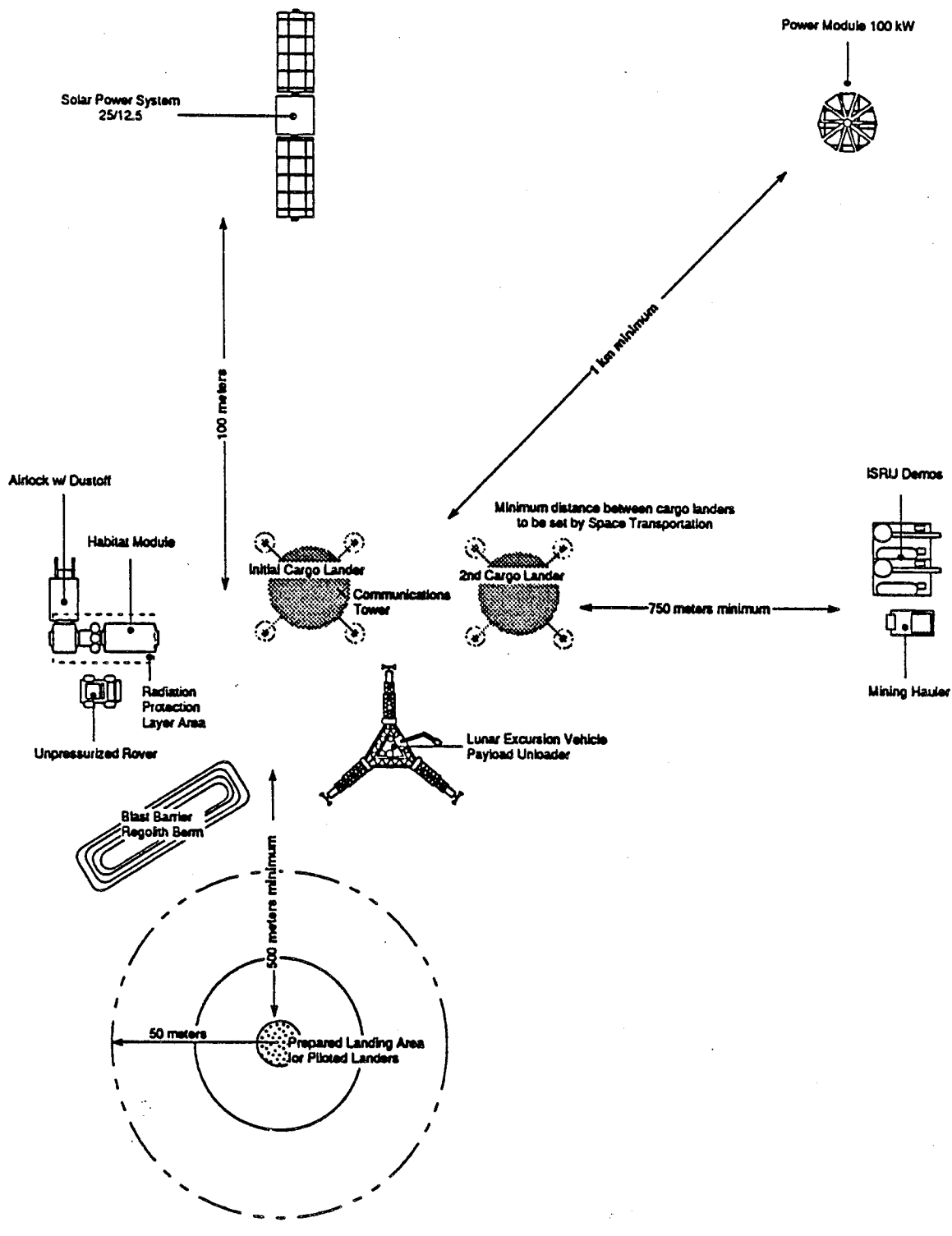


Figure 3 Space resource utilization Architecture
Lunar IOC.

A simulation of a Mars mission is also carried out on the Moon.

System Description

Following is a phase-by-phase description of the systems emplaced on the surfaces of the Moon, together with a discussion of what capability is provided and some of the reasoning behind the choices made. Further information on the surface elements can be found in JSC-45107.

Lunar IOC

Lunar IOC established the basic infrastructure to support five crew on the surface during the lunar day. Demonstration packages for candidate resource extraction processes are deployed. See *Figure 3*.

A single, integrated habitat which can support five crew for 14 days is provided. The habitat is a Space Station Freedom (SSF)-derived cylindrical module, with an airlock attached to one end and a docking adapter on the other end. Due to the down-mass limitations of the cargo lander, the module is 2/3 the length of a full SSF module, with length 8.2 meters and diameter 4.5 meters. Two such modules are needed to meet the crew requirements of the later lunar missions. A single, fully integrated module for six-crew missions of up to 90 days would weigh approximately 40 metric tons: this exceeds the capability of the lander.

The pressure shell is essentially identical to that of a SSF module, with leveling legs and deployable regolith-shielding retention devices. Internal systems of the habitat include life support, thermal control, power management and distribution, crew accommodations, limited health care equipment, science accommodations, and utilities distribution. The life support system is an advanced SSF regenerative system, with greater than 98% oxygen recovery, hygiene water processor, and non-expendable water polisher/bacteria barrier. Thermal control is provided by coatings, heat pumps, and composite reflux radiators with a two-phase non-toxic working fluid.

The airlock is a SSF-derived system which enables egress/ingress and also provides extravehicular activity (EVA) suit storage, checkout, and recharge. The airlock system is composed of an equipment lock, a crew lock, an EVA dust-off porch, and adjustable legs for leveling. The airlock's life support and thermal control systems are tied into the habitat. The EVA dust-off porch is side-deployed and a docking adapter for later use by the pressurized rover is attached on the end opposite the habitat (see *Figure 3*). Ideally, the airlock is delivered pre-attached to the habitat, in order to avoid the difficult operation of connecting the two in-situ.

A nuclear system for primary power, and a photovoltaic array (PVA) regenerative fuel cell (RFC) system for backup, are employed during IOC. The PVA consists of 150m² of sun-tracking panels. The cells are of amorphous silicon. The PVA/RFC system can provide 25 kW during the lunar day and 12.5 kW at night. The nuclear system consists of an SP-100 reactor fitted with four Stirling engines (two in use, two in reserve), providing 100 kW of electrical power continuously. It is designed for easy deployment, with little or no human intervention required. Limited shielding is provided on the reactor to enable short-duration proximity operations by humans. Additional shielding is provided by placing the reactor in a pre-excavated hold. The system is fully autonomous and employs fault detection, isolation, and recovery systems which result in a reliable, long-lived (nominal 15 year lifetime) unit.

Extravehicular Mobility Units (EMU) are provided for each crew member on the lunar surface. An EMU consists of a pressure suit, a Portable Life Support System (PLSS), and communications

subsystem. The suites are of back-entry, hybrid (fabric and hard components), 5.85 psi design. The PLSS is a regenerable system which provides for 8 hours of EVA. EMU accessories include helmet-mounted video cameras and lighting systems.

Radio frequency equipment and associated electronics are integrated into the habitat. A deployable tower and dish antenna are located near the habitat (they might remain on an expended lander). The system provides UHF communications to and from the tower, satellite communications (K-band) to Earth, S-band communications to the landers, a long range navigation-type means for navigation of surface rovers and landers (within 12 km of the outpost), and internal habitat communication.

A six-wheeled, unpressurized rover is provided. The rover can seat four suited astronauts, or can carry two together with a removable, self-contained extended life support package. The segmented chassis is composed of a light-weight tube framework, with independent drive on each wheel. Power is recharged from the base's power system. Thermal control is provided by a heat pump with metallic reflux radiators, enabling the rover to operate anytime during the lunar day. The range of the rover is 50 km from the outpost, or 150 km total traverse.

A multipurpose construction vehicle is also provided. The Lunar Excursion Vehicle Payload Unloader (LEVPU) is a three-strut, con-wheeled, teleoperated gantry crane. It is capable of unloading cargo from the lander, transporting cargo (up to and including an integrated habitat), and emplacing elements on the lunar surface. A set of implements and attachments designed for its three-joint manipulator arm enable the LEVPU to perform various other tasks, including light excavation (e.g. boulder clearing, regolith smoothing, and/or trenching), and precision surface element alignment and attachment. The choice of a LEVPU plus attachments avoids the need to deliver several specialized construction vehicles. The LEVPU's primary structure consists of open web, aluminum alloy members with telescoping struts, and independently driven and controlled wheel assemblies. The power and thermal control subsystems are similar to those on the unpressurized rover.

A mining hauler, loaded by the LEVPU, is used to transport loose regolith to the volatiles demo. It utilizes many of the same subsystems as the unpressurized rover, but is of heavier construction and operates autonomously or by teleoperation.

Two ISRU demonstration packages are emplaced and operated in IOC. The first is robotically deployed and operated and tests two-three different processes for extracting oxygen and metals from the lunar regolith, and forming ceramic materials from the resulting process slag. The second, delivered with the first crew, tests processes for extracting volatiles (hydrogen, CO/CO², nitrogen, helium, etc). Both units are self-contained, needing only power from the base and regolith feedstock (provided by the payload unloader and mining hauler). They operate for one-two years and the knowledge gained is used in the design and construction of subsequent pilot plants.

Some of the oxygen and hydrogen produced is used to re-load the fuel cells in the unpressurized rover, in a demonstration of the direct application of locally derived resources in base operations.

A small verification unit for demonstrating the storage of cryogenic liquids on the lunar surface is emplaced and operated at the initial outpost. It operates autonomously with monitoring from Earth, and conducts tests of systems to control cryogen boiloff by the use of thermodynamic vents, vapor cooled shields, low conductivity support, and refrigeration and reliquification equipment.

Limited crew time, power, and habitat volume is available for science activities. However, the LEVPU can deploy scientific instruments on the lunar surface, and the unpressurized rover can be used for geological traverses.

In addition to the systems described above, a warning system for solar flares is also emplaced near the habitat. It consists of an autonomously controlled system for monitoring the particle and electromagnetic output of the sun. Threshold alarms are included which alert the crew when the incident solar radiation exceeds a predetermined value, so that they may take shelter until the flare subsides. This system is a backup to solar monitoring stations on the Earth and in space.

Consumables pallets are delivered on each crew flight. Consumables include food, life support expendables, clothing, hygiene supplies and housekeeping items. The pallets provide pressurization and thermal control where required for the consumables.

Lunar NOC 1

Lunar NOC 1 extends the surface infrastructure in order to support crews of up to 12. Surface transportation range and functions are expanded. The capacity to produce significant quantities of locally derived gases and materials is developed.

During this phase, a second habitat unit is emplaced. This habitat is delivered with an interconnect node (similar to the SSF design) attached to one end, and a docking adapter on the other. It is externally identical to the initial habitat and is connected to the adapter on the end of the habitat away from the airlock (see *Figure 4*). Its critical internal systems can operate independently of the initial habitat, providing separate pressurized volumes in case of difficulty in either habitat. It differs only in its internal outfitting: crew quarters, galley, etc., are located in the initial habitat, while the second habitat contains an expanded crew health-care facility, scientific/workshop accommodations, and storage space for the consumables required during long term (30-90 day) missions. With the addition of this second habitat, and the emplacement of the requisite regolith shielding, the outpost can support 6-person crews for up to 90 days.

The second habitat is followed by a laboratory/workshop module (with attached airlock), connected to the node and oriented at a right angle to the other two modules (see *Figure 4*). This module's critical systems are also identical to those of the other modules. Its internal outfitting consists of storage, science racks, and a workshop area for servicing and repair of base machinery.

Across the interconnect node from the lab/workshop, a greenhouse is constructed. The greenhouse structure is composed of cast basalt produced by the ISRU plant. The interior is sealed by the installation of a double-layered bladder. Access is restricted/controlled by hatches in the node, since the greenhouse will operate at elevated CO² levels. The greenhouse tests the use of regolith as a root matrix, obtaining nutrients from a drip-emitter irrigation system.

The last cargo flight of this phase delivers another module, similar to the first habitation module, which is connected to the node in-line with the other habitats. This module constitutes one-half of the Mars simulation structure utilized in NOC 2. Since its internal outfitting is primarily crew accommodations, the addition of this module expands the capability of the base to 12 crew.

The power capability of the outpost is upgraded by the emplacement of two 55 kW nuclear systems whose delivery is phased with the increasing power demand of the ISRU plants. These plants are similar to the 100 kW system deployed in IOC. They employ an SP-100 type reactor placed in a hole in the regolith, with eight Stirling engines arranged on the surface around the hole. The Stirling engines operate at a higher temperature than on the 100 kW system (1300 K vs. 1050 K). The system is delivered in several packages and gross assembly is performed by teleoperation of the LEVPU. Final connections and checkout are performed by EVA. System health is monitored from the habitat.

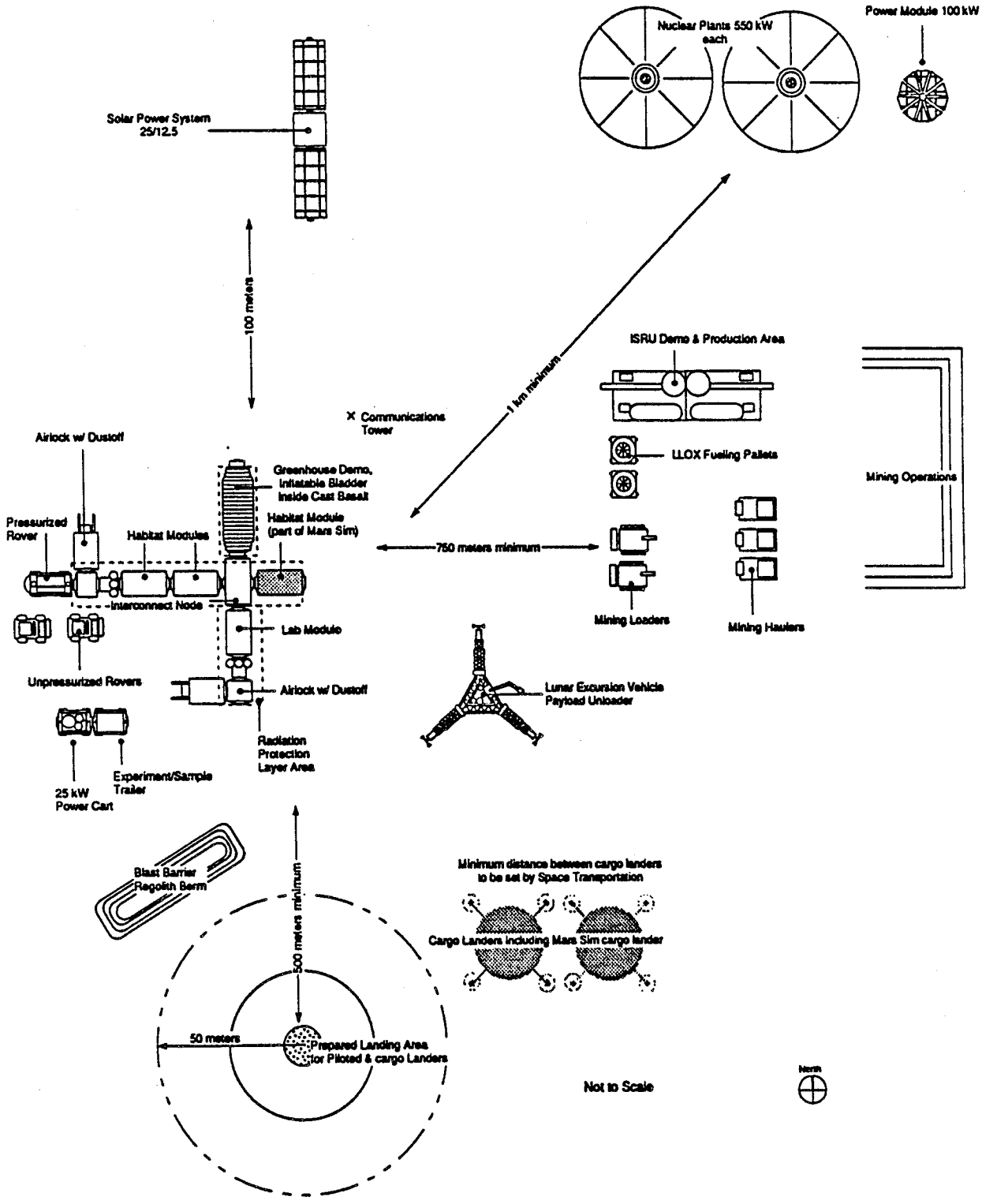


Figure 4 Space resource utilization Architecture Lunar NOC 1.

A pressurized rover system is delivered for use in this and subsequent phases. The pressurized rover itself has limited capability (on the order of 50 km from the base), but with the addition of an auxiliary power cart and an experiment/sample trailer, this extended to a range of 100 km from the base, for two crew members for up to six days. The rover has twin manipulator arms for geologic sample collection and intravehicular activity (IVA) access to surface equipment. Power is provided by regenerative fuel cells, thermal control is provided by coatings and a two-phase heat pump. The life support system is partially closed with storage of wastes for return to the base.

Three additional mining haulers and two mining loaders are delivered as the mining rate increases. The front-end mining loaders are fuel cell-powered vehicles with chassis similar to those of the haulers. They relieve the LEVPU of mining duties.

Two years after the oxygen/ceramics/metals demo, a pilot plant which produces eight metric tons of oxygen per year is deployed. This is followed two years later by a larger plant which produces 60 tons of oxygen per year. These plants also produce a variety of metal and ceramic items. The oxygen is first used in the fuel cells on the surface vehicles, then later in propulsion systems of the landers and as life support system make-up. Ceramic blocks (produced by hot-pressing or melting regolith) can be used as paving stones to control the dust around the base, or in building simple structures. Other uses for ceramics, and the metals produced, are subjects for further study.

The year after the oxygen pilot plant is emplaced, a volatiles pilot plant which each year produces five metric tons of hydrogen, 5 t helium, 5 t nitrogen, and 20 mt CO/CO² is delivered. This is followed three years later by 15 t helium, 15 t nitrogen, and 60 t CO/CO² per year. The hydrogen is used in the fuel cells on the surface vehicles and in the propulsion systems of the landers. Any excess can be used to make water for the crew or for plant growth. Nitrogen is used in the atmosphere of the habitats and in plant growth. CO/CO² can be used in methane/oxygen propulsion systems, and in the greenhouse. Helium-3 is separated from the helium produced, and exported to Earth for use in fusion reactors.

Liquifaction and storage of locally produced gases is provided by systems delivered with the plants. Transfer of the gases is achieved by delivering transfer pallets, transportable by the LEVPU, which utilize tanks scavenged from expended landers.

Support for reusable landers on the lunar surface is provided by an excursion vehicle-servicer package. This surface unit provides power, thermal control, and reliquifaction of the vehicle's cryogens. Heat rejection is provided by a heat pump with composite radiators, and reliquifaction is accomplished by Heyland cycle machinery. A tent structure is provided for covering the lander: this provides micrometeoroid protection and reduces the heating and cooling loads. Refueling of the landers is accomplished by using the transfer pallets described above.

Expanded science accommodations are available in the second habitat, the hab/lab/storage module, and the Mars simulation habitat. The pressurized rover extends the range of surface exploration.

Lunar NOC 2

Lunar NOC 2 emplaces habitats to be used in a simulation of a Mars mission. These are connected to the existing habitats, and become part of the base following the simulation.

An additional habitat/airlock assembly is delivered and connected in line with the first Mars simulation habitat emplaced at the end of NOC 1. Together, these two modules house the Mars

simulation crew. They differ from the other habitats in the life support system used: the Mars simulation will utilize the same life support technology as will be used for the Mars mission. In this implementation, this is an advanced SSF regenerative system which incorporates waste processing, to reduce consumables usage. To maintain the fidelity of the Mars simulation, the hatch between these modules is kept closed while the test is being conducted. After the simulation, the Mars habitats are used by lunar crews as crew quarters, science stations, and consumables storage.

The Mars simulation uses the power systems already existing at the base.

The simulation crew brings an unpressurized rover like the one described previously. They use the pressurized rover delivered to the base during NOC1. *Figure 5* schematically depicts the layout of the lunar base.

Mission Profile

Lunar Flights 1 & 2 (Cargo), 2003

A cargo lander delivers the payload unloader, unloader attachments, PVA/RFC power system, communication equipment, cryotank verification unit, the O₂/Ceramics/Metals demonstration unit, and flare warning system. A second cargo lander delivers the integrated habitat/airlock plus the 100 kW nuclear power supply. Delivering all of these systems on a single cargo lander would be preferable, but the total would exceed the capability of the current lander design. The unloader operates under supervised autonomy (autonomously, with supervision and intervention as needed from Earth). It self-deploys from its lander, and utilizing various attachments, it clears and levels areas for the habitat, power supplies, and ISRU demo. Other surface preparations include the excavation of hole for the nuclear power supply, and piling of a 1.5 m high regolith berm between the habitation area and the preselected crew landing site (in order to protect base elements from most of the blast ejecta from the landers).

By straddling the first lander the unloader removes the solar power system and ISRU demo, transports them to the prepared sites, and lowers them to the surface. The cryotank verification unit and flare warning system are similarly positioned.

By straddling the second lander the unloader removes the habitat/airlock, transports it to the prepared site, and lowers it to the surface. Next the nuclear power supply is moved to the excavation, already prepared. After it is placed into the excavation, its radiator panels self-deploy. The necessary connections are made by the unloader between the power supplies and the various surface elements. At the completion of this period of un-manned lunar operations, all systems are in their final positions and their integrity is verified from Earth to the extent possible. Once the unloader is freed from these duties, it is employed in supplying the O₂/Ceramics/Metals demo with the needed regolith feedstock.

Lunar Flight 3 (Piloted), 2004

A crew of five lands near the outpost at the beginning of lunar day bringing with them EMU's and the required consumables. They also bring the ³He Volatiles demonstration unit and two surface vehicles to support their operations -- an unpressurized rover and a mining hauler for the ISRU demonstrations. A limited set of geological exploration equipment is also delivered. The crew lives out of the lander for two-three days, performing EVAs to verify the proper deployment and connection of the photovoltaic array and the nuclear power supply to the habitat and ISRU demo delivered on Flight 1. The ISRU demo, flare warning system, and cryotank verification unit are

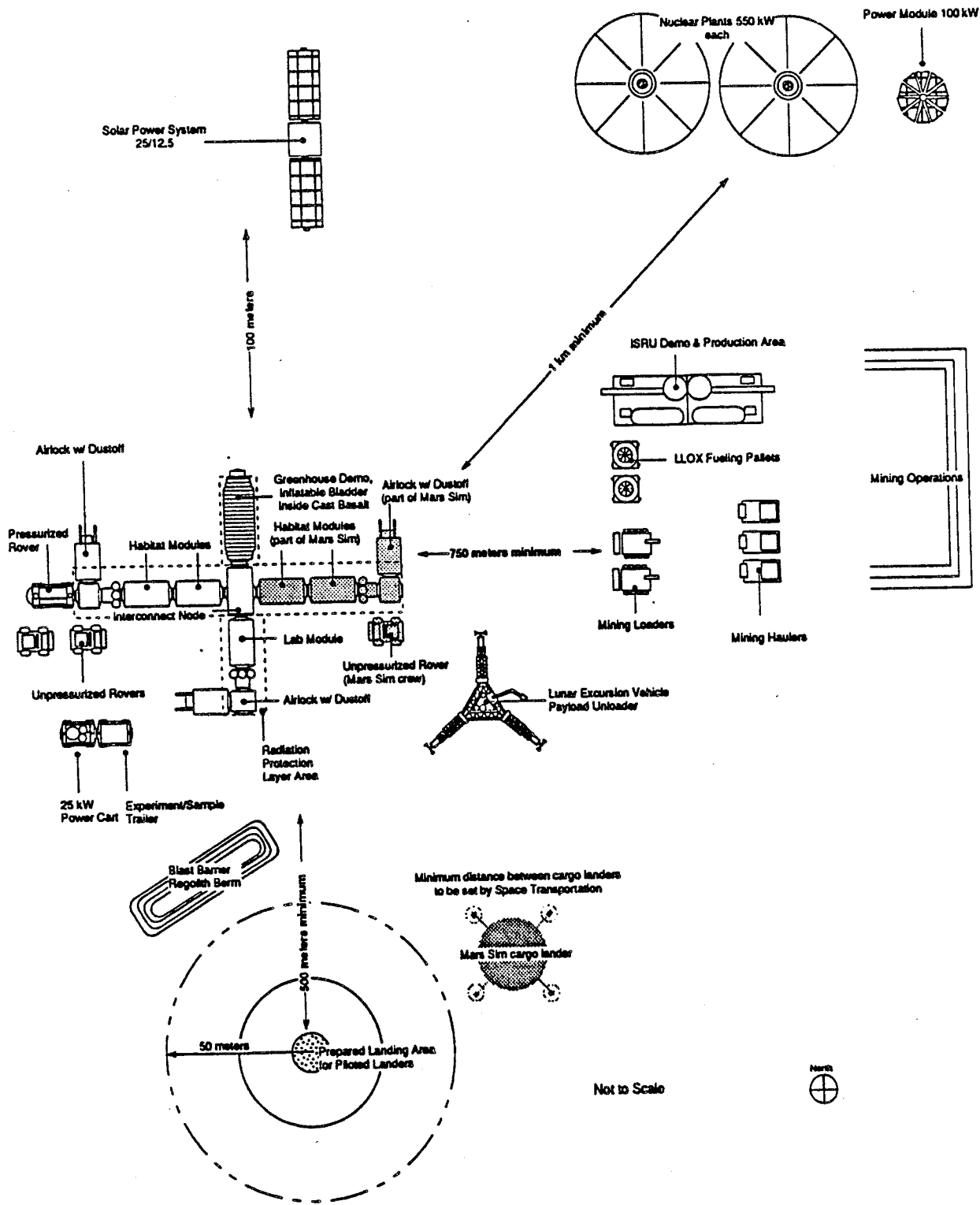


Figure 5 Space resource utilization Architecture Lunar NOC 2.

inspected and adjusted if necessary. After activating the verifying the habitat's internal systems, they occupy the habitat for the remainder of the 14-day stay.

Local geological exploration is carried out near the outpost and via the unpressurized rover, as time permits. A geophysical monitoring station is deployed within walking distance of the outpost.

At the completion of the 14-day stay, the crew powers down the habitat, placing it in standby mode until the next mission, and departs in the lander. With the completion of this flight a presence has been established on the lunar surface which marks the achievement of Lunar Initial Operating capability.

Lunar Flights 4 & 5 (Cargo), 2005

A cargo lander delivers the second habitat unit accompanied by an interconnect node. This flight also delivers the pilot plant for O₂/Ceramics/Metals production. The unloader transports the habitat and node (which are already docks together) from the lander and places them in the proper orientation to the existing habitat. The mating of the two is carried out under supervision from Earth. The unloader then removes the pilot plant and transports it to the same area of the demo previously delivered. Finally, the unloader uses various implements to emplace the regolith shielding layer over the habitats and excavate a hole for the next nuclear power supply.

Another lander delivers a 550 kW nuclear power plant, a LLOX fueling pallet, and supporting surface transportation vehicles -- a pressurized rover system and another mining hauler accompanied by a mining loader for the pilot plant operations. On command from ground control, the payload unloader moves the nuclear power plant pieces from the lander to the prepared site. After placing the reactor into the excavation, the other major subsystems are arranged in position. The unloader also lowers the pressurized rover and its power cart from the lander to the lunar surface. Teleoperated from Earth, the rover train moves to the vicinity of the outpost.

Lunar Flight 6 (Piloted), 2006

A crew of six arrives with science equipment, consumables for a 45-day stay, and spares and needed replacement parts for base systems. They also bring a ³He/Volatiles pilot plant. They verify the outpost systems and move into the habitat.

After occupying the base, the crew performs the necessary EVA to complete the assembly of the nuclear power plant and connect it to the power distribution system. The reactor is then remotely activated. This operation is followed by installation and startup of the volatiles pilot plant. Mining and resource production operations are assisted as necessary, until they can be controlled completely from Earth.

Science operations are carried out via the pressurized and unpressurized rovers, as maintenance and contingency requirements permit. Locally produced oxygen and hydrogen can be used to replenish the fuel cells of the rovers, if needed.

After 45 days, with the two ISRU pilot plants up and running and the habitation area now able to support crews for stays of 45-90 days, the crew powers down the habitat, placing it in standby mode until the next mission, and departs in the lander.

Lunar Flight 7 & 8 (Cargo), 2007

A cargo lander delivers and O₂/Ceramics/Metals production plant, two mining haulers, a mining loader, another LLOX fueling pallet, a lunar excursion vehicle servicer, and equipment necessary to conduct a power beaming demonstration. An experiment/sample trailer for the pressurized rover is also carried. On command from ground control, the payload unloader removes the production plant from the lander and transports it to the vicinity of the other ISRU units. The same is done with the fueling pallet. The mining vehicles are unloaded and driven to the mining area. The beamed-power demo is moved near the power supplies, and the LEV servicer is left near the landing areas.

Another cargo lander brings a laboratory module/airlock assembly, and an additional 550 kW power supply. The power supply components are positioned as described previously. The unloader transports the lab/airlock from the lander to the other habitats and performs the mating operation. The unloader then proceeds to emplace the regolith shielding over the new element.

Lunar Flight 9 (Piloted), 2009

A crew of six arrives with science equipment, EMU's, consumables for a 90-day stay, spares, and needed replacement parts for base systems.

The crew in combination with the unloader, utilizes the LEV servicer to safe the lander. After occupying the base, they perform the necessary EVA to complete the installation of the second nuclear power plant. They then complete the installation of the O₂/Ceramics/Metals production plant and initiate its operation. The crew uses the pressurized rover to explore outside of the vicinity of the base and carry on maintenance of emplaced systems, particularly in the ISRU production area.

IVA science activities are carried out in the habitats. EVA science, together with routine maintenance and contingency repairs, are carried out on foot and via the rovers.

With the power system at full capability, the ISRU units up and running, and the habitation area now able to support crews for stays of 180 days, the crew powers down the habitat, placing it in standby mode until the next mission, and departs in the lander.

Lunar Flight 10 (Cargo), 2009

A cargo lander delivers a He³/Volatiles production unit and outfitting for a demonstration greenhouse, plus needed spares. The unloader offloads and integrates the production unit into the ISRU area and the power network already in place. The greenhouse outfitting is also offloaded and delivered to the habitat area.

Lunar Flight 11 (Piloted), 2010

A crew of six arrives with EMU's and consumables for a 180-day stay. The crew, in combination with the unloader, utilizes the LEV servicer to safe the lander. After occupying the base, they perform the necessary EVA to verify the proper installation and operation of the new volatiles production unit.

Their next major activity is the construction of the greenhouse. The unloader is used to partially construct a cast-basalt structure adjacent to the interconnect node, utilizing pieces fabricated nearby. A bladder package is moved inside and mated to the node. The external structure is completed and the bladder inflated. Finally, the crew completes the internal outfitting of the greenhouse, and initiates plant growth experiments.

The remainder of the stay time is spent performing needed base maintenance operations and science investigations. After a stay of 180 days, the crew places the base in standby mode and departs.

Lunar Flight 12 (Cargo), 2010

A cargo lander delivers the first habitat for the Mars simulation. The unloader transports it to the base and mates it to the interconnect node, in-line with the two existing habitat modules. Installation of this module brings the base's crew capacity to 12, marking the achievement of Lunar NOC

Lunar Flight 13 (Cargo), 2011

A cargo lander delivers the second habitat for the Mars simulation, together with an airlock and science equipment. The unloader transports and mates this module to the one delivered on the previous flight. Regolith shielding is then placed over both Mars simulation habitats.

Lunar Flight 14 (Piloted), 2011 (Arrives in 2012)

After a stay in lunar orbit (to simulate the Mars transit), the Mars simulation crew of six arrives with EMU's, an unpressurized rover, a suite of science equipment and experiments, and consumables for a 40-day surface stay. They check and then occupy the Mars simulation portion of the base. While on the surface, they demonstrate as many of the operations to be performed at Mars as is practical. This may include weighting of the crew to simulate the effects of Mars-like gravity loads on the crew members immediately following the long zero-g transfer phase. The pressurized rover previously delivered to the base is also available for their use.

All operations are carried out while a support crew is present at the base. The support crew lends assistance as necessary to complete the simulation. At the end of their 40-day stay, the simulation crew may power down and safe the simulation habitats, or this may be left to the support crew.

Lunar Flight 15 (Piloted), 2012

Six crew arrive at the base some 25 days prior to the landing of the simulation crew. In addition to checking out the base for reoccupation, they verify that the Mars simulation habitats are properly positioned and ready for the simulation crew. When the Mars simulation crew is on the surface, they lend whatever assistance is required to maximize the usefulness of the simulation. After the Mars crew departs, they remain for an additional 25 days servicing base systems, monitoring the ISRU plants, performing science activities, and working the greenhouse.

The completion of Mars simulation marks the achievement of Lunar Next Operating Capability 2. What is subsequently done with the substantial assets of the lunar base is a subject for further study.

Issues for Further Study

Issue: Logistics and Resupply

Because this architecture is aggressive in its buildup, there is a greater need for efficient delivery and distribution of logistics and resupply materials. The large number of surface elements, and the complex tasks they perform will make supportability vitally important.

Recommended focused studies: Supportability concepts incorporating logistics strategies.

Issue: Spares Philosophy/Maintenance Burden

The makeup of spares inventories and the requirements for maintenance operations on planetary surfaces have only been roughly estimated to date.

Trend analysis, to date, project that conventional design practices will require an order of magnitude for more man-hours than available for maintenance.

Recommended focused studies: Maintenance burden studies and spares analysis for surface elements.

Issue: Optimization of Lander Concept & Unloading Concept

The current Lander Concept requires design of mobile gantry crane that can "Straddle" payload on top of lander. This results in a heavy design with risky operational procedures.

Recommended focused study: Combine lander design requirements to optimize design of both.