

**Final Report:**  
**Design of a Lunar Farside Observatory**

**Submitted to**

**Dr. George W. Botbyl  
Professor, ASE 274L  
The University of Texas at Austin  
Austin, Texas**

**By**

**The OUTLOOK Design Team  
The University of Texas at Austin  
Austin, Texas**

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**The OUTLOOK Design Team:**

**Project Manager:**

Brent Harding

**Technical Area Managers:**

Marlene Ewing

Ido Dubrawsky

Michael Wofford

Mary Wendricks

**Engineers:**

Robert Hazzard

Todd Copeland

Richard Metzger

Roy Silva

Jose Sanchez

Brodie McDougald

**Project Advisors:**

Dr. George Botbyl

Dr. Wallace Fowler

Dr. Harlan Smith

Mr. George Davis

Miss Barbie Kozel

## **Abstract**

This document presents the Final Design Report for the design of a man-tendable Lunar Farside Observatory and Science Base by the OUTLOOK Design Team. A farside observatory will allow high accuracy astronomical observations, as well as the opportunity to perform geological and low gravity studies on the Moon. The requirements of the observatory and its support facilities will be determined, and a preliminary timeline for the project development will be presented.

The primary areas of investigation include Observatory Equipment, Communications, Habitation, and Surface Operations. Each area was investigated to determine the available options, and each option was evaluated to determine the advantages and disadvantages. The options selected for incorporation into the design of the farside base are presented.

The observatory equipment deemed most suitable for placement on the lunar farside consist of large optical and radio arrays and seismic equipment. A communications system consisting of a temporary satellite about the L<sub>2</sub> libration point and followed by a satellite at the stable L<sub>5</sub> libration point was selected. A Space Station common module was found to be the most practical option for housing the astronauts at the base. Finally, a support system based upon robotic construction vehicles and the use of lunar materials was determined to be a necessary component of the base.

The design process was governed by a management structure headed by a project manager and four technical managers. The total cost for the design of the Lunar Farside Observatory was \$38,100.70, which was less than the estimate presented in the project proposal of October 9, 1989.

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## **Executive Summary**

This report presents the final design of a man-tendable Lunar Farside Observatory and Science Base by the OUTLOOK Design Team. A farside observatory will allow high accuracy astronomical observations, as well as the opportunity to perform geological and low gravity studies on the Moon. The requirements of the observatory and its support facilities will be determined, and a preliminary timeline for the project development will be presented.

The primary areas of investigation in the design of a Lunar Farside Observatory (LFO) included observatory equipment, communications, habitation, and support operations. Each area was investigated to determine the available options, and each option was evaluated to determine its advantages and disadvantages. This document discusses the options deemed most suitable based upon current information.

Several assumptions were made before the design of the LFO could proceed. These assumptions were that

- 1) a lunar nearside base was in place and has the capability to process lunar materials for the production of fuel and oxygen,
- 2) an advanced launch system (ALS) consisting of a heavy lift launch vehicle (HLLV) existed to transport materials to low earth orbit (LEO),
- 3) the use of nuclear power in space is reliable and accepted, and
- 4) semi-autonomous robotic capabilities exist to facilitate teleoperated and fully automated robotic construction of the observatory.

The above assumptions were used in conjunction with the mission groundrules to guide the design of the observatory. Some of the groundrules were: that the maximum set -up time for the observatory would be three (3) years, that two launches from the LEO transportation node were permitted per year, and that after construction was complete, one piloted mission per year

from Earth would be scheduled to conduct maintenance of the observatory. Periodic maintenance of the observatory would also be supported by crews stationed at the nearside base.

The science equipment necessary for the successful operation of a farside observatory includes a mixture of optical telescopes, radio interferometers, x-ray and gamma ray telescopes, and selenographic experimental packages. This equipment must be shielded from the harsh thermal environment which exists on the moon; the equipment must also be protected from the lunar dust, radiation, and micrometeorites. To provide power for the observatory, an SP-100 nuclear reactor will be used at the observatory. A schematic of the base layout is shown in Figure 1.1.

To provide constant communication with the lunar nearside base as well as Earth, a communication system was devised where the relaying point is a satellite in a halo orbit about the L<sub>2</sub> unstable libration point. This would permit full coverage of the lunar farside and the constant monitoring of the construction activities being conducted. Since L<sub>2</sub> is an unstable libration point, stationkeeping burns totaling 93.3 fps/yr and period control burns totaling 240 fps/yr will have to be conducted in order to maintain the orbit. After three years, the satellite at L<sub>2</sub> will be refueled and moved to the stable libration point L<sub>5</sub>, where it will remain throughout the lifetime of the observatory.

To transport the materials and equipment of the LFO to the observatory site, a lunar cargo lander designed by students at the Department of Mechanical Engineering at the University of Texas at Austin will be used. This lander will transport the habitation module, robots, and observation equipment to the observatory site. Two unpressurized lunar rovers were included in the design for transportation around the base.

For the habitation module of the astronauts, OUTLOOK chose the Space Station common module. The module will be covered by a layer of lunar regolith supported by the lunar cargo lander platform. This covering will shield the module from the radiation of outer space, as well as provide some degree of thermal and micrometeorite protection for the module. Figure 5.4 shows the final habitation configuration.

A completely closed atmospheric regeneration system was chosen for life support since it reduces the need for resupply and waste removal. To

replenish the water used at the observatory, the Super Critical Wet Oxidation (SCWO) system was selected. For the thermal control of the observatory systems, an active thermal control system (ATCS) will be used. This system uses redundant two-phase outer loops with two-phase inner loops to perform the heat acquisition and transport phase of the ATCS. The system will utilize two-phase fluid flow to allow for higher heat transfer coefficients. Surface radiators will be used to reject heat.

Two areas were considered in surface operations: extravehicular activity (EVA) and robotics. A zero pre-breathe suit (ZPS) will be used for astronaut EVA. Furthermore, the astronauts will not conduct more than two EVA shifts in one day. The robotics used at the LFO will consist of a foreman robot and worker robots. The foreman robot is programmed to the level of artificial intelligence and assigns jobs to the worker robots. The worker robots are lunar construction utility vehicles (LCUV) designed by students at the Department of Mechanical Engineering at Old Dominion University. These workers use a manipulator arm to lift objects. Also, lunar telerobotic servicers (LTS) will be used to perform high risk tasks at the farside observatory. To perform heavy lifting tasks, a lunar crane developed by the students at the Department of Mechanical Engineering at the University of Texas at Austin will be used.

The OUTLOOK management structure is shown in Figure 8.1. The design team was led by a project manager and four technical managers. The job of the technical managers was to oversee the completion of tasks which the engineers were assigned. The project manager ensured that all groups interacted with one another so that the project development proceeded smoothly.

The costs for the design project consisted of manpower costs and materials costs. Based upon current salary information, the total manpower cost of the project was \$36,313.20. The total materials cost, which included photocopies, personal computer usage, and model construction was \$1787.50. Therefore, the total cost for OUTLOOK's design of a lunar farside observatory was \$38,100.70.

## **1.0 Overview**

This document represents the final design of a Lunar Farside Observatory and Science Base by the OUTLOOK Design Team. The purpose and scope of the project is discussed, as well as the assumptions and groundrules governing the project. A mission profile and base layout are presented and the individual components of the observatory and support systems are discussed in detail. Finally, management and cost reports for the project are presented.

### **1.1 Purpose and Scope of Project**

The purpose of this project is to establish requirements for a maintainable lunar farside observatory and science base. The scope of the project was limited to operations on the lunar surface and the communications system required to support these operations.

### **1.2 Benefits of a Lunar Farside Observatory**

Locating an observatory on the lunar farside has several advantages over Earth-based or Earth-orbiting observation facilities. First, the radio interference generated by sources on Earth will be eliminated, as will the adverse effects of Earth's atmosphere. Also, the Moon provides a low gravity, vacuum environment, allowing larger arrays to be deployed without additional support needed to withstand added weight loading or weather conditions. Therefore, measurements can be made which are orders of magnitude more sensitive than those currently available. An additional benefit of the lunar setting is that it provides a gravity environment for humans, allowing operations to take place under conditions to which humans are better adapted. Further benefits of a lunar farside observatory include the ability to support future projects such as the Search for Extra-Terrestrial Intelligence and missions to other planets.

### **1.3 Assumptions**

To facilitate the design process and narrow the scope of the project to operations on the lunar surface, the following assumptions were made:

- A lunar nearside base is already in place, and has the capability to process lunar materials for the production of fuel and oxygen. The nearside base will provide valuable construction and operational experience on the Moon, as well as insure the existence of an adequate infrastructure to support large-scale lunar missions. The farside observatory construction could begin as soon as five years after the establishment of the nearside base.
- The infrastructure mentioned above consists of a heavy lift launch vehicle (HLLV) to transport materials to low earth orbit (LEO), a space station in LEO to serve as a vehicle construction area and transportation node, and an orbital transfer vehicle (OTV) to transport payloads from LEO to lunar orbit.
- The use of nuclear power in space is reliable and accepted, based upon prior use at the lunar nearside base.
- Semi-autonomous robotic capabilities exist to facilitate tele-operated and fully automated robotic construction of the observatory.

### **1.4 Mission Groundrules**

The following groundrules were adapted from rules set forth by the Office of Exploration of the National Aeronautics and Space Administration [1:24]. These rules were established to provide a framework to govern the design process by limiting the burden such a project will place on the launch capabilities of the United States.

- A maximum time of 3 years is allowed for construction of the observatory.

- Two launches from the LEO transportation node are allowed each year during construction.
- Each piloted mission consists of a four-member crew.
- The piloted missions may last a maximum of 90 days during the construction phase.
- After the observatory is constructed, one piloted mission per year from Earth is allowed. These missions will consist of instrument calibration and maintenance, scientific experiments, and selenological surveys. Intermediate support missions will be performed by crews stationed at the lunar nearside base.

## 1.5 Mission Timeline

Table 1.1 presents a mission timeline for observatory construction. These missions may be reordered to deal with unforeseen incidents. As mentioned previously, one mission per year will be allowed after construction is completed. A description of each mission is presented below.

**Mission 0:** This mission consists of the deployment of a communications satellite from Earth to the L<sub>2</sub> libration point by use of an unmanned launch vehicle. The communications system will then be used to monitor and control the robotic operations of subsequent construction missions.

**Mission 1:** This unpiloted mission consists of the delivery of the robotic construction vehicles, the base habitation module, and the nuclear power plant. The robotic vehicles will self-deploy from the lander and begin preparation of the observatory site by removing any obstructions and smoothing the surface where the instruments, habitation, and roads will be located. The habitation module and power plant are removed from the lander and placed in the area designated for each component. A crater is then constructed around the power plant to provide shielding for the rest of the base from the radiation produced by the nuclear generator. The lunar lander platform is placed over the habitation module to serve as a protective barrier to meteor impacts, and a protective

"blanket" is placed over the lander platform to provide radiation protection and support the layer of lunar regolith piled upon the structure by the robots.

**Table 1.1 Mission Timeline for Observatory Construction**

Year	Mission	Payload	Activities
0	0 unmanned	Communications Satellite	Satellite Deployment
1	1 unmanned	Habitation Module Power Supply Robotic Vehicles	Site Preparation Module Location
1	2 unmanned	1st Obs. Package Airlocks Shields	Equip. Placement Shield Set-up
2	3 manned	Supplies Support Facilities Emergency Equip.	Hab. Initialization Equip. Prep. Power Up
2	4 unmanned	2nd Obs. Package Supplies	Equip. Set-up (Delivered Day 30 of Mission 3)
3	5 manned	3rd Obs. Package Science Package Supplies	Equip. Set-up Calibration Maintenance
3	6 manned	As Needed	As Needed

**Mission 2:** This mission involves the unpiloted delivery of the first package of observatory equipment and support facilities. The robotic vehicles unload the equipment components from the lander and place them in the prescribed areas. Construction of the equipment is then telerobotically controlled from Earth or the nearside base.

**Mission 3:** This is the first piloted mission, with a payload comprised of the airlock for the habitation module, emergency equipment such as small radiation shelters, and the necessary supplies for the astronauts. The activities of the crew in the first portion of the mission will focus primarily upon the initialization of the habitation module while they live temporarily in the lunar lander. Preparation of the module will be completed in approximately 14 days. Once the habitation is prepared, the crew will complete construction of the previously

delivered observation equipment and connect the entire base to the nuclear power supply. The projected stay time for this mission is 60 days.

**Mission 4:** This mission is the second of year two, and consists of the unpiloted delivery of the second package of observatory equipment. The arrival of this mission at the farside base is projected to be near day 30 of Mission 3. Therefore, when the crew is finished preparing the habitat and equipment which were delivered in Missions 1 and 2, they will begin construction of the next set of observatory equipment.

**Mission 5:** The only mission currently slated for year three of the observatory construction phase, this mission consists of the piloted delivery of the final components of the farside base. Equipment construction and calibration is performed by the astronauts, as well as any necessary maintenance required for previously placed equipment. By the conclusion of this mission, the base will be fully operational, allowing the full range of astronomical and selenological studies to be performed. The predicted stay time for this mission is also 60 days.

**Mission 6:** This mission was included to be used as required by payload launch limitations or failure of some base component. The three year construction time limit could still be satisfied by using this additional launch as needed.

Reordering of the above missions can be done if necessary, using the contingency Mission 6 to recover from any setbacks. However, if the construction cannot be completed in the three year time period, some observatory equipment may have to be omitted from the final configuration. Therefore, the observation packages will be delivered according to priority to insure the placement of the most scientifically valuable instruments on the lunar farside.

## **1.6 Site Selection Criteria**

Selection of an appropriate site for the observatory is important, since the location of the observatory will have considerable effects on its capabilities. The following criteria have been established in order to evaluate possible sites:

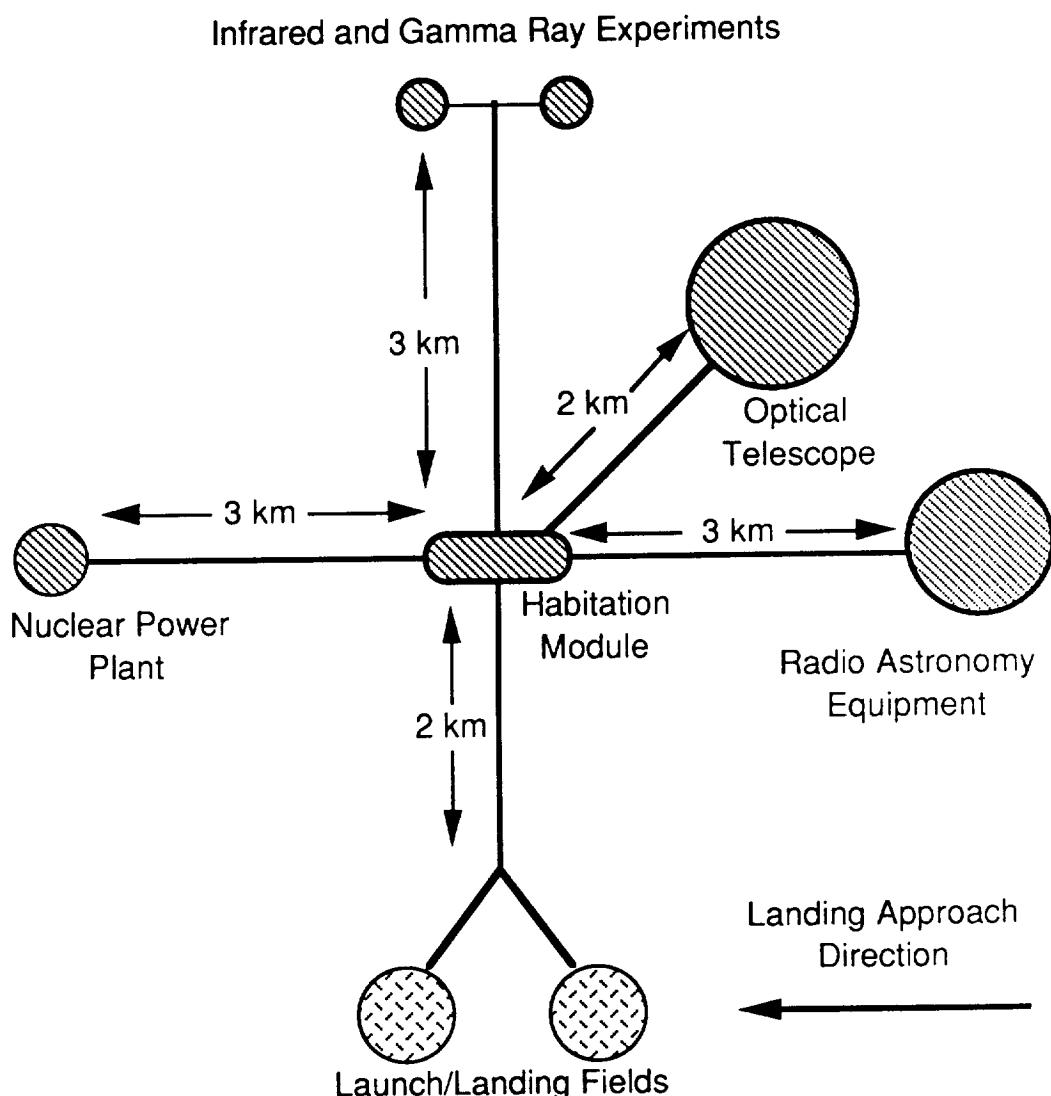
- An equatorial site near  $180^{\circ}$  longitude is desirable in order to limit horizon interference with the field of view of the instruments.
- An area with a smooth floor, relatively free of cliffs, mountains, canyons, and large craters is necessary to allow easier operation of automated landers, construction vehicles, and rovers.

The site selected for this analysis is the crater Tsiolkovsky, located near  $20^{\circ}$  south latitude,  $130^{\circ}$  east longitude. This site was selected because it satisfies the above criteria, and is conveniently positioned to allow the desired communications system to be deployed. The communications system is described in Section 3 of this report. An alternate site which was considered was the crater Korolev, located at  $7^{\circ}$  south latitude and  $158^{\circ}$  west longitude.

## **1.7 Base Layout**

A preliminary layout for the lunar farside observatory is presented in Figure 1.1. As shown, the nuclear power plant is placed away from the main part of the base to avoid exposing the habitation and sensitive equipment to residual radiation. Also, the optical instruments are placed away from the launch/landing fields in order to eliminate interference caused by dust agitated by the rocket motors. To reduce the problems posed by the dust, blast shields will be erected to contain the dust and the possibility of bonding the surface layers of lunar soil by using polymers or sintering methods will be examined. These latter methods can also be expanded for use on the roads joining the different areas of the base. Lastly, in an attempt to reduce the risk of damage to the base or injury to the astronauts, the base is configured so that incoming and

outgoing spacecraft will not pass directly over the observatory equipment, habitation module, or nuclear power plant upon approach to the landing field. The actual components of the base are discussed in Sections 2 and 5 of this report.



**Figure 1.1 Preliminary Base Layout**  
(Equipment not to scale)

## **2.0 Science Base and Observatory**

The lunar farside is a prime location for an observational facility. The type of equipment to be located at this base, the shielding necessary, and the power required for the equipment are discussed below.

### **2.1 Advantages of a Lunar Farside Observatory**

When asked why a lunar farside base was desirable, astronomer Dr. Harlan Smith of the University of Texas at Austin replied that "There is only one place in the universe that is so lucky as not to hear the Earth." [2]. That place is the lunar farside. The lack of radio, television, and atmospheric interference allows observations from the Moon to be clearer and totally independent of the capricious weather of Earth. Observations from the lunar farside are also free from the "spectral noise" that is produced by pollutants in our atmosphere. Other advantages over an Earth-based observatory include wide field of viewing without moving equipment, stable pointing and tracking, easy vibration isolation from low seismic activity, and the capability of building larger instruments and platforms.

The lunar farside observatory has advantages over space telescopes also. Instruments on the farside will not be subject to radio noise from Earth, Earth-to-Moon communications, or from Station-to-Moon communications. The equipment on the farside can also be repaired by technicians from the lunar nearside base; a much cheaper proposal than lifting a crew from Earth to an orbital facility. The lunar farside base can be expanded without the worry of stationkeeping or size restrictions. Another benefit is that the observatory can be expanded to maintain a full-time crew, without the severe muscle atrophy that occurs in zero-gravity, and with greater protection from radiation for crew members.

Next, the quality of the observations will increase due to the location of the base. Without atmospheric interference, the other planets in our solar system may be observed and surface-mapped to such an extent that other projects, such as the Mars Explorer, may be decreased in scale or terminated. Views of the further planets that required a twelve year trip for the Voyager spacecraft can be obtained in a few seconds. The lunar observatory will also be used to study other solar systems in the search for planets. Quasars,

pulsars, neutron stars, and black holes will also be searched for from the lunar farside without interfering radiations amplified by Earth's atmosphere. The long-term goal to define the structure and origin of the universe and to study stellar evolution and formation will also benefit from the advantages of the lunar farside site. The Search for Extraterrestrial Intelligence will also be enhanced by the lunar environment.

Geological research will involve further lunar regolith studies, lunar polar studies, seismic activity studies, and lunar atmosphere studies. The low surface gravity on the Moon will provide an excellent opportunity to study the behavior of systems (mechanical, fluid, e.g.) in low gravity.

## **2.2 Science Equipment**

The previously mentioned scientific goals will not be sufficient reasons for establishing a *primary* lunar base; however; a farside science base is a logical step in the evolution from a nearside base. The original observatory will contain simple equipment which can be upgraded by extensions, new instruments, or new systems as technology and funding develop. A list of proposed first generation equipment with advantages and functions is presented in Table 2.1. Appendix A contains sketches of some typical Earth-type scientific equipment.

## **2.3 Prioritization of Equipment**

Equipment will have to be prioritized in order of importance because of possible limits in mass that may be transported to the lunar surface, time required for maintenance, and possible budgetary constraints. The equipment will be prioritized based on which equipment produces the most valuable data, and which equipment benefits most from the lunar environment.

A list of equipment priorities, approximate masses, and power requirements is displayed in Table 2.2.

**Table 2.1 Summary of Future Astronomical Observations on the Moon [6]**

Telescope	Lunar Advantages	Scientific goals
<u>X-RAY AND GAMMA-RAY</u>	No atmospheric absorption. Large collecting area, high throughout high resolution via long focal lengths	Cosmology: clusters of galaxies information. X-ray background. Bursting sources: Black holes. Supernova nucleosynthesis. Direct emission from accretion disks of black holes.
<u>OPTICAL</u>		
A. Large apertures (15 to 20 m)	Diffraction-limited imagery with high sensitivity. Use glass mined on the Moon.	Galaxies information. Distant quasars. Expansion and evolution of the universe.
B. Optical interferometer	Phase-coherent interferometry. Very high resolution: 10 $\mu$ arcsec for 10-km baseline at 500 nm. 100000 times better than ground-based. 10000 times better than Hubble Space Telescope.	Detect planets around other stars. Study sunspots and flares on other stars. Resolve optically violent variables. Resolve cores of elliptical galaxies.
<u>INFRARED</u>	No atmospheric absorption. Excellent vacuum. Passive thermal shielding. “Naked cathode arrays.”	Probe center of Milky Way. Direct examination of star formation. Study planets information.

**Table 2.1 - Concluded**

Telescope	Lunar Advantages	Scientific goals
<b>RADIO</b>		
A. Arecibo-style antennas	Low gravity. Natural shaping in craters. High sensitivity to extended radio emission. Simple observations.	Radar measurements of planets and asteroids. Sensitive to HI and continuum mapping of gas in Milky Way. Study solar wind/magnetosphere for integrated view.
B. Lunar very large array (VLA) or very-long-baseline array (VLBA)	High phase stability. Stable baselines. Lunar materials for construction.	High-accuracy astrometry. Short spacings for longer baseline interferometers.
C. Moon-Earth radio interferometer	Very high resolution: 12 $\mu$ arcsec at 10 GHz. 0.4 $\mu$ arcsec at 300 GHz.	Determination of Hubble constant using statistical parallax of extragalactic masers. Mapping of the "engines" at the cores of active galaxies and quasars.
D. Very low frequency array	Lunar far side provides natural insulation from manmade radio static. Opening new window to the universe.	Evolution of extragalactic radio sources. Measure nonthermal emission from stars. Study low-energy population of energetic particles in planets, pulsars, active galaxies.
E. Millimeter-wave array	No atmospheric attenuation. High resolution.	Mapping new formation regions in other galaxies.
<b>COSMIC-RAY AND NEUTRINO TELESCOPES</b>	New window of energies. Low radiation background. Weak magnetic field. Large-volume detectors.	Distribution of primaries. Monitor radiation exposure for humans. Very-high-energy cosmic rays and neutrinos. Solar flare production and solar nucleosynthesis.

**Table 2.2 Equipment Specifications**

	Equipment	Mass kg	Power kW	Priority
Visual Observation	3m Optical telescope	870	1-2	3
	20x30m radio telescope	16,600	2-4	2
	very low frequency radio interferometer	2100	1-2	1
	Solar observation package	2300	1-2	6
	X-Ray and Gamma Ray telescopes	2850	1-2	4
	Cosmic Ray and neutrino telescopes	5700	1-2	5
Selenographic Research	Portable selenographic package	52	.4	8
	Selenographic experimental package	89	.2	7

\* low numbers indicate higher priority

## 2.4 Design Criteria for Equipment Located on the Moon

The masses and power requirements for the equipment that is currently slated for the farside observatory are estimates. Exact values are unavailable due to the re-design that will be necessary to obtain efficient equipment to function in the lunar environment. Some areas that must be considered for this new class of equipment are the low gravity/vacuum environment, radiation

effects, temperature fluctuation, micrometeor impacts, and the availability of lunar materials.

#### **2.4.1 Lunar Environment**

Because of the low gravity on the lunar surface, science equipment can be made of lighter materials, such as aluminum, as opposed to steel. Lack of wind and precipitation also allows equipment to be built of lighter, frailer materials. Most Earth-based equipment is limited in size due to the environmental forces that act upon them. Lunar equipment will not have this drawback; therefore equipment and platforms may be built larger than is feasible on the Earth.

Lunar materials will also be considered in the construction of scientific equipment. Once a manufacturing facility is established on the Moon at the nearside base, elements can be extracted from the lunar regolith that will be used to build the farside equipment. This will allow easy creation of replacement parts and will reduce the mass that must be lifted from Earth to support the farside observatory.

#### **2.4.2 Shielding of Equipment**

Due to the complexity and delicacy of modern day scientific equipment, a protected environment is required to maintain accuracy and operability. Some elements that the equipment must be protected from are radiation, thermal fluctuation, micrometeor impact, and dust.

##### **2.4.2.1 Radiation Shielding**

Radiation in space primarily comes from Galactic Cosmic Radiation (GCR) and solar flares. GCR is constant and intense. Solar flares occur in periods of from 7 to 17 years [3:36] with the average cycle being 11.1 years in length. Radiation sources in space originate from all directions, and in the case of solar flares expand outwards from their source until they, too, are omnidirectional. Therefore, construction of a temporary, directional shield to protect equipment is impossible. Equipment must be protected on all sides at all times to prevent distortion of data or damage due to radiation effects.

Two methods of shielding against radiation are building with protective material, or covering with protective material. In either case, a material must be chosen that will not produce secondary radiation and that will provide an adequate shield. Materials to be avoided because of secondary radiation are lead or iron, while good shielding elements are water, carbon composites, Kevlar, or lunar regolith [3:38]. Of these, water is vulnerable to freezing and boiling in the lunar temperature changes, and Kevlar and composites would need to be brought up from Earth. Lunar regolith, however, is in great supply, costs nothing, and requires very little relocation to function as a shield.

Burying sensitive equipment with lunar regolith will provide the necessary radiation shielding; however, some of the observational equipment must be on the surface to function. Methods other than burying, such as choosing shielding materials for construction must be explored in this case. Another disadvantage of burying is that it will also increase the maintenance time necessary to repair any malfunctions because the robots or crewmembers will be forced to uncover the instrument and re-bury it.

#### **2.4.2.2 Thermal Fluctuation**

Another disturbing effect on equipment on the lunar surface is the extremes of temperature experienced on the Moon. From lunar day to lunar night, a temperature fluctuation from  $200^{\circ}\text{C}$  to  $-200^{\circ}\text{C}$  is experienced. These extreme temperatures could cause warping of surfaces, melting, freezing or simple burn-out of sensors.

Once again, burying provides one solution to the shielding problem. By burying equipment, the temperature can be more easily regulated. Equipment that must be located on the surface and free of covering must be heat-shielded by other methods such as choice of material, by shading the equipment with some sort of structure, or by removing the equipment from the surface during the more extreme temperatures. Thermoplastics could be chosen to cover or comprise the outer skin of the equipment because they are resistant to heat changes and are easily repaired. Shading of equipment must be done by use of permanent structures that can shield the devices without impeding their range of vision. Removing equipment from the surface will be too time consuming to be feasible.

#### **2.4.2.3 Micrometeor Shielding**

Micrometeorites are a relatively common occurrence in space. Though these meteors are often the size of a dust particle, their high velocities make them deadly projectiles. The Moon, because of its lack of atmosphere, is impacted by many of these micrometeors. Any equipment or habitation on the lunar surface should ideally be shielded from these impacts. However, because of the omni-directional origin of these particles, shielding is a difficult operation. Fortunately, it is believed that damage from these particles will be minimum. Methods of determining the approximate damage that would be expected include examining equipment left by previous lunar missions to determine the extent of the damage over a known period of years, or examining an area mapped by an earlier Moon landing to find the number of micrometeor impacts during the given time period since the mission [4].

Objects that can be buried with lunar regolith will be protected from most of the micrometeors. Equipment on the surface can only be shielded by using strong, dense materials in their construction or as an outer layer. This of course incurs the problem of transporting such heavy equipment from Earth. Another problem concerns some of the more delicate scientific instruments, such as the radio telescopes and arrays, whose integrity depends on smooth, symmetrical surfaces. Though these instruments may be protected from destruction by use of strong materials, dents and scratches from micrometeor impacts will reduce the accuracy of the data. Removable covers would not protect the equipment while during operation and would require many hours of labor to cover and uncover the equipment between experiments.

#### **2.4.2.4 Dust Shielding**

If dust were to infiltrate any of the scientific equipment or the mechanical equipment used at the lunar observatory, it could cause incorrect data or mechanical failure. Due to the lack of lunar atmosphere, dust is thrown up in ballistic-type arcs and falls quickly back to the surface. There is no wind to blow the dust in random directions, so trajectories can be computed and dealt with.

Equipment can be dust-protected by turning it away from the landing, launching, and ground vehicles that throw up dust. Temporary shielding can be placed against the side of the equipment that will be vulnerable to dust,

though the time necessary to place and remove such coverings may be prohibitive. Another protective method is to place the observational equipment far from the areas where dust is most often stirred up. The dust particles lifted from the surface will not travel great distances because there is no atmosphere to slow their descent or to blow them further from their origin. No dust will fly about without human-originated disturbance.

## 2.5 Support Systems

Observation equipment will need some type of control for pointing and tracking as well as a data acquisition and storage system. A limited information data-base and a hard storage system will also be needed for astronauts to use during their missions. The information data-base must contain vital base status information, base position relative to earth, and emergency procedures in the event of a communication data-link loss or a surface system failure. The data acquisition and control system will be an expert system with fault detection capabilities. The lunar support facilities must be capable of preprocessing of data and executing limited analysis. The preprocessing capability would include being able to delete astronomical data taken during times of known erroneous operations.

The astronomical data taken will be at a maximum rate of  $10^9$  bits/sec (125 Megabytes/sec) for a frame of  $10^5$  square pixels. This data rate is for a Schmidt plate exposure which usually lasts for 1000 seconds [2]. Approximately 1000-1000000 optical disks would be needed to store Schmidt exposures for a year. The Hubble Space Telescope will read data at approximately 1 Terabyte/year [5:41]. Obviously with more than one instrument, these data rates become excessively large and storage of data would be impractical with current available technology. Astronomers are also known to always want more data. Therefore, data management capability is recognized as an area where advanced technology developments would be beneficial to a lunar farside observatory. The computer system as well as the science base research instruments will need shielding from high-event cosmic rays and micrometeorite showers.

## 2.6 Power Systems

A reliable, continuous source of power is essential for the construction and operation of any lunar outpost. The selected power system must be capable of meeting all energy demands of the lunar observatory. The Table 2.3 presents the peak power requirements of the various observatory systems during astronaut tended operations [6:123].

The total power is an estimate of the power required during peak operation of the lunar observatory. During periods in which the observatory is untended, power to the habitation and life support systems will be reduced, decreasing the peak power requirement to approximately 15 kilowatts.

**Table 2.3 Power Requirements for Lunar Farside Observatory**

<u>System</u>	<u>Required Power (kW)</u>
Habitation Module	41.11
Life Support	2.27
Thermal Control	4.71
Communication	≈ 2
<u>Observatory Equipment</u>	<u>≈ 8</u>
TOTAL	58.09 kW

### 2.6.1 Primary Power Options

Two energy sources which were considered as candidates for the primary power systems were nuclear and solar power. Nuclear power offers a reliable source of continuous energy to fulfill the power requirements of the lunar observatory. The SP-100 space-based nuclear power system, currently under development, offers a relatively compact source of power, which could be modified for use on the lunar surface. The reliability of this power source will be proven by use at the nearside base. The SP-100 will weigh approximately 3000 kg and will be able to produce 100 kW of electric power. Operational lifetimes for this system have been estimated between seven and ten years [7:99].

The alternative to the SP-100 nuclear power system is a solar power system. The solar power system would consist of a combination of silicon solar

cells and hydrogen-oxygen ( $H_2$ - $O_2$ ) regenerative fuel cells. Solar cells would provide power for the observatory during the lunar day, while the fuel cells would operate during the lunar night when the solar cells would be dormant. This system requires a large solar-fuel cell combination in order to supply power to the observatory. In addition, solar cells degrade in the lunar environment from solar radiation and micrometeorite impacts, reducing the reliability and longevity of the system.

Comparing the benefits and costs of these two systems, the SP-100 system was chosen as the most viable power source for the lunar observatory. Table 2.4 illustrates the decision matrix used to choose the power system.

**Table 2.4 Comparison of Power Sources**

<u>Criteria</u>	<u>SP-100</u>	<u>Solar/Fuel Cell</u>
Weight	1	2
Power/Weight Ratio	2	1
Reliability	1	2
Potential Danger	2	1
Environmental Vulnerability	1	2
Lifetime	1	2
<u>Cost</u>	<u>1</u>	<u>2</u>
TOTAL	9	12

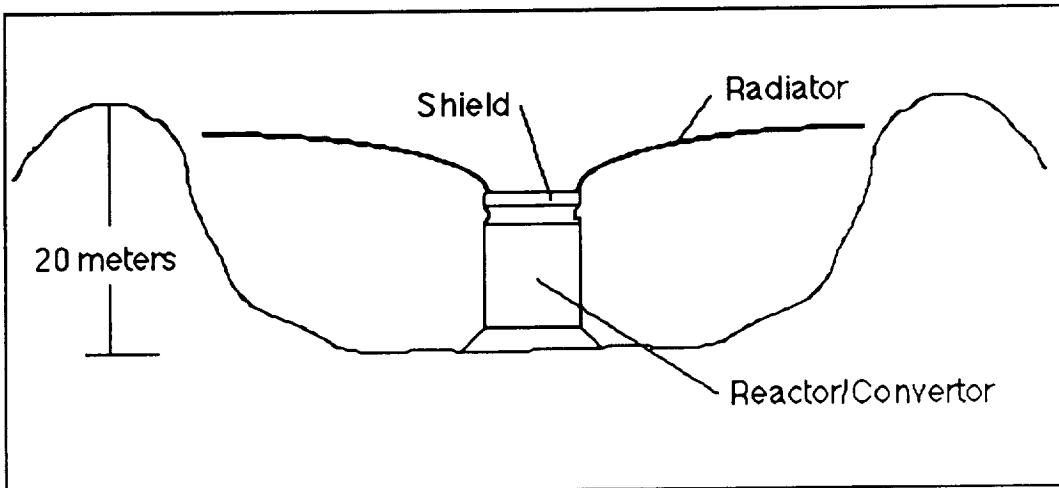
\*Lowest total indicates best alternative

Evaluating the power requirements of the lunar observatory, one SP-100 system will be able to support all observatory activity with an adequate safety margin. During unoccupied periods, power requirements will be reduced. Reducing observatory power requirements will reduce the SP-100 operating requirements and increase the lifetime of the system.

#### **2.6.1.1 Reactor Shielding**

To protect the lunar observatory from radiation generated by the SP-100 nuclear reactor, the unit will be placed in a man-made crater, approximately 20 meters deep. This depth should be sufficient for radiation protection of the observatory.[7] The crater will be made by placing regolith around the nuclear

reactor, using construction vehicles at the site. This configuration is shown in Figure 2.1.



**Figure 2.1 Reactor Shielding Configuration**

## **2.6.2 Secondary Power System**

A contingency power supply will be required to provide power for any emergency in case of a shutdown of the SP-100 reactor. The secondary power system will be composed of five H<sub>2</sub>-O<sub>2</sub> regenerative fuel cells, capable of producing 10 kW of electric power each [8:57]. The battery of fuel cells must be capable of providing power to the life support, thermal control, and communications systems until the crew can be removed or the SP-100 reactor can be repaired.

### **3.0 Communications**

The most important resource of the farside observatory will be the astronauts. Constant communication with them will be vital for ensuring their safety. In addition, there are five other support tasks for a communication system.

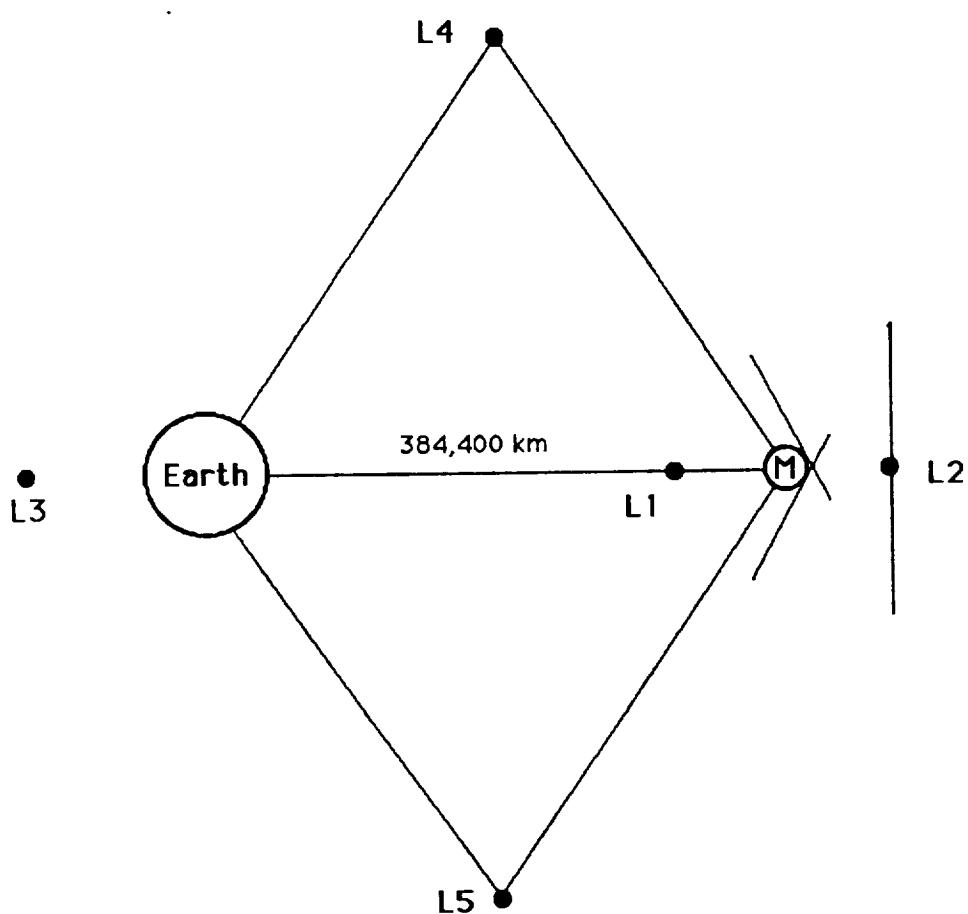
- 1) Relay spacecraft telemetry data to Earth and command signals to spacecraft during lunar landing and takeoff operations.
- 2) Transmit scientific data from stations located on Moon's far side.
- 3) Relay television and teleoperations signals from lunar rovers and robots to an Earth based control center. Control commands from Earth are also relayed to rover and robots.
- 4) Track lunar orbiters when they are occulted by the Moon during the construction phase.
- 5) Provide a real time, two-way communications line between Earth stations and a manned spacecraft that is occulted by the Moon.

A far side observatory will never be in direct line of sight with the Earth, therefore the communication system must transmit signals around the moon to a point within line of sight of the Earth. The best method for overcoming this obstacle is with relay satellites. There are three very good options for the placement of these satellites. The first is to position a satellite at the L<sub>5</sub> stable libration point (see Figure 3.1) which would provide partial backside coverage. The second option is to place a satellite in a halo orbit about the L<sub>2</sub> unstable libration point . Such an orbit would ensure entire coverage of the backside while in constant view of the earth. The third option is to place three satellites in polar orbit about the Moon in an 11,000 km orbit with at least one satellite in view of the observatory at all times.

After careful evaluation and comparison of the three design options, the best option was found to be placing a satellite into a halo orbit about L<sub>2</sub> during

the construction phase of the observatory. Following the construction phase, the satellite will be fueled via OTV mission from the near side and sent to L5.

Other elements of the communication system include a lunar ground receiving and transmitting station, earth stations, and smaller elements on the moon for audio and video monitoring of equipment and EVA.



**Figure 3.1 Earth - Moon Libration Points**

### **3.1 Satellite Options**

Communication between the Earth and the lunar far side requires a means of acquiring a line of sight between the Earth and the point of interest on the far side. A relay satellite may be placed in a position to be in view of both. A relay satellite would be able to handle as much data transmission as necessary and would be a more reliable platform than alternate methods such as a series of relay towers on the lunar surface. The three options for placement of a communication satellite(s) mentioned above are addressed separately here.

#### **3.1.1 L<sub>2</sub> Libration Point**

The L<sub>2</sub> libration point is shown in Figure 3.1. It is an unstable, collinear point in the Earth-Moon system. However, an orbit about the L<sub>2</sub> point would be relatively stable and in full view of the Earth and lunar far side. A satellite in orbit about L<sub>2</sub> would require station keeping and range and range-rate period control burns for maintaining the proper distance with respect to L<sub>2</sub>. Figure 3.2a shows the halo orbit plane with respect to the Earth-Moon axis. The halo orbit's nominal trajectory was determined using a set of linearized equations of motion derived from a restricted 3-body model. The effects of non-linearities, such as lunar eccentricity and solar perturbations were neglected [9]. The orbit as seen from Earth is shown in Figures 3.2b and 3.2c. Figure 3.2b shows the orbit path after approximately one year. The satellite is maintained in its orbit by station keeping burns totaling approximately 93.3 fps/yr and period control burns totaling about 240 fps/yr [9]. Figure 3.2c shows the orbit without period control inputs. Occultation occurs less than 52 days after orbit injection due to solar and lunar perturbations.

The main advantage of utilizing a satellite in a halo orbit about L<sub>2</sub> is that it gives total backside coverage. The main disadvantage is its limited lifetime based on fuel consumption for station keeping and period control.

#### **3.1.2 L<sub>5</sub> Libration Point**

The L<sub>5</sub> libration point is shown in Figure 3.1. It is a stable point in the Earth-Moon system at a distance of 384,400 km from Earth, 60 degrees behind the Moon in the same orbit plane. L<sub>5</sub> is an ideal position for a satellite because

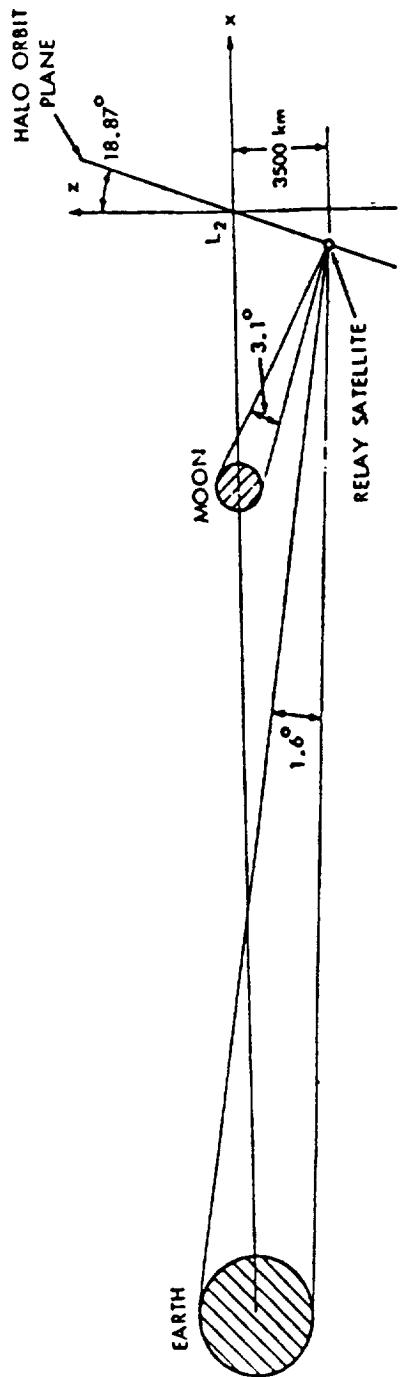


Figure 3.2a Halo Orbit Configuration

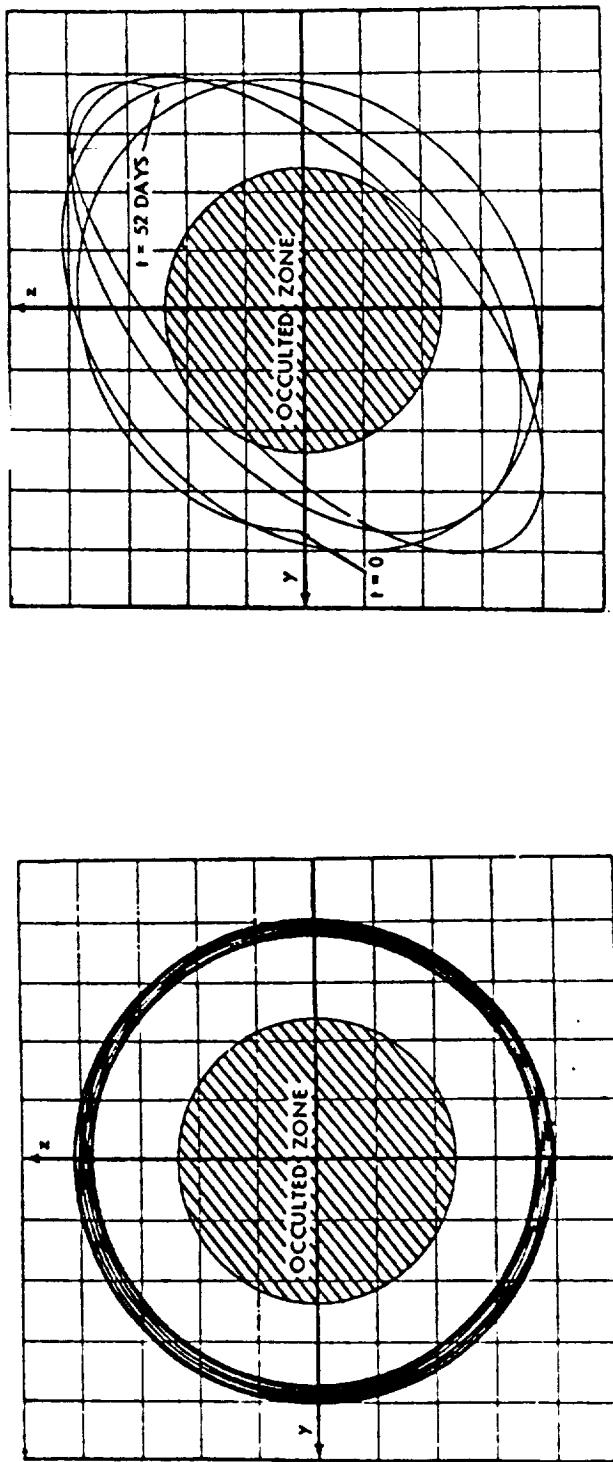


Figure 3.2c Halo Orbit Without Stationkeeping  
Figure 3.2b Halo Orbit with Stationkeeping

From Farquhar, R., *The Utilization of Halo Orbits in Advanced Lunar Operations*

it would require minimal satellite attitude adjustments. A disadvantage is the limited view of the far side. A station must be within 135 degrees east longitude for direct line-of-sight coverage from L<sub>5</sub>. This criteria is met with the selection of Tsiolkovsky as a base sight. It is centered at 128 degrees east longitude. Long term benefits of a satellite at a stable point are the fewer control maneuvers required , which will extend the life of the satellite, and the satellite's lower position in the sky with respect to the observation equipment than that of the halo orbit about L<sub>2</sub>.

### **3.1.3 Constellation in Polar Orbit**

Another option explored was placing a constellation of 3 satellites in polar orbit around the moon. This option was rejected due to the following constraints.

- 1) A large plane change is required to position the satellites in a lunar polar orbit.
- 2) Large station keeping maneuvers are required to maintain the orbit due to lunar perturbations.
- 3) The satellites would provide only 90% coverage and would require a rotating tracker to acquire and monitor a new satellite every 12 hours.  
[9]

### **3.1.4 Decision Matrix**

Table 3.1 is a decision matrix for the satellite configuration options. Each option was ranked according to a criteria that included stationkeeping maneuvers and the amount of backside coverage. The options were ranked 1 to 3 with the lowest numbers being the best. Overall, the L<sub>5</sub> satellite was the best option with the L<sub>2</sub> option a close second. The three satellite constellation proved to be the least desirable.

**Table 3.1 Communications Options Decision Matrix**

Criteria Option	Injection Delta V	Station Keeping	Backside Coverage	Refuel	Obs. Interfere	Tracking	TOTAL
L <sub>2</sub> Halo Orbit	1	3	1	2	2	1	10
L <sub>5</sub> Stable Point	2	1	2	1	1	1	8
3 Sat Constell	3	2	3	3	3	2	16

### 3.2 Mission Profile

Total backside coverage will be most important during the base development phase. Transportation operations between earth, the lunar near side and the lunar far side will be relatively frequent and monitoring these operations completely, in addition to the daily operations of base construction, is vital for telerobotic communications. The best option is therefore to place a satellite in an orbit about L<sub>2</sub> for approximately three years, then when the base construction is completed, refuel the satellite and move it to L<sub>5</sub>.

The refueling may be performed by a service satellite from the lunar near side base or directly from earth. The only other alternative for inserting a satellite at L<sub>5</sub> is to somehow destroy the L<sub>2</sub> satellite ( to keep it from colliding with the base when it runs out of fuel and deorbits ), and place a new one at L<sub>5</sub>. Since L<sub>5</sub> is 60 degrees behind the moon in the moon's orbital radius from earth, a simple Hohmann transfer from LEO to L<sub>5</sub> can be used to conserve fuel with a TOF of approximately 5 days. The total delta V required for the two burn trajectory is 12,934 ft/sec.

If a satellite is placed at L<sub>5</sub> directly from LEO, the initial satellite at L<sub>2</sub> may just be downgraded to a less capable and less expensive satellite than one which was to be moved to L<sub>5</sub> from L<sub>2</sub> since it will be deorbited after its service life. We have decided, however, that the most economical method is to

invest in a fully capable satellite for positioning at L<sub>2</sub> then refueling and moving it; the refueling would be done via an OTV mission from the near side.

The L<sub>2</sub> mission profile appears in Table 3.2 and includes all delta V's and the weight of the fueled satellite. Figure 3.3 shows the proposed trajectory for transferring the satellite from a 100 nmi Low Earth Orbit (LEO) to L<sub>2</sub>. A three burn trajectory augmented with a lunar swingby was selected to reduce fuel expenditure. The Time of Flight (TOF) is 212 hours. Once in the halo orbit, stationkeeping of one pulse every three days is required and period control of one pulse every 7.32 days is required to maintain the 3500 km radius about L<sub>2</sub>.

**Table 3.2 L<sub>2</sub> Mission Profile**

Operational Lifetime	3 Years	
Radius of Halo Orbit	3500 km	
Launch Vehicle	TAT(9C) /DELTA	
Spacecraft Weight at Translunar Injection	408.2 kg	(900 lb)
<u>Delta V Requirements</u>	<u>m/sec</u>	<u>(ft/sec)</u>
Midcourse Corrections	30.48	100
Halo Injection	335.28	1100
Stationkeeping (one pulse every 3 days)	85.34	280
Period Control (one pulse every 7.32 days)	310.90	1020
Attitude Control	<u>22.86</u>	<u>75</u>
TOTAL	784.86	2575
Fuel Weight (Hydrazine I <sub>sp</sub> = 230 sec)	119.7 kg	(264 lb)

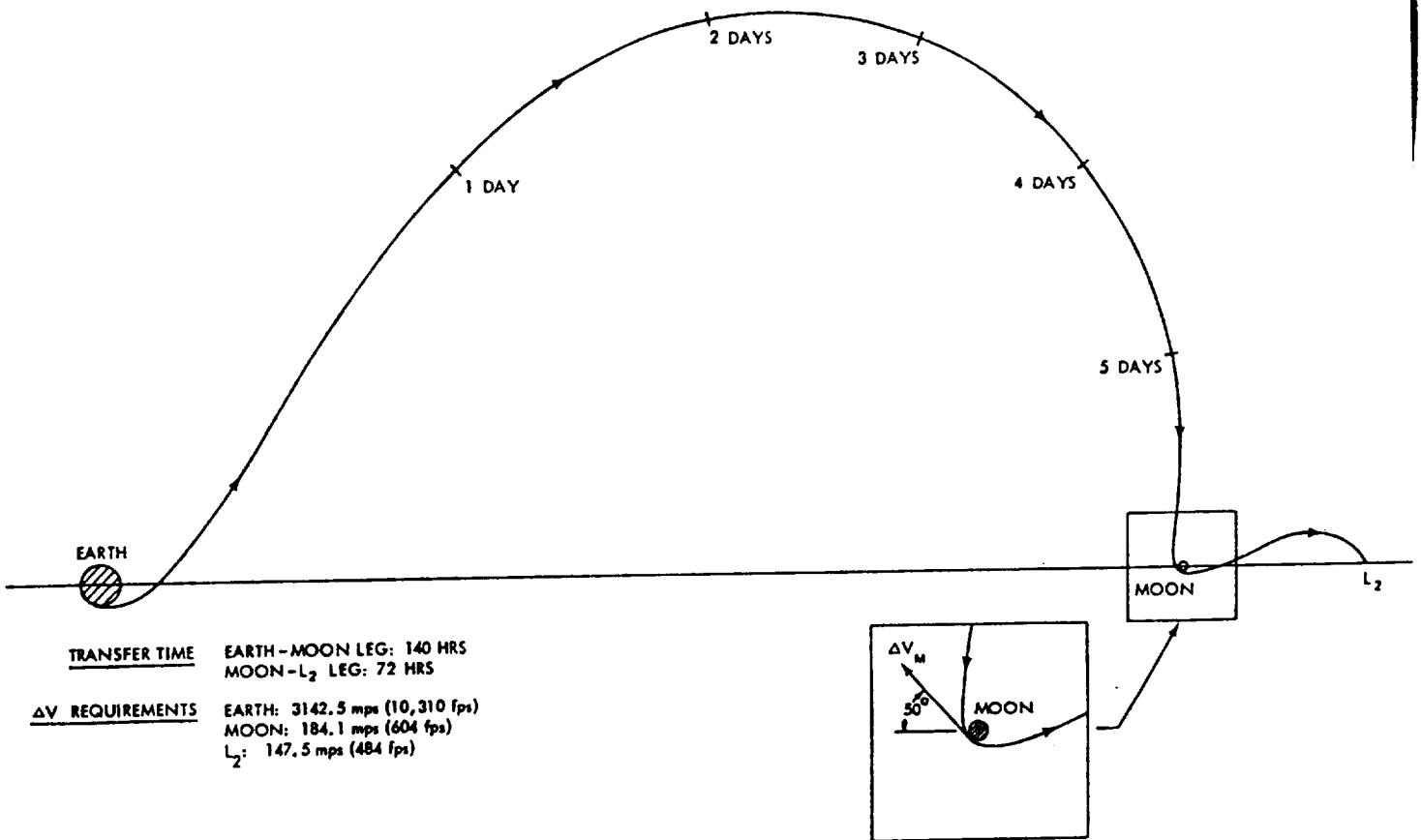


Figure 3.3 LEO to L<sub>2</sub> Transfer Trajectory [9]

### 3.2.1 Transfer from L<sub>2</sub> to L<sub>5</sub>

A planar, circular, restricted three-body model of the Earth-Moon system can be used to study transfer trajectories from the L<sub>2</sub> libration point to L<sub>5</sub>. The family of trajectories from L<sub>2</sub> to L<sub>5</sub> is characterized by low transit times and small arrival velocities ( no larger than 200 m/s ). These trajectories offer low fuel or energy consumption for travel between L<sub>2</sub> and L<sub>5</sub>.

Analysis of L<sub>2</sub>-L<sub>5</sub> trajectories is performed using a synodical coordinate system that rotates with unit angular velocity about the Earth-Moon system center of mass. In this coordinate system, the earth is located at X<sub>1</sub>= - $\mu$  and the Moon is at X<sub>2</sub>= 1- $\mu$ . Mu is determined from the Earth-Moon mass ratio, 1- $\mu$ / $\mu$ = 81.301, which leads to  $\mu$ = 0.012150526. Computation units used in the analysis are the average Earth-Moon distance, 384,400 km, and a time unit of

375,700 sec. which corresponds to a period of  $2\pi$  of the circular motion of the Earth and Moon about the system center of mass. The equations of motion are:

$$x'' + 2y' = \delta\Omega / \delta x$$
$$y'' + 2x' = \delta\Omega / \delta y$$

where

(') indicates a time derivative, and  
 $\Omega = 1/2(x^2 + y^2) + 1-\mu/\mu_1 + \mu/\mu_2$

Numerical integration of the equations of motion lead to four functions:  $x(t)$ ,  $y(t)$ ,  $x'(t)$ , and  $y'(t)$ . The initial conditions of the two point boundary value problem are the coordinates of L<sub>2</sub> (1.155699,0) and the initial velocity components:

$$x'_0 = [2(E-EL)]^{1/2} \cos(\alpha)$$
$$y'_0 = [2(E-EL)]^{1/2} \sin(\alpha)$$

where

$$EL = -1.586102, \text{ potential energy of L}_2$$
$$\alpha = \text{angle of the velocity vector with the x axis}$$

Trajectory determination can be accomplished by varying E (energy) and  $\alpha$ . Actual integration of the equations of motion was not performed due to time constraints. However, Broucke performs similar orbit calculations which indicate that the  $\Delta V$  required for transfer from L<sub>2</sub> to L<sub>5</sub> is not prohibitive. [10:257-259]

### 3.3 Communication Redundancies

Two redundant communications systems were studied. One option was to robotically lay a fiber optic transmission cable from the observatory to the limb of the moon. At the limb, the robot rover would serve as a transmitter/receiver. The second option was to utilize a series of microwave towers -- one at the observatory and one at the Moon's limb. A transformable lander would be used to place the limb tower. After evaluating the two options, the microwave tower option proved to be the most suitable scenario. The communications group decided the moon's farside terrain was too rugged to be successfully traversed by the robotic cable laying vehicle. Positioning the limb tower offered fewer

obstacles. A smooth landing site, Smyth's Sea, is available. Smyth's Sea is located on the Moon's equator at a longitude of 90 degrees. The primary tower design concern is to ensure line of sight between the two towers. The curvature of the Moon must be considered for determining the proper tower height. A tower height of approximately 40 miles is required for 3 towers with one intermediate tower between the observatory and Smyth's Sea. A three configuration is dependent upon the availability of technology to construct large towers. An alternative would be to add additional towers to reduce tower height.

### **3.4 Base Communication and Data Relay**

Due to the high data rate of information and the need for quick, reliable communication within the base and relayed to earth, the mode of communication has to be able to handle large amount of information and be able to withstand the rigors of space. Based on these requirements, fiber optics and optic satellite relay was chosen for communication and information relay. The reasons, advantages, and design of the fiber optic system is contained in the following sections.

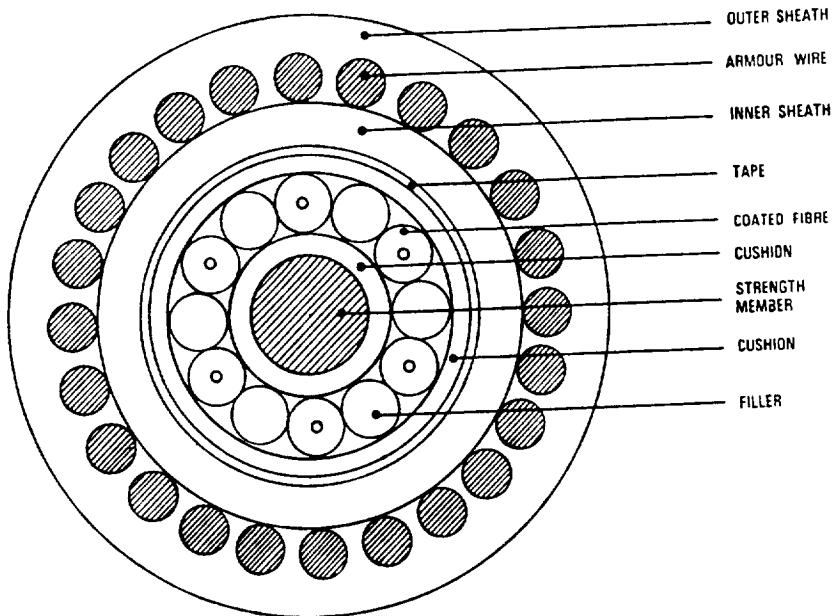
#### **3.4.1 Intrabase Communication**

Since the base is relatively small, (about 4 km across at the most) and data and communication signals need to be relayed quickly and with a high baud rate, a fiber optic system was determined to be the best modem of communication. Because of the baud rate, about  $1.0 \times 10^9$  bits/sec (bps) per large astronomy package, fiber optics is the logical choice to handle this large amount of information. A single mode optic fiber can transmit 140 Mbps. With very high speed codes, i.e. 900 channels encoded at 70 Mbps, can provide analogue as well as digital applications.[11:231] Because of the high bandwidth of an optical fiber, a graded index, single mode fiber could transmit up to 40 Gbps at 800 microns using laser transmission.[11:285] Also, an optical fiber system could be multiplexed for many components due to the high bandwidth capability. As mentioned above, the distances between the base components are relatively short (about 2 km) and the attenuation of a fiber optic signal is minimal at these distances. For a 1 km single mode direct modulation fiber running at 11 GHz, the signal loss is 35 dB. [12:142] Because of the short

transmission distance within the base, repeaters and retransmitters, which would contribute further to signal loss, do not need to be used.

There are other advantages to using fiber optics for an intrabase communication system. For one, they are extremely compact, which cuts down on weight and size. Second, they are rugged and flexible and, because of their small size and permissible bending radius, can be stored on reels to minimize storage and transportation space and to aid in handling. Third, optical fibers are made out of material that is not rare (such as silica) so they are inexpensive. Fourth, the fiber is impervious to electromagnetic interference (EMI) and electromagnetic pulses (EMP); and link security is greatly increased. Lastly, because the signal is a light signal, there can be large potential differences between the ends of the cable without protective circuitry. With these considerations in mind, the actual cable can be designed.

Due to the harsh environmental conditions on the Moon, the best cable design for a fiber optic cable is a series of single mode silica fibers held in geometric shape with cushions around a central strength member of Kevlar 29. The outer shielding of Kevlar 49 and a protective sheathing would keep the silica fibers free from most radiation. The cable could be buried if needed to further shield it from radiation and micrometeor strikes. (See Figure 3.4).[11:78]. A cable constructed as described above would have a working strength of 1000 Newtons and an outside diameter of 2 mm. The attenuation of a single mode silica fiber for a transfer rate of 140 Mbps is 3.0 dB/Km for a laser wavelength of 850 nm and 0.9 dB/Km for a 1.16 micron wavelength.[11:63]. The type laser to transmit the pulse and the optimum wavelength is discussed in the next section of this report. Launching the signal by laser is very reliable with a negligible delay time for the transmission.



**Figure 3.4 Structure of a Concentric Optical Cable [11]**

### **3.4.2 Moon-Satellite-Earth Communication and Data Relay**

Now that the communication and data relay system within the base has been designed, the most critical task of getting the information back to the earth, communicating in real-time, and telerobotic operations arises. Once again, the use of optical signals proved to be the best solution for the large amounts of data to be transferred. Higher rates of data can be transferred by optical signals than by microwave signals. Optical components are smaller and lighter than standard receiving and transmission dishes for microwave and precise navigational tracking of the satellite may be performed using the optical signals.

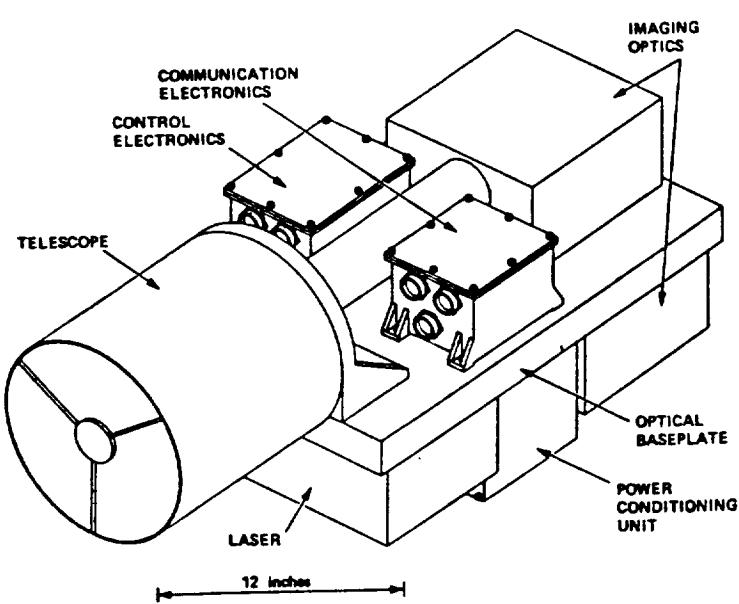
With the advances made in laser efficiency in the last few years, it is likely that by the time this project is launched much more efficient lasers and optical transmitting and receiving equipment will exist. These advances would further advance the capability for single photon detection and the retrieval of bits of information per photon which would reduce the awesome task of transmitting

and recovering the vast amounts of data to be produced by the far-side observatory.

In order for an optical system to work one needs a way to send the optical signal to the satellite, collect the photons at the satellite, retransmit the signals from the satellite to earth and collect the photons at earth. To transmit the signal, a teleoptical device, much like a telescope, is used to transmit the signal of a laser diode with encoded photons. At the satellite, an Optical Transceiver Package (OPTRANSPAC) is needed to receive and transmit the signals to earth where an Optical Receiving Station (OPRECS) collects the photons for processing.[13:10].

A central communications OPRECS is placed on the moon to receive and transmit data. The OPRECS on the moon would be much like the OPRECS in low earth orbit. As envisioned, the OPRECS would contain two telescopes. The first is a large diameter (about 5 meters for the moon OPRECS, about 10 meters for the earth OPRECS) aperture for collecting weak, intensity modulated data signals. This large collecting telescope is called a photon bucket.[13:9]. The second telescope is a small diameter, (about 0.5 meters for both earth and moon OPECS) diffraction limited transmitter. The small scope can also be used for range, tracking and trajectory measurements, and serve as a beacon. Techniques similar to those used in astrometrics would permit precision angle tracking in sub-milliarcsseconds relative to guide stars. [13:9]. The OPRECS transmits to and receives signals from the OPTRANSPAC located on the satellite.

The OPTRANSPAC consists of a single telescope, 10 to 30 cm in diameter used for uplink reception and downlink transmission. A pointing accuracy of only milliradians is required to place the earth OPRECS in the field-of-view. The beacon signals from the earth OPRECS would aid the OPTRANSPAC to refine its pointing angle. With a 400 mW laser, a data rate of 2 Mbps could be returned to the earth OPRECS from the moon. Since these OPTRANSPACs are small, (see Figure 3.5), many could be placed on a platform to increase the amount of data that could be returned. The total mass and power for the system are 50 kg and 57 watts respectively.[13:9].



**Figure 3.5 Optical Transceiver Package [13]**

### 3.4.3 Telerobotic and Rover Communication

The same concept that is used for data and communication relay can be used for telerobotics and rover monitoring. Since the construction system will have a foreman hierarchy, a receiving telescope of approximately 5 meters will be connected to the foreman to receive instructions from earth or the near-side. Once the foreman receives the instructions, it can direct the robots to their individual tasks which will be included in the robotics section of this report. For the roving vehicles, a 10 cm telescope with a 400 mW laser will be placed on each rover and relay and receive signals from the satellite or the habitation module at the observatory. The communication module for the rovers weights 16 kg and requires 35 watts of power.[13:10]. The optical system on the rovers could also be used for rover vicinity laser ranging for obstacle avoidance.

## **4.0 Transportation**

Construction vehicles and lunar rovers will be the two types of general ground terrain vehicles which will assist in the base construction and maintenance. The lunar hopper will serve as a connection to the near side station. Explosive charges will be used to excavate at the construction site.

### **4.1 Construction Vehicles**

The construction vehicles required at the Lunar Farside Observatory (LFO) include a lunar lander and a heavy lift crane. These vehicles will be used in setting up the habitation module, the nuclear reactor, and the observatory equipment.

#### **4.1.1 Lunar Lander**

The lunar lander chosen by OUTLOOK's transportation group was the unmanned cargo lander developed by the students at the Department of Mechanical Engineering at the University of Texas at Austin. This lander will be disassembled into a shelter for the habitation module.

The lander consists of a platform with four legs attached underneath. The engines of the lander are attached underneath as well. The cargo module, in this case the habitation module for the LFO, is placed in between the spherical fuel tanks which supply the engine. This configuration is shown in Figure 4.1. Figures 4.2-4.4 show the front, side, and top views of the lunar cargo lander respectively. The center of mass of the lander is at a height of approximately 7 meters.[14:30] The total mass of the cargo-laden lander without propellants is at most 36,600 kg.[14:35] The amount of propellant required by the lander is 4000 kg of liquid hydrogen and 24000 kg of liquid oxygen.[14:47].

After arriving at the observatory site, the lander can be unloaded and dismantled. The parts can then be used in the construction of structures at the lunar farside observatory.

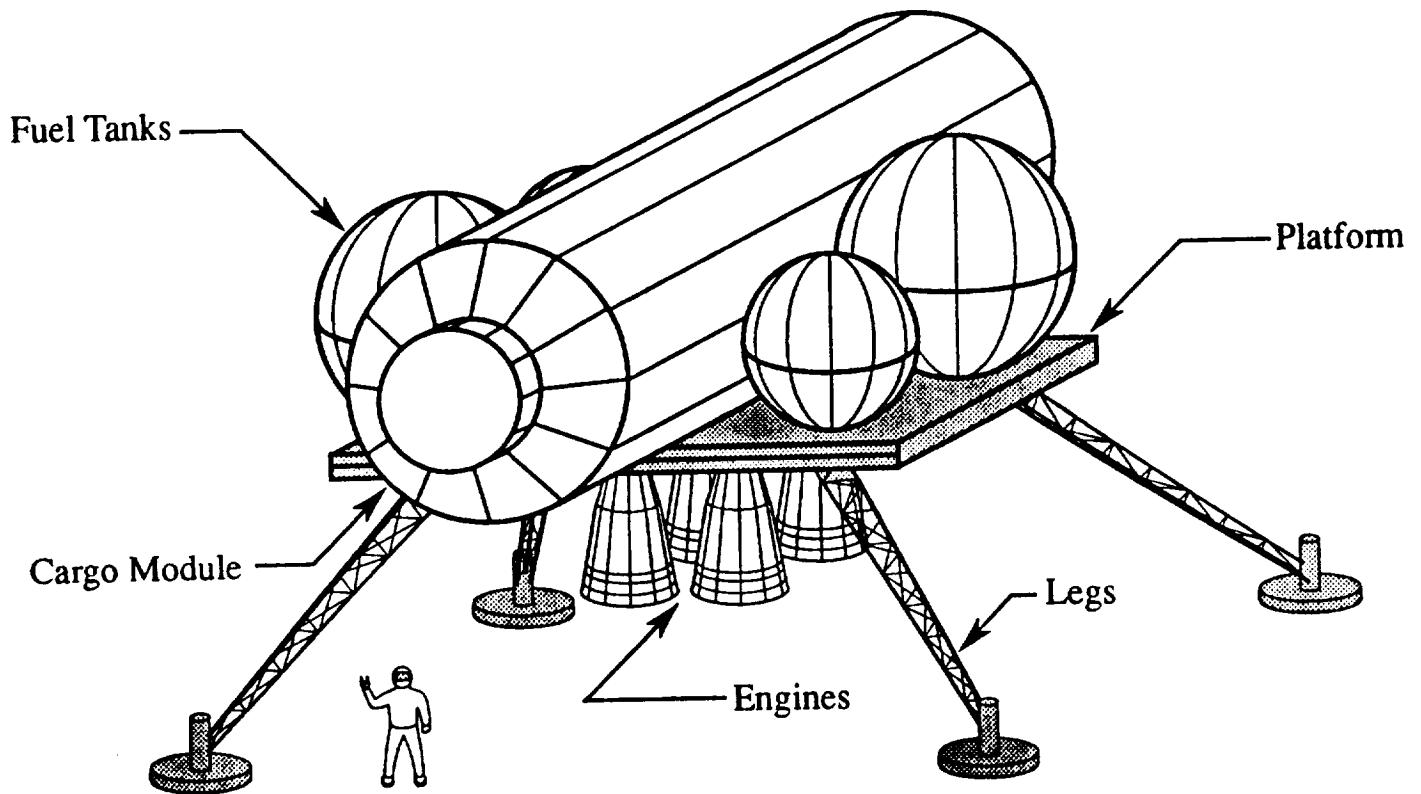


Figure 4.1 Cargo Lander Configuration [26]

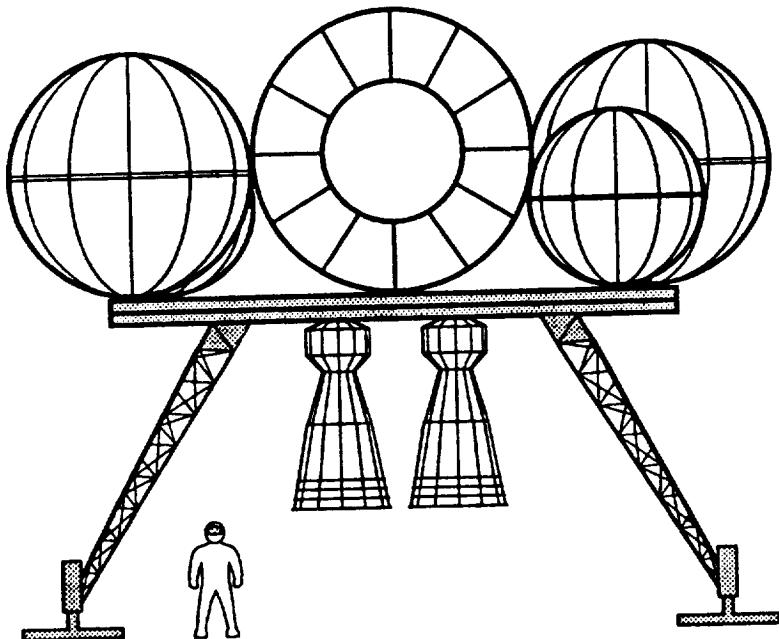


Figure 4.2 Front View of Lunar Cargo Lander [26]

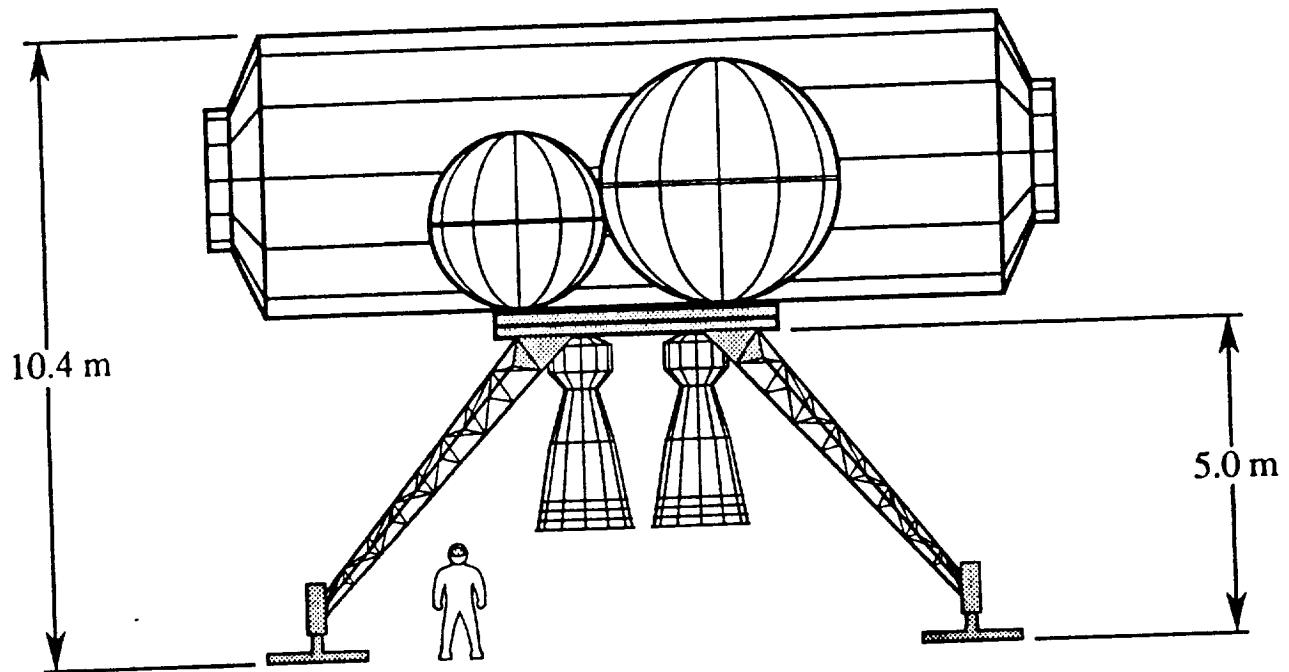


Figure 4.3 Side View of Lunar Cargo Lander [26]

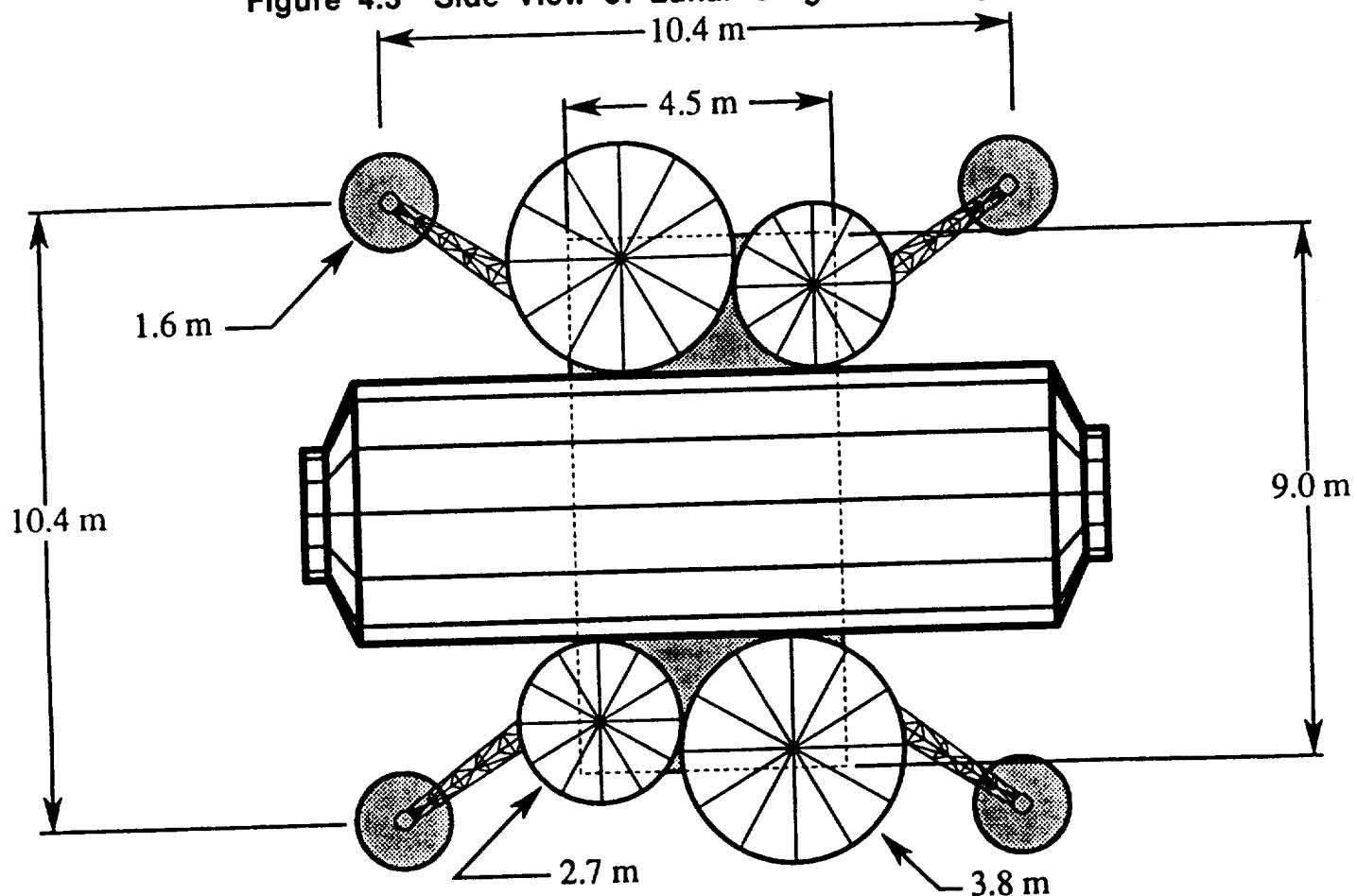


Figure 4.4 Top View of Lunar Cargo Lander [26]

#### 4.1.2 Lunar Crane

Another piece of construction equipment which will be needed at the LFO is a heavy lift crane. This would be used to remove observatory equipment such as the habitation module, robots, nuclear reactor, and pre-fabricated observation equipment from the lunar lander. The crane which was chosen for use at the observatory was the teleoperable, towable lifting machine designed by the students at the Department of Mechanical Engineering at the University of Texas at Austin.

The lifting crane, shown in Figure 4.5, has a variable angle telescoping boom.[15:50] At the end of the boom is a cable and hook which will be used for heavy lift operations. To facilitate the hook, all components at the LFO will have an appropriate receptacle attached to them.[15:59] For light lifting operations which require a high degree of dexterity, the crane is equipped with a seven degree of freedom robot arm as shown in Figure 4.6. This arm uses a three-jaw gripper in order to grasp and lift objects. This appendage will require that all objects at the LFO capable of being lifted by the lunar crane be equipped with an appropriate receptacle for the robot arm.

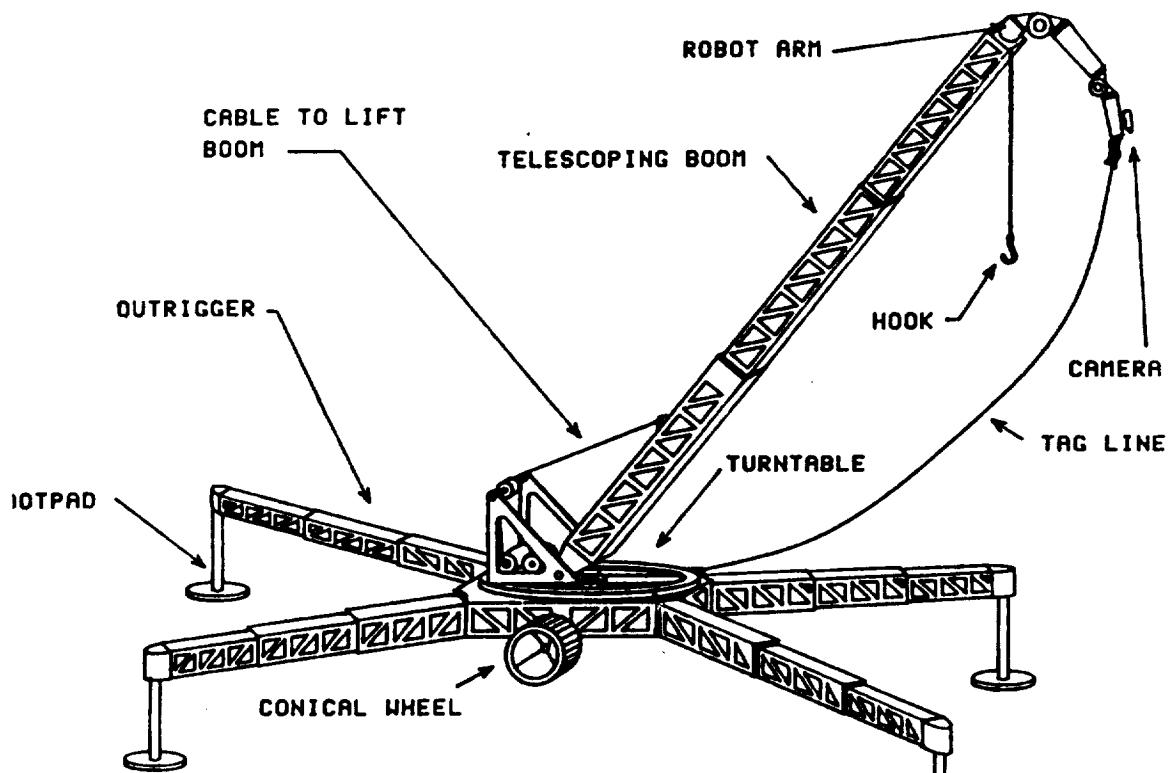
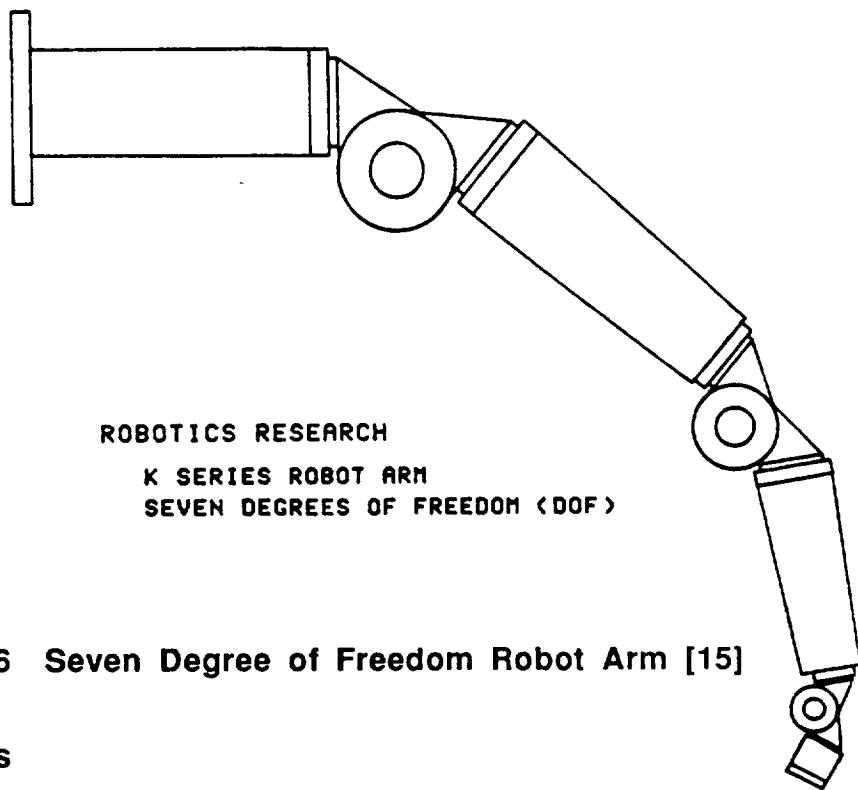


Figure 4.5 Lunar Teleoperated Crane [15]



**Figure 4.6 Seven Degree of Freedom Robot Arm [15]**

#### **4.2 Lunar Rovers**

Two unpressurized rovers will be required for base operations. The top speed of the rovers will not exceed 13 km/hr because of adverse experiences during the Apollo mission, when such a speed was exceeded. The cruising speed will be from 6 to 7 km/hr and turning speed will not be greater than 5 km/hr due to skidding possibilities [16:35].

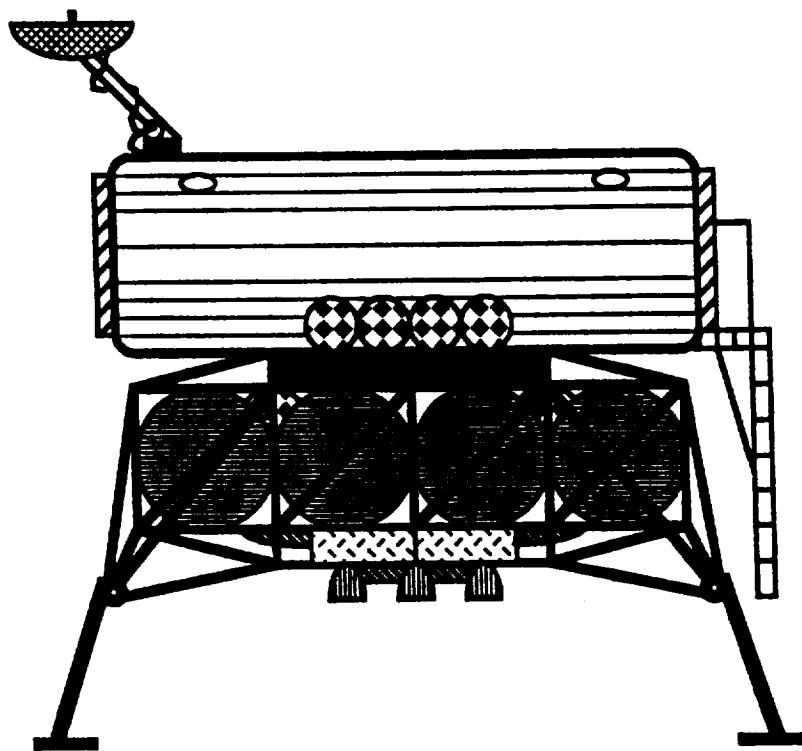
One rover will be used in the base set-up, maintenance and farside lunar exploration. It will be completely robotic and teleoperated. The rover will also have robotic arms which will allow it to turn knobs, run lines and perform basic functions that a human hand might. The other rover will be capable of being manually operated or teleoperated and used by the astronauts for ground transportation and have features which allow it to be altered into a cargo transport vehicle.

The rovers will traverse on wheels which are mechanically efficient and can be designed into extremely reliable, lightweight systems. The main advantage to a wheeled system is the variety of wheel types, sizes and numbers which may be utilized for any given design [17:85]. Also, the traction requirements are less for the rovers. The rovers will use the same type battery packs as the construction vehicles.

#### 4.3 Lunar Hopper

The hopper will serve as a mode of transport for men and supplies between the near and farside bases and from lower lunar orbit to the moon surface. It will operate in ballistic trajectories which will also allow it to explore remote areas of the Moon [18:5].

The lunar hopper will consist of a supporting structure, landing gear, propulsion system, power supply and requisite avionics to land on the surface from orbit and ascend to rendezvous with an orbiting node.(Figure 4.7) [18:6] In a ballistic trajectory, the hopper will require a burn at launch and at landing; each round trip will require four burns. The vehicle will perform an engine burn for ascent and then a second burn to brake when near its destination.[18:44-45]



**Figure 4.7 Schematic of the Lunar Hopper [18]**

## **5.0 Habitation**

Habitation includes the module which the crewmembers live in as well as the airlocks that they use to exit the module to perform EVA operations on the lunar surface. Other considerations which must be taken into account are the radiation shielding, meteorite shielding, dust protection, and thermal control of the habitation module.

The habitation module will provide the crew of the LFO a place in which they can eat, sleep, work, and exercise. This module will be the control hub of the observatory. The module will provide the crew protection from radiation as well as provide them with an environment in which they can live comfortably during their tour of duty on the Moon.

### **5.1 Habitat Module Options**

OUTLOOK considered three options for habitation for the crew of the LFO. The habitat must provide an atmosphere pressure of 14.7 psi with a PO<sub>2</sub> of 3.04 psi and a nitrogen partial pressure of 11.44 psi.[16:76] The options were,

- 1) a lander/shack,
- 2) an Inflatable Module (IM), and
- 3) a Space Station Common Module (SSCM).

The habitat module for the LFO These options are discussed below.

#### **5.1.1 Lunar Lander/Shack**

The Lunar Lander/Shack was envisioned by OUTLOOK's construction team as a temporary dwelling in which the crewmembers lived in. The lander/shack would be an Apollo type craft (similar to the Lunar Excursion Module (LEM)) but would not leave the lower section of the craft on the surface of the moon. Instead, the lower section would house the ECLSS, the propulsion system, and all the necessary consumables for the crewmembers stay on the surface of the moon. The crew would live in the upper section of the lander/shack for the duration of their stay. Upon completion of their mission, the

crew would take off in the lander/shack for a return journey home. The major disadvantage to this concept is that it is temporary. This concept provides no permanent base in which the astronauts can live in during their stay. Since OUTLOOK is concerned with designing a permanent habitation facility the Lunar Lander/Shack was not considered as a feasible option for permanent habitation at the observatory. The lander/shack can be used, however, as a temporary habitation facility while a more permanent facility is being constructed. Also, it can be used as an emergency habitat if problems arise with the permanent facility.

### **5.1.2 Inflatable Module (IM)**

The IM shown in Figure 5.1 was another option which OUTLOOK considered as a habitation facility for the LFO. The IM consists of a flexible shell made of Kevlar-29 which arrives at the observatory site prior to the crewmembers' arrival. The module is laid out, anchored, and erected at the site by the construction robots sent during the first mission. After construction, the module is covered with Lunar regolith as radiation protection.[19:91] The module has more volume for a given mass and if the internal pressure is lost the internal cage (the radial lines in the bottom view in Figure 5.1) supports the outer envelope. The primary disadvantage to the IM is that it requires more time to set-up than an SSCM; Although this does not affect surface operations after the observatory is up and running, it does require more robot time and human EVA time during the construction phase. Since it was decided by OUTLOOK that the habitation module would be set up in a minimal amount of time, the IM was not chosen. Specifications for the IM are given in Table 5.1.[19:92]

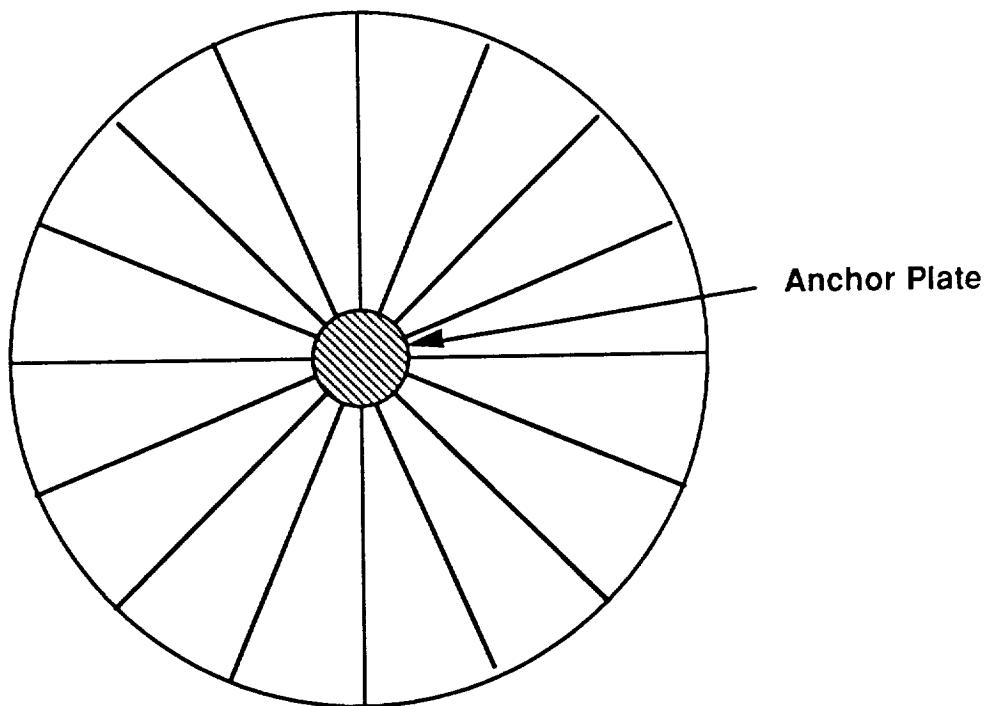
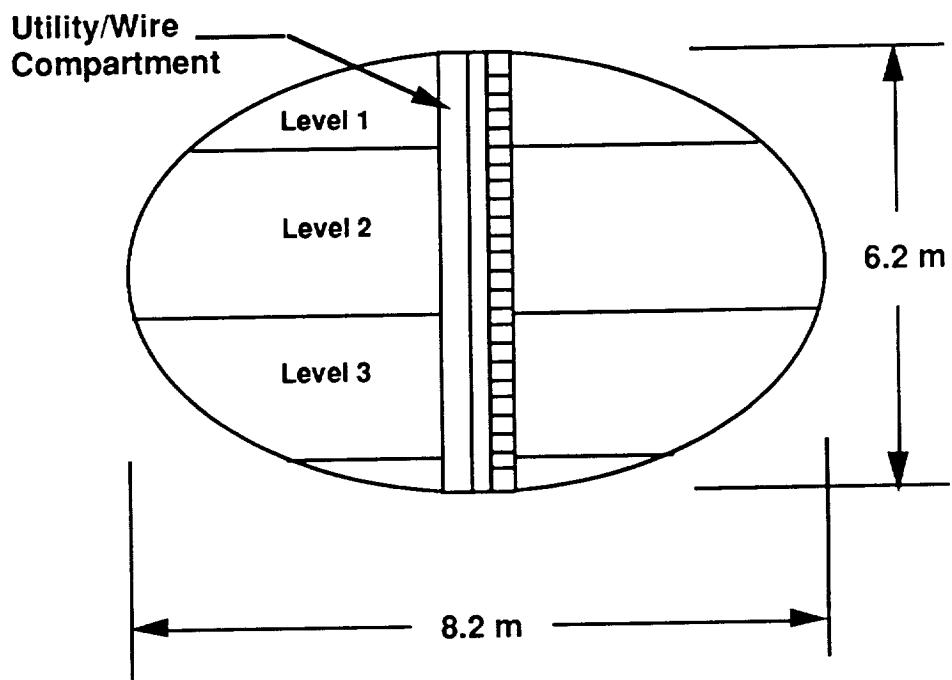


Figure 5.1 Inflatable module schematic

**Table 5.1 Inflatable Module Specifications**

Crew Size	4
Exterior Surface Area	482.8 m <sup>2</sup>
Module Thickness	5 mm
Total Volume	108.6 m <sup>3</sup>
Total Weight	25,196 kg

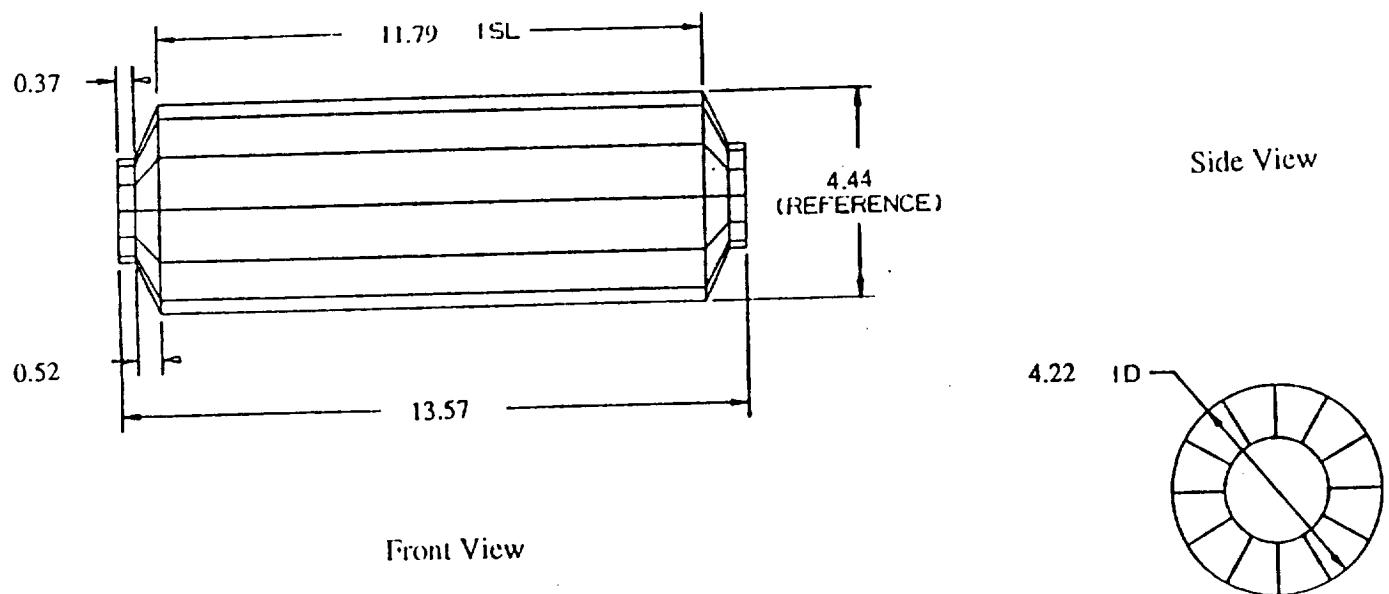
### **5.1.3 Space Station Common Module (SSCM)**

The SSCM was also considered as an option for a habitation module for the LFO. The SSCM's greatest advantage is that it comes preassembled. The interior has space for the crew as well as other equipment necessary for the operation of the observatory. Table 5.2 gives the dimensions and mass of the habitation module. The SSCM is shown in Figure 5.2. The SSCM was chosen as the best option for a habitation module for the LFO. The criteria used in this selection is shown in Table 5.3. In this decision matrix, the lower the total number, the better the option.

**Table 5.2 Space Station Common Module Specifications**

Crew Size	4
Interior Volume	74.36 m <sup>3</sup>
Allowable Free Space	8.5 m <sup>3</sup> /p
Set Free Space Volume	34.00 m <sup>3</sup>
Allowable Minimum Volume	108.36 m <sup>3</sup>
Module Length	11.79 m
Cylindrical Volume	180.42 m <sup>3</sup>
Surface Area	171.18 m <sup>2</sup>
Mass of Module Shell	2682.37 kg
Interior Mass	6514.66 kg
Total Mass	10,431.06 kg

Note: All Dimensions in Meters.  
ISL is Inner Skin Line.



**Figure 5.2 Space Station Common Module [6]**

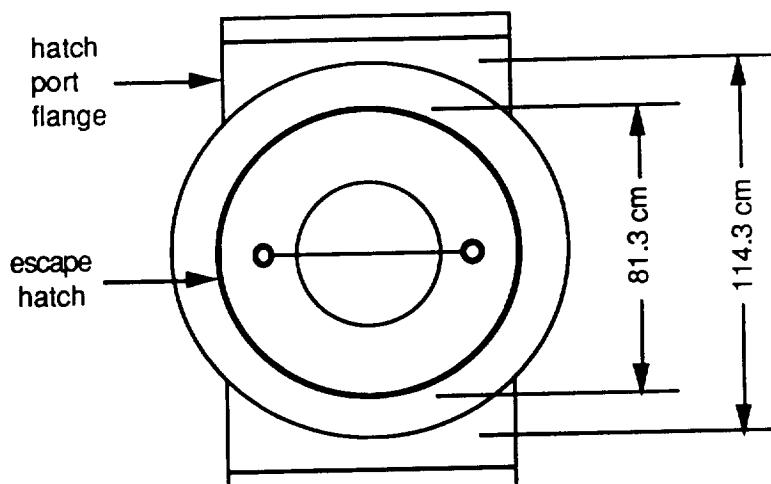
**Table 5.3 Habitation Decision Matrix**

Criteria	Inflatable Module	Space Station Module
Integrity	2	1
Mass	2	1
Launch Cost	2	1
EVA Requirement	2	1
Expandability	2	1
Living Space	1	2
Storage Space	2	1
Burying Time	2	1
Design Flexibility	2	1
Assembly	2	1
Transportation	1	2
TOTAL	20	13

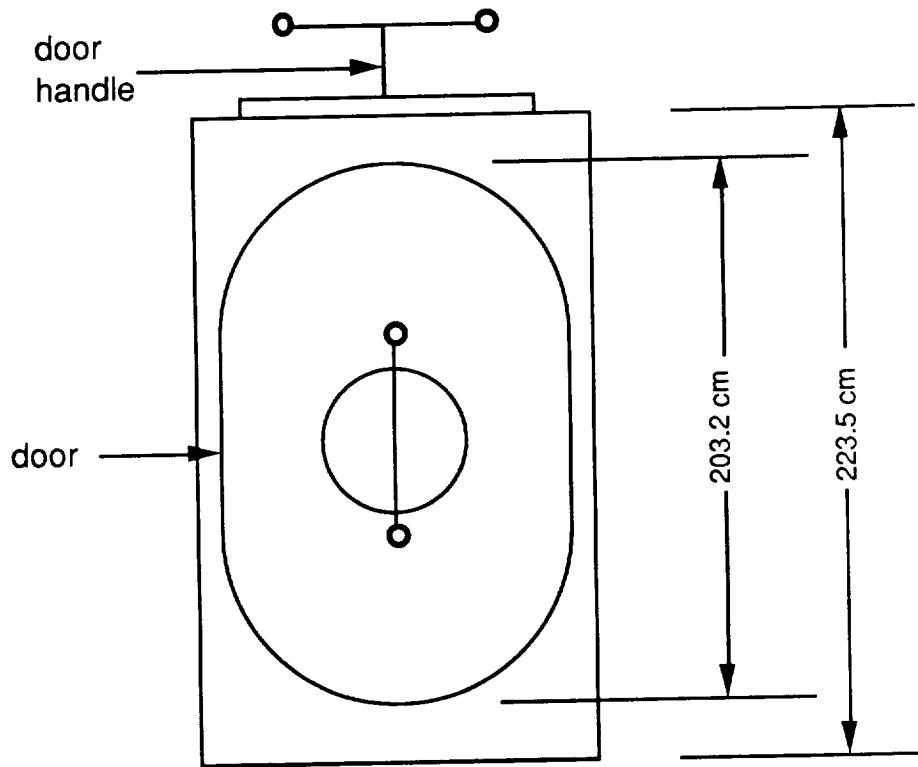
## **5.2 Ingress/Egress from the Habitation Module**

A minimum loss airlock, shown in Figure 5.3, designed by the University of Texas at Austin Mechanical Engineering students was chosen to provide the crew access to the lunar surface. The airlock is a one-man airlock which consists of a vertical entry, two-door cylindrical airlock with a staging chamber. The user enters and exits in a vertical position. A circular escape hatch on top of the airlock provides an exit in case of malfunction. The doors are manually operated and can easily be opened and closed by one person. If an emergency arises, the staging chamber can also be used as an airlock [20:53]. The airlock uses an o-ring seal placed within a machined dove tail groove to provide an air tight seal. The o-ring is made of Kel-f plastic, a teflon polymer; a rotation seal is used for sealing the door locking system [20:55-57].

The status of the airlock door is determined by four magnetic proximity sensors which are continuously monitored by the habitat computer. Furthermore, the temperature and pressure inside the airlock is measured by a thermocouple and strain gage pressure sensors respectively; the thermocouple and strain gage pressure sensors are also continuously



Top View



Front View

Figure 5.3 Airlock Configuration

monitored by the habitat computer. The computer sample the pressure inside the airlock at predetermined intervals and, if the computer senses a dropping trend in the airlock pressure, warns the crew of air loss [20:67-71].

### **5.2.1 Dust Control**

To prevent any dust from entering the airlock (and subsequently the habitation module) a "mud room" will be placed outside the airlock. This room will be equipped with alpha-particle emitters to neutralize any garment static charge build up that would attract dust particles. Furthermore, crewmembers returning from EVA will also be required to use a dust brush similar to that used in Apollo missions to remove any dust not removed by the alpha-particle emitters prior to entering the airlock [21:12].

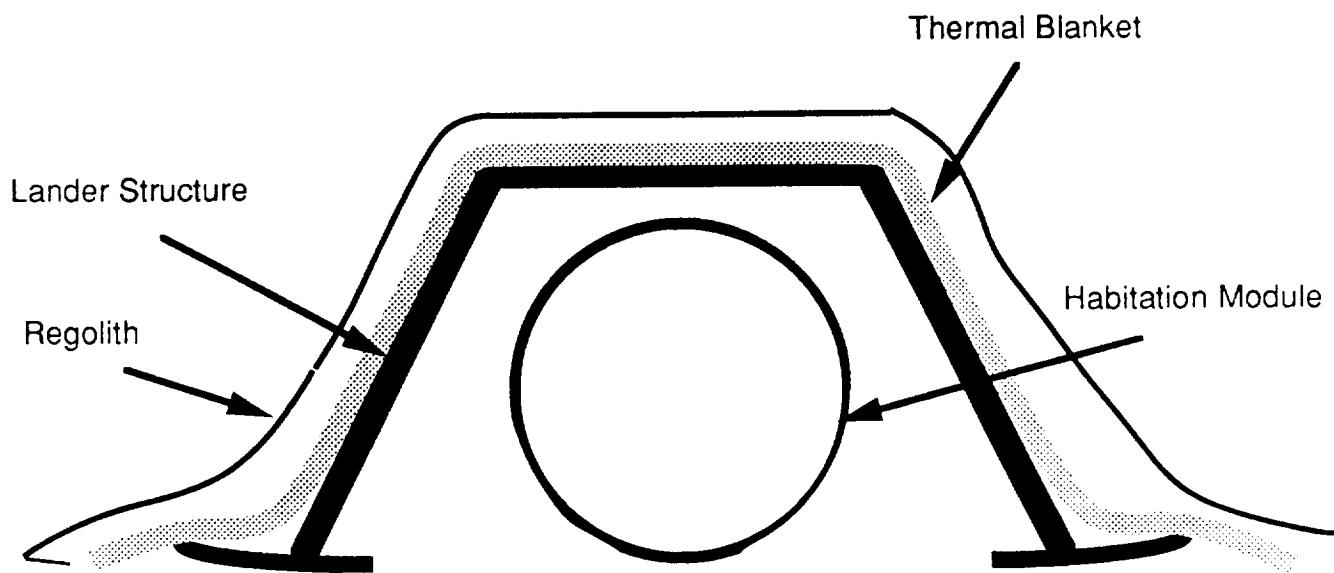
## **5.3 Habitat Shielding Methods**

For any lunar settlement to be man-tendable the astronauts and their living quarters must be protected from radiation, the lunar thermal environment, and meteoroids due to the lack of atmosphere. Protection from the lunar environment will be done primarily using lunar regolith, since it is readily available. Figure 5.4 shows the selected shielding method which is further discussed below.

### **5.3.1 Radiation Shielding**

The types of radiation that astronauts must be shielded from for stay periods up to 90 days are ultra-violet and cosmic-ray radiation [22:1]. The gamma rays found on the Moon have no significant biological effects [23:668] whereas, exposure to ultra-violet and cosmic-ray radiation can lead to chromosome damage. To avoid any radiation injury, radiation annual levels should not exceed 5 rems per astronaut [24:2]. Since haze and water vapors are absent from the Moon, the radiation intensity levels are high. The lunar regolith can greatly reduce the radiation intensity level emitted to the astronauts because it has a solar radiation absorption coefficient near unity. This coefficient was extrapolated from sand and black soil data having coefficients of radiation absorption between 0.77 and 0.99, respectively [25:39]. This factor

indicates that habitation modules and the working facilities do not require a thick covering of lunar soil for protection, and also that lunar soil does not significantly reflect or transmit radiation to the modules.



**Figure 5.4 Shielding Layout for Habitation Module**

To block radiation to acceptable levels assuming a soil density of 1.5 g/cm<sup>3</sup>, the modules and working facilities need only 0.5 meters of lunar regolith for protection from solar flares [22:2]. The angle of repose of the lunar soil should not hamper covering the facilities, enhancing lunar soil cohesion. The 0.5 meter depth will be made possible by the additional protection provided by a lunar lander platform currently being designed by the Fall 1989 mechanical engineering students at The University of Texas at Austin [26]. Since the platform positioned over the habitation modules and other facilities is solid, the radiation will be absorbed and not transmitted through. In the event of a solar flare having both large fluxes of low energy protons and an abundance of high energy particles, a "fallout shelter" buried in the ground will be accessible to the astronauts. The advantage of a fallout shelter is that it eliminates the additional

structural loading of the modules and the other facilities from the increase of lunar regolith. During the eleven year solar flare cycle, lunar regolith would have to be increased by at least 2 meters, since the annual radiation dosage on the Moon increases from 30 to 1000 rems [23:663]. This increase of lunar regolith corresponds to an increase structural loading of more than 5000 N/m<sup>2</sup> [23:376].

The fallout shelter will be constructed of the same material as the habitation module, but thicker and stronger since it will be underground. There will be at least three of these shelters around the base; one located near the habitation module, a second located at the landing field area and a third near the observatory equipment. The shelters will have room for an occupancy of four astronauts and will have sufficient space for food storage for three days. Normally, the high and low energy particles of a solar flare last approximately 24 hours [27:2].

### 5.3.2 Thermal Environment Shielding

The site selection criteria discussed in Section 1.6 and economic feasibility of delivering payloads to the Moon have led to a lunar observatory near the equator. At the equator, extreme temperature cycles are experienced; thus, heat rejection is of great concern. To keep the heat loss from the modules and working facilities at a minimum, lunar regolith will act as insulation. The minimized heat loss, as well as reduced heat exposure, leads to easily regulating the temperature without overburdening the thermal controls and overloading the nuclear power system. The fact that the lunar soil is close to being a perfect blackbody (i.e. absorbs all radiation), indicates that lunar regolith can readily be heated and cooled because all the heat is radiated to the soil from the absorbed radiation. The lunar soil has a low thermal diffusivity because of the vacuum environment and lack of water vapors [23:401]. Therefore, the exposed layer will be extremely hot or cold and the lunar soil will not disperse the heat very deep into the soil. The bottom of the layer of regolith covering the lander platform or the facilities will remain cool and retain the inside temperatures of the modules and the facilities.

The 0.5 meter depth of lunar regolith should be adequate to minimize heat loss and gain since a thermal blanket being designed by the Fall 1989 mechanical engineers will be incorporated [28]. The thermal blanket is 3 mm

thick and will lay on top of the lunar lander platform. A multilayer configuration will be applied since it is lighter than increasing the lunar depth on top of the platform. Without a thermal blanket protection, a 2 meter depth would be necessary to minimize heat affects [22:4].

### **5.3.3 Meteoroid Impact Shielding**

Due to the lack of a lunar atmosphere, the Moon is susceptible to meteoroid impacts. Astronaut's living quarters and working facilities run a risk of being damaged or destroyed by these meteoroids. Due to their very high kinetic energy, meteoroids are capable of excavating a mass 1000 times their own mass [24:2].

The lunar soil can absorb the kinetic energy of the impact, thus, protecting the facilities. Since lunar regolith absorbs energy very well, bouncing meteoroids pose no hazard to astronauts and vehicles. To insure the safety of the astronauts from large meteoroids, the modules and working facilities will be further protected with the lunar lander platform.

## **5.4 Life Support and Consumables**

Because there are many tasks that require original thinking and manual dexterity beyond robotic capability, people will be an important element in the construction and operation of a lunar observatory. To accommodate these personnel, the observatory must provide a livable environment. Maintaining this condition will be the job of the Environmental Control and Life Support System (ECLSS). During operation, the ECLSS must provide a livable atmosphere, water, and food for the stationed crew. To determine the systems which will provide these functions each process must be examined separately to find the most efficient and economical system.

### **5.4.1 Atmospheric Regeneration**

A livable atmosphere is a primary requirement for lunar occupation. Three types of systems which can be considered for this function are a Completely Open System, a Partially Closed system, and a Completely Closed system [6 and 29]. In each system, carbon dioxide must be removed from the

atmosphere to maintain a sufficient oxygen level. Examining the Completely Open system shows that it is impractical, because it assumes that all atmospheric consumables, once used will either be stored as wastes or vented to the lunar environment. Constant resupply of atmospheric elements and removal of waste products makes this option unfeasible for extended stays at the lunar observatory.

The Partially Closed system eliminates some of the waste present in the Open system by removing carbon dioxide from the atmosphere. Carbon scrubbing increases the breathable portion of the habitation atmosphere. Lithium Hydroxide cells have been widely used for this function on previous American spacecraft, however, stays at the lunar observatory will greatly exceed the flight lifetimes of these previous spacecraft. Since carbon scrubbing is used primarily for short spaceflights, it will be insufficient to supply the lunar observatory.

The completely Closed system, although more complex than the other two systems, was chosen because it creates almost total atmospheric regeneration, reducing resupply and waste removal needs. Oxygen for the crew will be regenerated using the following procedure.

1. Removal of Carbon Dioxide from the atmosphere
2. Reduction of Carbon Dioxide with Hydrogen to produce Methane gas and water.  
$$\text{CO}_2 + 4\text{H}_2 \Rightarrow \text{CH}_4 + \text{H}_2\text{O} + \text{Heat}$$
3. Replenishment of atmosphere using oxygen from hydrolysis.
4. Storage of methane gas for transport to nearside base.

Steps one through three of this procedure will each be accomplished using a separate subsystem designated for that task. Subsystems being considered for each function are shown in Table 5.4 [30 and 31]. To maximize efficiency, each subsystem must minimize the amount of resupply while also minimizing mass,

**Table 5.4 Atmosphere Regeneration Systems**

Criteria	CO <sub>2</sub> Concentration				CO <sub>2</sub> Reduction		O <sub>2</sub> Generation	
	LiOH	MS	SAWD	EDC	SAB	Bosch	SP	SF
Power kW	0.03	3.2	0.47	0.14	0.03	0.2	1.3	0.7
Weight kg	1053	1622	332	319	78.5	414	681	322
Volume m <sup>3</sup>	1.5	1.3	0.17	0.25	0.2	2.23	0.34	0.08
Maint. hours per 90 days	60	2.4	1.0	2.4	11.2	20.2	15.8	15.8
Resupply per 90 days kg	1012	4.5	1.4	1.8	1.8	79	7.25	5.0

LiOH - Lithium Hydroxide

SAB - Sabatier Reactor

MS - Molecular Sieve

Bosch - Bosch Reactor

SAWD - Solid Amine Water Desorber

SP - Solid Polymer Electrolysis

EDC - Electromechanical Depolarized Concentrator

SF - Static Feed Electrolysis

volume, power and maintenance. Based on these criteria, the following subsystems have been chosen for each function:

CO<sub>2</sub> Concentration - Electromechanical Depolarized Concentrator  
 CO<sub>2</sub> Reduction - Sabatier Reactor  
 O<sub>2</sub> Generation - Static Feed Electrolysis

These systems will perform their designated function, while maintaining high efficiency.

Atmosphere within the observatory will be regulated at a 20% oxygen-80% nitrogen mixture at a pressure of twelve pounds per square inch (psi). All atmospheric operations will be monitored by habitation computer systems. Oxygen and nitrogen for the habitation will be provided from cryogenic storage. Each of these supply will have primary and secondary systems to provide for emergency situations.

#### **5.4.2 Water Replenishment**

Extended stays on the Moon will require a constant supply of water. To reduce the amount of resupply necessary for extended stays, the system will need to be able to recycle water from condensation, washwater, and other water sources. Two waste systems which are being examined for use at the lunar observatory are a Space Station (SS) type system and a Super Critical Wet Oxidation (SCWO) system [6 and 32].

The Space Station type system is an almost completely closed system and consists of three water reclamation subsystems; one for drinking water, one for wash water, and one for hygiene water. Resupply needs for this system include water filters, Nitrogen, and post-treatment chemicals.

In this system, potable water is reclaimed from humidity condensate, which includes water formed during the removal and reduction of carbon dioxide. This is the least contaminated source of water in this system, and will require only taste enhancers to improve water quality. Hygiene water will be used for showering, washing hands and the generation of oxygen. This source of water is derived from dirty hygiene water and urine using a distillation process. The third system uses a filtering system to process washwater used for laundry and dishes. Dividing water management into these three subsystems, saves energy, since all water in the system does not need to be potable.

In contrast to the SS type system, the SCWO uses only two systems for all water reclamation. The SCWO system utilizes the physics and chemistry of molecules when they are raised above their supercritical pressure and temperature. When water is raised above its supercritical pressure (25.3 MN) and temperature (627.6 K), elements which are not normally soluble in water, undergo combustion and can mix freely as hydrocarbons. Combustion of organic compounds will occur when there is a sufficient amount of oxygen in the mixture, and will yield CO<sub>2</sub>, H<sub>2</sub>O, N<sub>2</sub>, and a solid salt precipitate. The heat needed for this system can be attained by introducing H<sub>2</sub> and O<sub>2</sub> into the SCWO feed mixture, and using their heat of reaction to drive the system. This system has the advantage that N<sub>2</sub> and other atmospheric trace elements are produced as a byproduct of the system and can be used in atmospheric regeneration.

The SCWO system will require only potable water and hygiene subsystems. Hygiene water, used for washing, will be cleaned, filtered, and

returned to hygiene water storage after post-treatment for future use. Potable water will come from the CO<sub>2</sub> reduction system and the SCWO system. Chemicals will be added to this water to enhance taste and restrict bacteria growth.

Comparing the two systems, the SCWO requires less subsystems than the SS system, while increasing the amount and potential uses of the recycled water. In addition, the SCWO system can be used to supplement atmospheric regeneration by supplying N<sub>2</sub> and other atmospheric trace elements, reducing the amount of resupply needed for atmospheric components. Based on these factors the SuperCritical Wet Oxidation system will be used to support water reclamation.

#### **5.4.3 Food Supply**

Because the lunar observatory will be occupied only sixty days each year, food supplies for each mission will be brought with the crew and transferred to the habitation upon arrival. Food for each mission will include rehydratable food and drink, irradiated meats and thermostabilized fruits.

### **5.5 Thermal Control System**

The Lunar Farside Observatory will need an active thermal control system (ATCS) to transport and reject a maximum waste energy of 100 kW from habitat systems with pumps and storage devices designed for heat loads of 75 kW [6:140]. The proposed system will consist of three phases: 1) heat acquisition, 2) heat transport, and 3) heat rejection.

#### **5.5.1 Heat Acquisition and Transport**

Redundant two-phase outer loops in combination with two-phase inner loops will perform the heat acquisition and transport phases of the ATCS. The system will utilize two-phase fluid flow which will allow for higher heat transfer coefficients than a single-phase system. Two-phase flow also provides weight and surface area advantages. A basic layout and cycle of an ATCS is shown in Figure 5.5, and system specifications are given in Tables 5.5 and 5.6. This system is similar to the ATCS which will be used on Space Station Freedom.

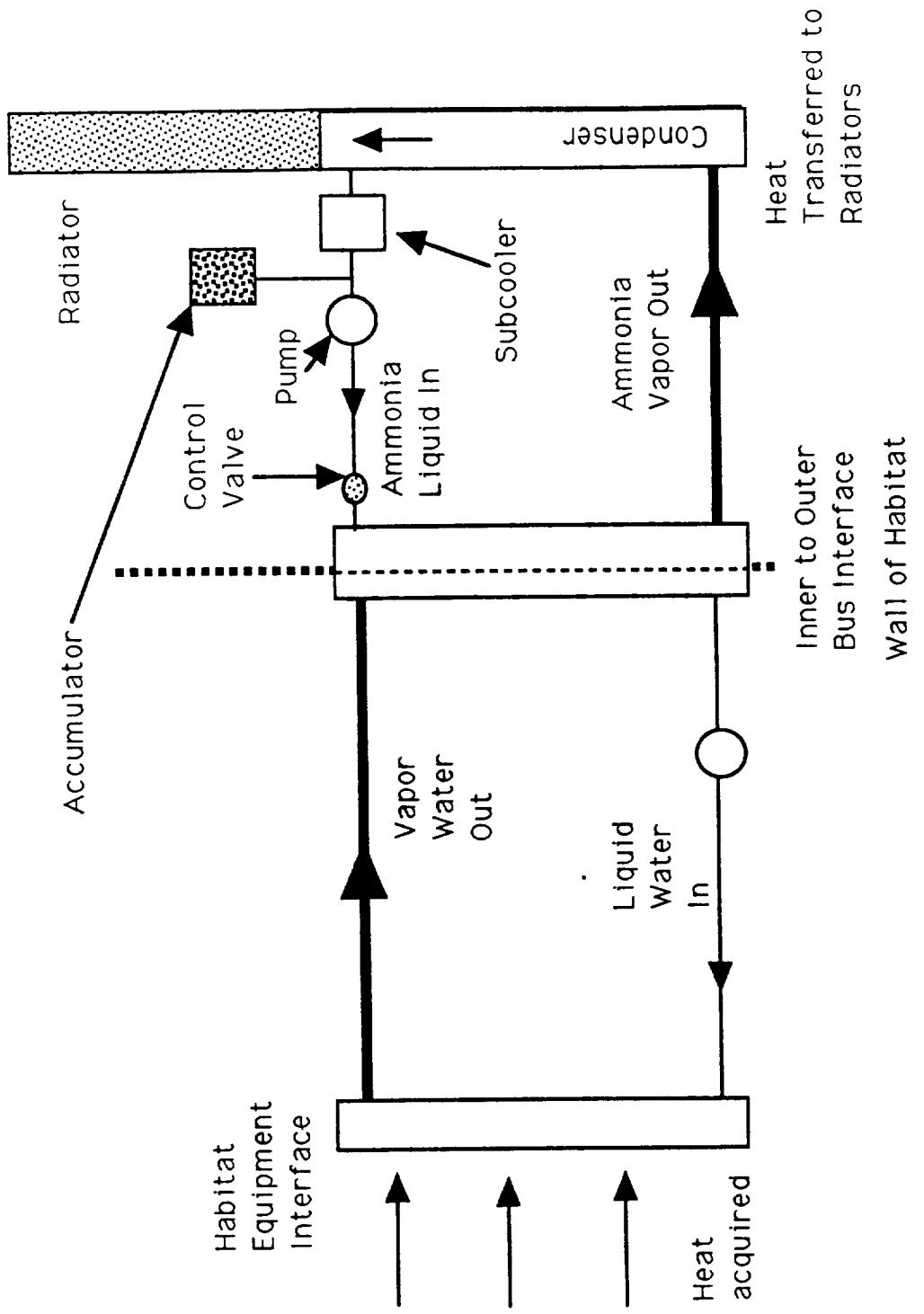


Figure 5.5 . Basic ATCS Layout and Cycle

**Table 5.5 External Thermal Bus Components of ATCS [6:87]**

2°C LOOP HARDWARE	VOLUME, m	MASS, kg	POWER, w
Heat Exchanger H <sub>2</sub> O/NH <sub>3</sub>	0.03	27.22	0
Flow Control Valves (2)	0.004	10.88	50
Liquid Sensors (8)	0.001	3.63	80
Fluid Disconnects (8)	0.002	7.28	0
Isolation Valves (8)	0.005	14.48	0
Instrumentation/Sensors (4)	0.001	1.82	12
Accumulator	0.01	9.53	35
Pressure Regulator	0.008	2.27	0
NCG Trap	0.007	2.72	35
Regenerative Heat Exchanger	0.03	22.68	0
Thermal Storage Device	0.045	113.4	0
Bus/Radiator Heat Ex.	0.028	16.33	0
A/D Converter	0.001	0.91	15
Working Fluid - Ammonia, NH <sub>3</sub>	0.001	3.63	0
Plumbing:			
Liquid Line	0.00014	0.27	0
Vapor Line	0.01214	23.15	0

21°C LOOP HARDWARE	VOLUME, m	MASS, kg	POWER, w
Heat Exchanger H <sub>2</sub> O/NH <sub>3</sub>	0.05	43.54	0
Flow Control Valves (2)	0.004	10.88	50
Liquid Sensors (8)	0.001	3.63	80
Fluid Disconnects (8)	0.002	7.28	0
Isolation Valves (8)	0.005	14.48	0
Instrumentation/Sensors (4)	0.001	1.82	16
Accumulator	0.01	9.53	35
Pressure Regulator	0.008	2.27	0
NCG Trap	0.007	2.72	35
Regenerative Heat Exchanger	0.05	45.36	0
Thermal Storage Device	0.075	226.8	0
Bus/Radiator Heat Ex.	0.028	16.33	0
A/D Converter	0.001	0.91	15
Working Fluid - Ammonia, NH <sub>3</sub>	0.001	3.63	0
Plumbing:			
Liquid Line	0.00014	0.26	0
Vapor Line	0.00753	14.35	0

**Table 5.6 Internal Thermal Bus Components of ATCS [6:89]**

2°C LOOP HARDWARE	VOLUME, m	MASS, kg	POWER, w
Pump Package	0.036	14.51	212
Control Valves - primary (3)	0.0057	3.82	75
Control Valves - secondary (3)	0.0057	3.82	75
Heat Exchanger	0.007	6.12	0
Coldplate	0.024	20.32	0
Quick Disconnects (17)	0.001	2.93	0
Working Fluid - H <sub>2</sub> O	0	2.83	0
Temperature Sensors (3)	0	0.12	6
Pressure Sensor	0	0.17	2
Flow Meter	0.002	0.75	0
Controller	0.01	4.45	0
Readout Equipment	0.028	9.07	5
Thermal Storage	0.043	45.36	0
Plumbing :			
Liquid Line	0.0005	0.95	0
Vapor Line	0.0425	81.02	0

21°C LOOP HARDWARE	VOLUME, m	MASS, kg	POWER, w
Pump Package	0.036	7.26	212
Control Valves - primary (3)	0.0038	2.54	50
Control Valves - secondary (3)	0.0038	2.54	50
Heat Exchanger	0.007	6.12	0
Coldplate	0.024	20.32	0
Quick Disconnects (17)	0.001	2.92	0
Working Fluid - H <sub>2</sub> O	0	2.83	0
Temperature Sensors (3)	0	0.123	6
Pressure Sensor	0	0.172	2
Flow Meter	0.002	0.748	0
Controller	0.01	4.45	0
Readout Equipment	0.028	9.1	5
Thermal Storage	0.043	45.36	0
Plumbing :			
Liquid Line	0.0005	0.92	0
Vapor Line	0.0263	50.21	0

### **5.5.1.1 Inner ATCS**

The inner ATCS will consist of four inner transport loops for redundancy: two at setpoint temperatures of 2° C for lower heat loads and two at 21° C for higher heat loads. The inner loop will acquire excess heat directly from the habitat systems using two-phase heat exchangers and water as the working fluid. Although water provides only moderate heat transfer properties, another working fluid such as Freon or Ammonia ( $\text{NH}_3$ ) would endanger the Lunar crew if leaks were present [6:88]. If the safety standard were reduced, a working fluid with better heat transfer properties could be used for ATCS inside the habitat. A leak proof system or a new working fluid could be an advanced or new technology requirement. The inner ATCS will transport the heat from the habitat systems to which interface with the outer ATCS. The interface will be designed for 10 kW at 2° C and 20 kW at 21°C [6:140].

### **5.5.1.2 Outer ATCS**

The outer ATCS will also consist of four transport loops similar to the inner ATCS. The working fluid of the outer ATCS will be  $\text{NH}_3$ . The outer ATCS will acquire the heat from the inner loop through the two-phase  $\text{NH}_3$ /single-phase water heat exchangers. Heat will be transported to the condensers which will transfer the heat to the radiators.

## **5.5.2 Heat Rejection**

The excess heat will be rejected to deep space by using surface radiators in a vertical configuration. The heat pipe layout inside a surface radiator is shown in Figure 5.6. The working fluid inside a surface radiator is two-phase  $\text{NH}_3$ . A radiator area of approximately  $41.86 \text{ m}^2$  total will be needed to satisfy the heat loads for both the 21°C and 2°C set points [6:99]. The surface radiators for the space station have a surface area of  $4.65 \text{ m}^2$ ; therefore, 9 one-sided surface radiators (one side insulated) or 5 two-sided surface radiators will be needed for the lunar farside observatory ATCS.

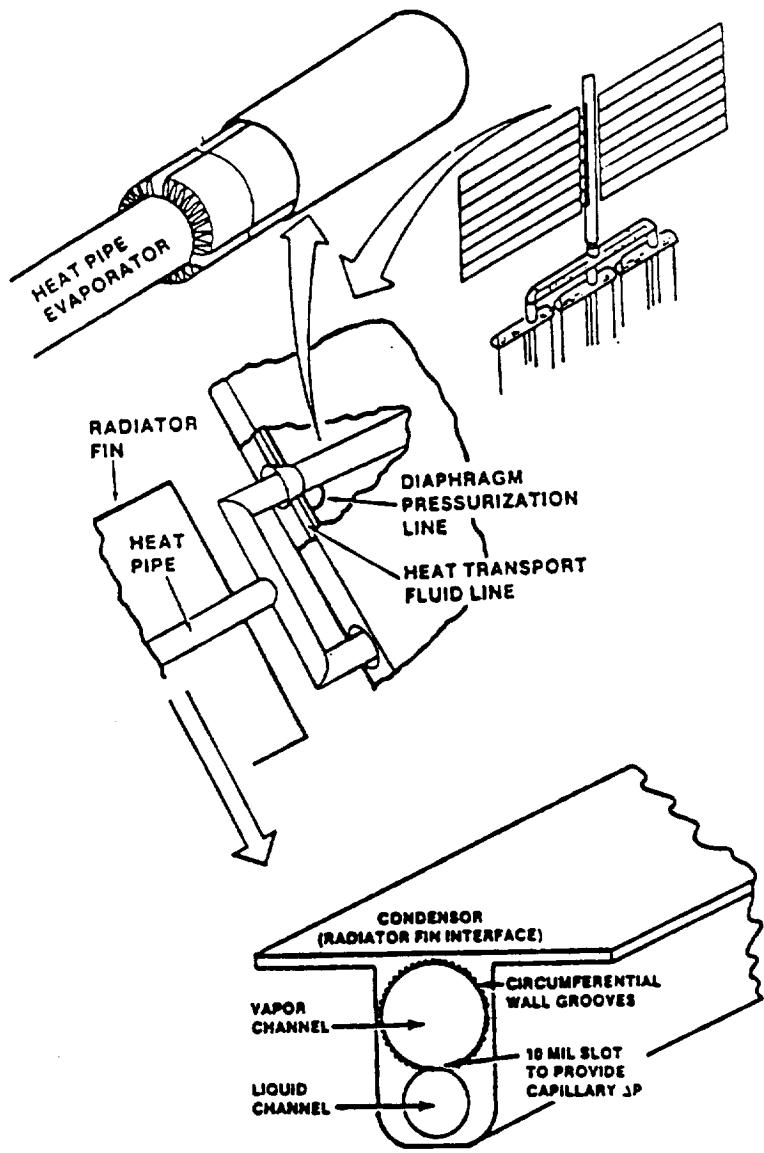


Figure 5.6 Surface Radiator Heat Pipe [6:95]

### 5.5.2.1 Heat Rejection During the Day

Adequate heat rejection becomes a problem during the lunar day since the sink temperature becomes greater than the radiator surface temperature. Two options exist to deal with this problem. The radiators could be gimballed so that they may be rotated toward an optimal heat rejection position with respect to the sun (i.e. deep space) and shielded from surrounding heat sources (i.e ground) by a canopy, or a vapor cycle system (VCS) connected between the outer ATCS and the radiators could be used to raise the radiator temperature above the sink temperature in order to allow for adequate heat rejection. The VCS would significantly increase needed power requirements which is not feasible; therefore, the gimbal-canopied approach will be used [33:9]. Radiator sizing is shown in Table 5.7 for a full view radiator, a rotating radiator, and a canopied radiator [6:99]. Negative surface area reflects that the specified radiator configuration would not be able to reject the required excess heat loads. Table 5.7 shows that a canopied radiator configuration is needed to provide adequate heat rejection for the lunar farside observatory. The canopy system for the radiators has yet to be designed.

**Table 5.7 Radiator Sizing for Three Shielding Options [6:99]**

<u>21°C Radiator Sizing</u>	<u>@ Full View</u>	<u>Rotating</u>	<u>With Canopy</u>
Radiating Area, m <sup>2</sup>	1230.75	110.18	41.86
Effective Area, m <sup>2</sup>	615.37	55.09	20.93
Radiator Mass, kg	8412.66	753.15	286.10
Radiator Volume, m <sup>3</sup>	375.13	33.58	12.76
<u>20°C Radiator Sizing</u>	<u>@ Full View</u>	<u>Rotating</u>	<u>With Canopy</u>
Radiating Area, m <sup>2</sup>	-25.48	-161.01	18.86
Effective Area, m <sup>2</sup>	-12.74	-80.50	9.43
Radiator Mass, kg	impossible	impossible	128.92
Radiator Volume, m <sup>3</sup>	impossible	impossible	5.75

### 5.5.2.2 Other Heat Rejection Methods

Other methods considered for heat rejection were Liquid Droplet Radiators (LDR), rejecting heat through Lunar regolith, and rejecting heat through a water tank. Surface radiators were chosen on the basis of the factors depicted in Table 5.8. The major factors against LDRs was the availability of the working fluid (liquid metals) and the versatility to operate at desired heat loads [6:90-1]. The lunar regolith has a low thermal conductivity which makes it impractical for heat rejection due to the large areas which would be necessary [33:8]. Water is scarce on the moon; therefore, it should be saved for the crews not wasted on thermal control which could be achieved in another way [6:93]. Due to the disadvantages of the other systems, surface radiators were chosen for heat rejection purposes. The technology to utilize the surface radiator concept is being developed for space station; therefore, it is dependent on the space station program.

**Table 5.8 Thermal System Decision Matrix**

Radiator Option	Mass	Working Fluid	Heat Rejection	Versatility	Growth Capacity	TOTAL
Surface Radiators	3	2	2	1	1	9
Liquid Droplet	2	4	1	2	1	10
Lunar Soil	1	1	4	3	3	12
Water Tank	4	3	3	4	4	18

## **6.0 Surface Operations**

OUTLOOK defines surface operations as those activities which need to be conducted, either by humans or robots, which are essential to the proper operation and maintenance of the LFO. These operations include crewmember extra-vehicular activity and the robotic construction and operation of the LFO.

### **6.1 Extra-Vehicular Activity**

This section discusses the requirements for the Lunar Extravehicular Mobility Unit (LEMU). These requirements include radiation and dust protection—two areas which are especially important in the design of a lunar EVA suit. A discussion of two EVA suits which were considered as candidates for the LEMU. The first suit was the Space Station Extravehicular Mobility Unit (SSEM). The other suit was the Zero Pre-breathe Suit (ZPS). Finally, the crew workday schedule was determined for two cases—the one-shift workday cycle and the two-shift workday cycle.

#### **6.1.1 EVA Requirements**

The LEMU must provide the crewmember oxygen and drinking water. Furthermore, the suit must remove exhaled carbon dioxide and water vapor from the interior suit environment, provide for cooling, and the collection of various body wastes. [21:8] The LEMU must protect the crewmember by providing,

- 1) a pressurized envelope in which to work on the lunar surface,
- 2) insulation from the varying lunar thermal extremes, and
- 3) shielding from micrometeoroids. [21:8]

Other requirements which the LEMU must meet are radiation protection, ease of cleaning and maintenance, maximum lower body mobility, and variable light attenuation to cut the glare of brightly lighted areas. [21:12]

### **6.1.1.2 Radiation Protection**

For radiation protection, the suit is expected to provide minimal protection during relatively short EVA excursions on the surface under regular conditions (i.e. non-solar maximum). During solar maximum, solar flares are preceded by approximately thirty (30) minutes by a burst of x-rays.[21:11] To permit the crewmember the maximum amount of warning, the suit will include a radiation badge which will be sensitive to x-rays. This badge will be connected to a warning light and alarm inside the astronaut's helmet. When the level of x-rays exceeds a preset level, indicating a solar flare event, the warning light will be lit and the alarm will sound. The crewmember may then begin the return journey to the habitation module and protection or construct a lunar storm shelter.

### **6.1.1.3 Dust Protection**

The micron-fine lunar dust tends to embed itself into the fabric weave of LEMUs. This dust could affect the pressure seals of the LEMU by contaminating the sealing surface, thereby disturbing the pressure retentive properties of the seals. Furthermore, the dust could negatively affect the LEMU's mobility bearings. The dust which settled in the races would cause both an increase in the torques of rotating joints and in wear of the bearings [21:11]. The options considered for protecting the LEMU from the lunar dust included a dust-off room for the habitation module or a dust garment that would be worn over the LEMU during EVA operations.

## **6.1.2 EVA Suit Options**

The two options which OUTLOOK considered for an EVA suit at the lunar farside observatory were the Space Station Extravehicular Mobility Unit (SSEM) and the Zero Pre-breathe Suit (ZPS). The two suits were evaluated for mobility, ease of use, and simplicity of maintenance.

### **6.1.2.1 Space Station Extravehicular Mobility Unit (SSEM)**

The SSEM is the standard suit that will be developed for use in the zero gravity environment of the space station. The suit pressure would be set at 8.3

psia with 100% breathing O<sub>2</sub>. [16:76] The drawback of this suit lies in its internal environment. Since the suit environment is 100% oxygen, crewmembers would have to undergo a pre-breathe period, during which they breathe pure oxygen to facilitate the removal of other gases from their system, before being able to begin the EVA. For a suit pressure of 8.3 psi and a habitation pressure of 14.7 psi, the pre-breathe interval is 1.5 hours [16:77]. Another drawback lies in the fact that the crewmember would be exposed to an oxygen partial pressure (PO<sub>2</sub>) of 8.3 psia while in the suit. The NASA-STD-3000 report gives the following toxicity limits for O<sub>2</sub> exposure:

<u>PO<sub>2</sub>(psi)</u>	<u>Limitation (hrs/period)</u>
10 - 14.7	6 hr/24 hr period, 18 hr/120 hr period (5 days)
6 - 10	18 hr/120 hr period
3 - 6	none

Since at a suit pressure of 8.3 psia and 100% O<sub>2</sub>, the actual PO<sub>2</sub> is not at 8.3 psi for the entire EVA. Figure 6.1 gives the PO<sub>2</sub> time history for the suit. Using the oxygen toxicity limitation given in NASA-STD-3000, the result is a maximum of 2 hrs 20 minutes at PO<sub>2</sub> above 6 psi/8 hr EVA [16:50]. This data indicates that EVA is not limited by an oxygen toxicity constraint if one EVA is performed each day. For example, five days of eight hour EVA missions would result in a total of 11 hours and 40 minutes, which is less than the limitation of 18 hours [16:50].

#### **6.1.2.2 Zero Pre-Breathe Suit (ZPS)**

The ZPS will be constructed of aluminum and carbon fiber. The suit would resemble a medieval suit of armour. [19:148] The benefit of the ZPS is that its internal environment would be 14.7 psi, the same as in the habitation module. This eliminates the need for a pre-breathe interval before an EVA excursion. The drawbacks of the ZPS are that it is heavier than the standard suit (23 kg heavier), it takes up more storage space, and the "stove pipe" joints also require the crewmember to change positions in a special way.[16:148] Even with these drawbacks, the ZPS is considered the better choice of the two suits.

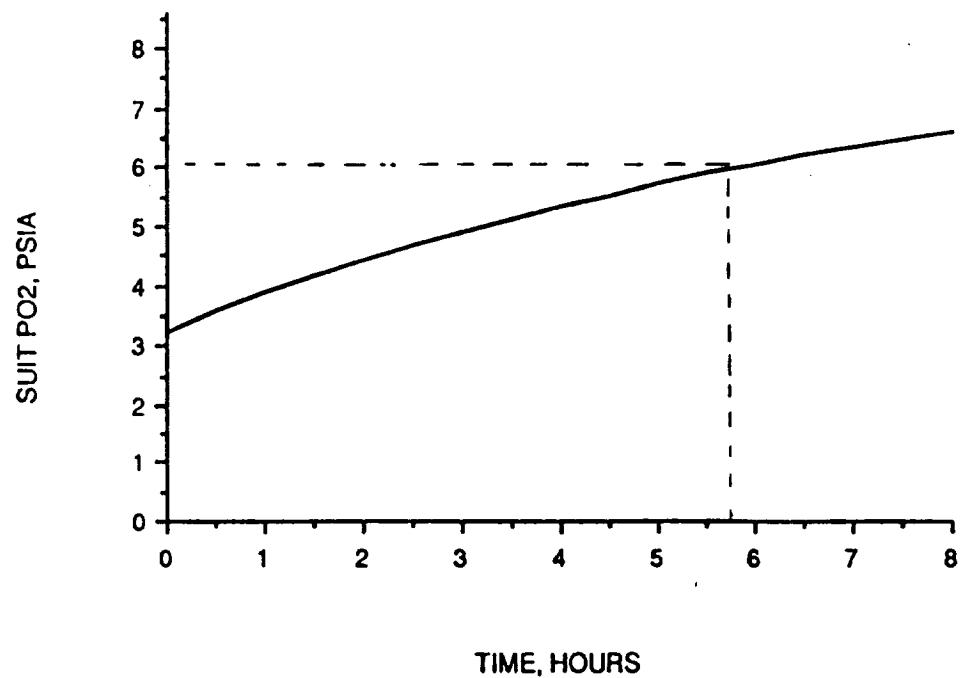
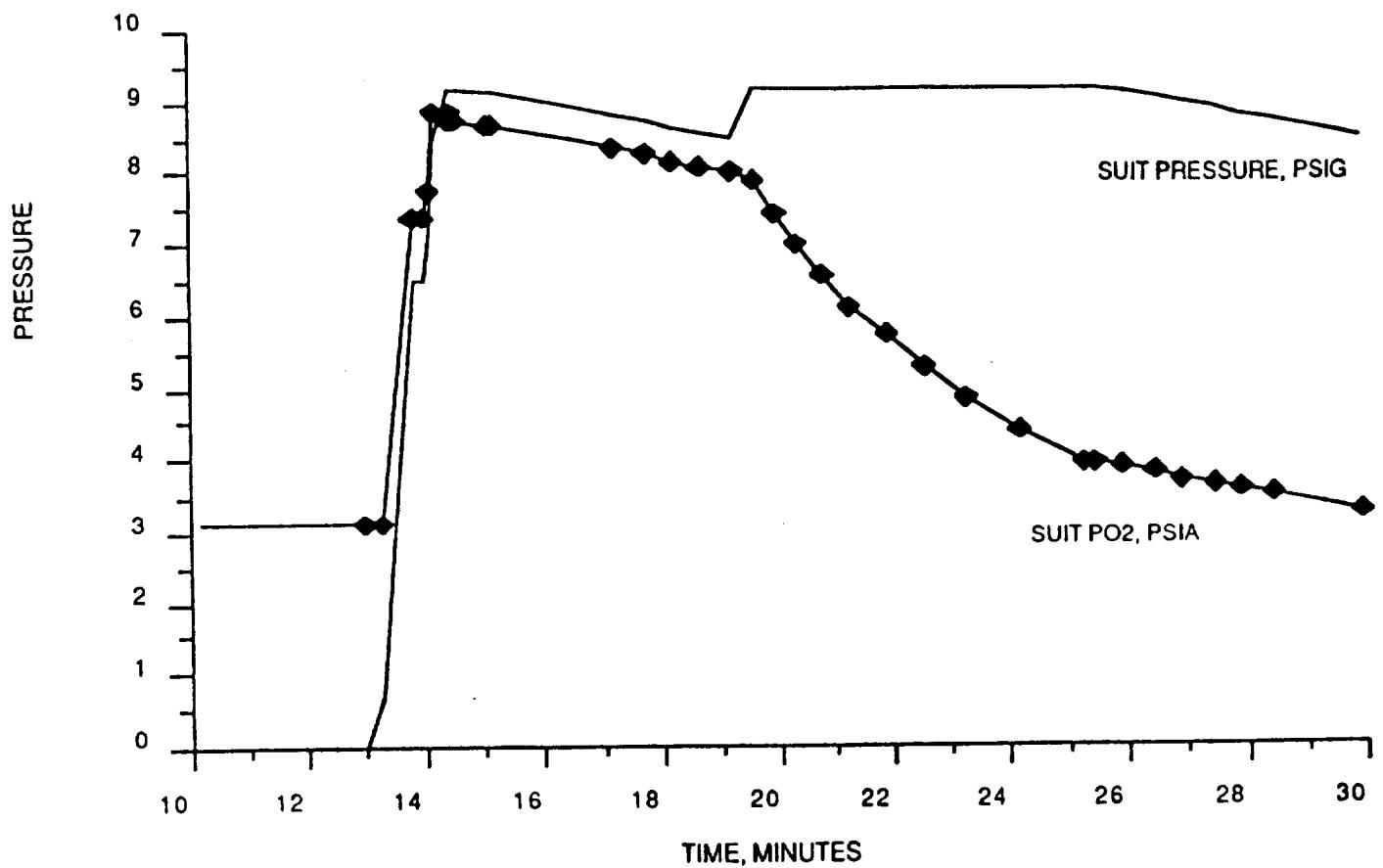


Figure 6.1 SSEMU Suit PO<sub>2</sub> during an EVA mission [16]

### **6.1.3 EVA Duty Cycles**

The EVA work cycle for the LFO will consist of a minimum of two EVA crew involved in an EVA activity so that the "Buddy" system can be employed. Furthermore, nominal operation of the observatory will be conducted with one EVA crew per day which yields a duty cycle for a 4 person mission of three days on EVA, three days off. It is possible that the crew of the LFO can be reduced to three crewmembers only in one mission. This reduction in the crew at the LFO would simply entail a redistribution of the work cycles so that the "Buddy" system is still being used in EVA activities.

#### **6.1.3.1 Crew Work Schedule**

Table 6.1 shows the typical one-shift workday cycle for a crewmember at the LFO. This cycle was chosen since it ensure that the normal duty time for the crewmembers is less than eight hours at one time. This schedule would be modified somewhat during periods of EVA so that the crewmember would perform one eight-hour EVA in one duty period. The two-shift workday cycle is shown in Table 6.2. This cycle would be used during periods of high activity at the LFO such as during the construction phase, etc. If a crewmember was required to perform an EVA while the two-shift workday cycle was in effect, he or she would perform one eight hour EVA in place of two five hour duty shifts. In both the one-shift and the two-shift workday cycle, the extra two hours that the crewmember would have had to perform had he or she not performed an EVA would be devoted to maintenance of the EVA suits.

**Table 6.1 Typical One-Shift Workday Schedule**

Post-Sleep 2 hrs	Duty 5 hours	Meal Exer 2 hrs	Duty 5 hours	Pre-Sleep 2 hrs	Sleep 8 hours
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**Table 6.2 Typical Two-Shift Workday Cycle**

A	Pre-Sleep 2 hrs	Sleep 8 hours	Post-Sleep 2 hrs	Duty 5 hours	Meal Exer 2 hrs	Duty 5 hours
B	Duty 5 hours	Meal Exer 2 hrs	Duty 5 hours	Pre-Sleep 2 hrs	Sleep 8 hours	Post-Sleep 2 hrs

### 6.1.3.2 EVA Workday Length

The nominal period for an EVA workday is seven hours at the EVA work site. The maximum in-suit time for the crewmembers will be limited to eight hours. The nominal work period assumes at most a 30 minute travel time to the EVA site. The half hour travel time was chosen so that if a solar flare event does occur, the thirty minute warning that the crewmember would receive will be sufficient time for a return journey to the habitat module or to the nearest lunar storm shelter. The value of a maximum in-suit time of eight hours was chosen to reflect the regular eight hour workday on Earth.

## 6.2 Robotic Construction and Maintenance

Robots will be used at the LFO to do construction tasks, maintenance, and some selenological surveys. The robot's task is to minimize the amount of EVA time of the observatory crewmembers by performing simple, repetitive tasks easily and efficiently. This section describes the individual robots used, the robot control network, and the tasks which the robots will carry out.

### 6.2.1 Robots

The robots used at the LFO can be classified into two categories: worker robots and foreman. The worker robots are simple machines which are given a task to complete and are programmed to a level so that they can chose the method necessary to complete that task. The foreman is the central control of

all other robots. Its function is to assign jobs to the workers and to assist those worker robots which reach an impasse in completing a job.

### **6.2.1.1 Worker Robots**

#### **6.2.1.1.1 Lunar Construction Utility Vehicle (LCUV)**

One of the prime considerations of OUTLOOK's robotics team was that the LCUV of the LFO be small in size. This would facilitate easy transport of the robot to the observatory site. The LCUV chosen by OUTLOOK was designed by students at the Department of Mechanical Engineering at Old Dominion University. This all-purpose vehicle is comprised of a mobility unit with an attached manipulator arm at the top. Figure 6.2 shows the LCUV final design. The hull and body of the LCUV is constructed of aluminum. [34:7] An elastic loop made of a titanium alloy was chosen for the mobility system which will run around drive drums suspended by the use a variant of a MacPherson strut.[34:27-31] Figure 6.3 shows an enlarged schematic of the track system employed by the LCUV. In order to tow other implements, the LCUV was provided with a one piece flexible coupling.[34:44] The coupling will be used to connect one LCUV to another in case one of the vehicles is disabled or the coupling may be used to pull the sidedump (sd) module which will be used to move large amounts of regolith around. For power, the LCUV will use hydrogen-oxygen fuel cells.[34:54] The manipulator arm used by the LCUV is 15 m in length from its base to the point of attachment of its hoist implements.[34:102] Some of these implements include a backhoe (bh), a hopper/conveyer (hc), and a hitch (ht). [17:91] The mechanical arm of the LCUV will be designed for easy removal so that a Lunar Telerobotic Servicer can be attached for more delicate work around the LFO.

#### **6.2.1.1.2 Lunar Telerobotic Servicer (LTS)**

Some tasks at the LFO will require a robot with a high degree of dexterity in its manipulator arms. Since the LCUV possesses only a rudimentary manipulator arm which can only grasp, pull, or push objects, OUTLOOK's robotics team determined that a more sophisticated robot would be needed. This requirement was fulfilled by the Lunar Telerobotic Servicer (LTS). The

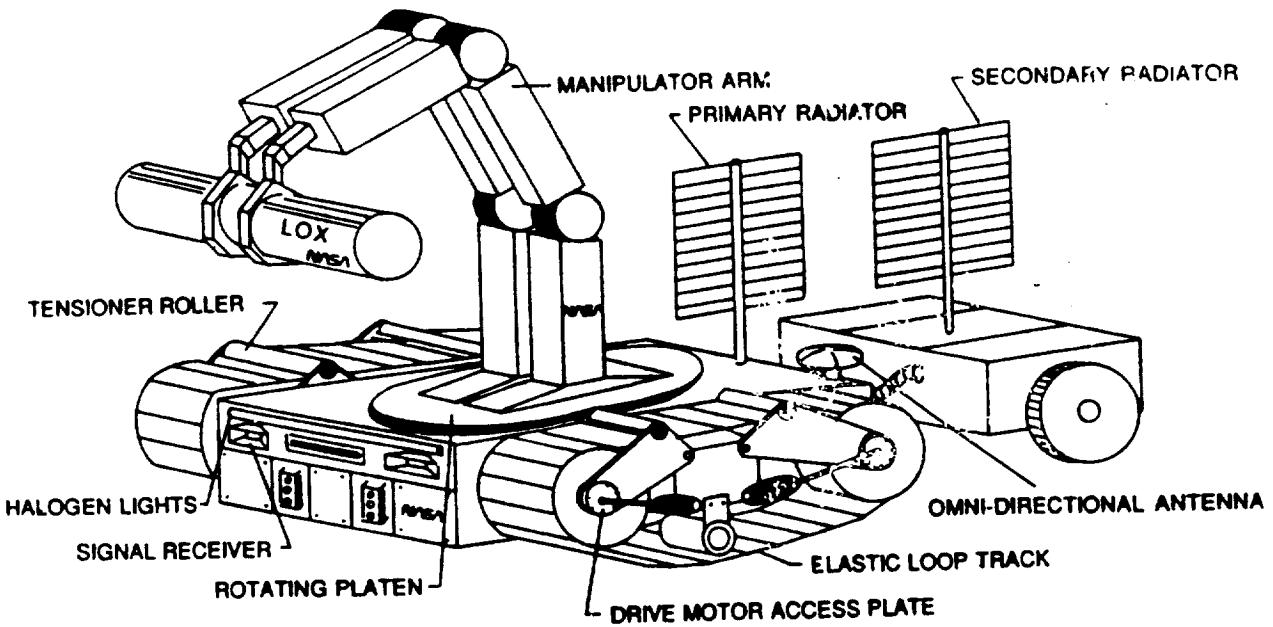


Figure 6.2 LCUV Configuration [34]

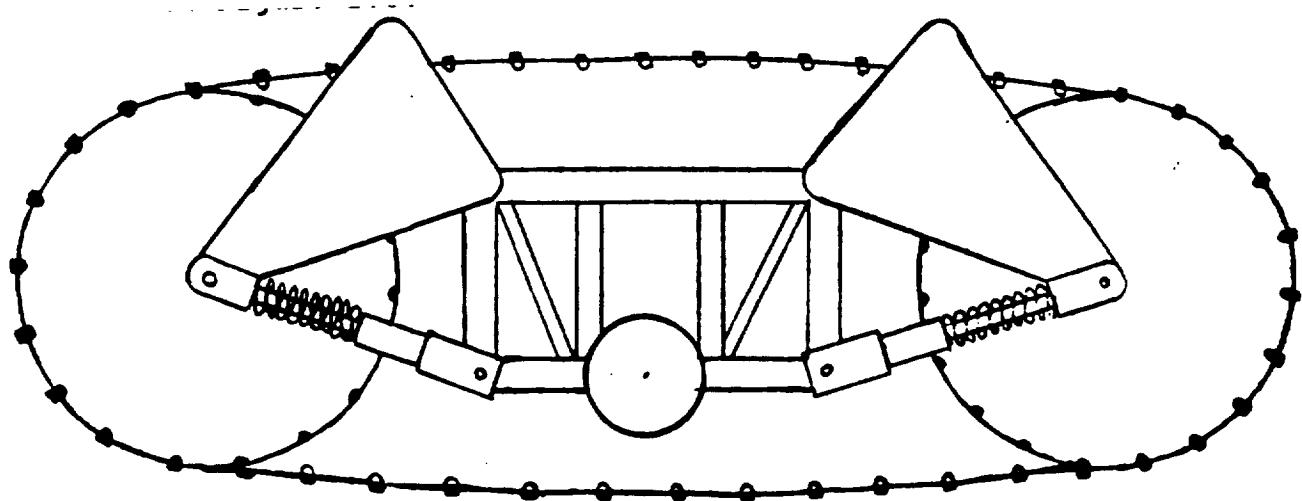


Figure 6.3 LCUV Track System [34]

LTS was adapted from the Eagle Engineering Lunar Surface Operations Study. The LTS would use the Lunar Construction Utility Vehicle's (LCUV) mobility base as a means of transportation. The telerobotic servicer would replace the manipulator arm of the LCUV.

The LTS's primary responsibility would be to repair or maintain equipment at the observatory site during periods when the LFO is unattended by a human crew. Some of the responsibilities of the LTS would include performing tasks during periods when the LFO is tended by humans (e.g. reducing human EVA time), replacing damaged modules, repairing faulty LCUVs, repairing the SP-100 nuclear reactor, and repairing the foreman if necessary. These tasks require the LTS's manipulator arms to be capable of delivering the torque and force equivalent of a suited crew person; these requirements are

- Arm Reach: 36 inches
  - Arm Tip Speed: >20 inches/second
  - Arm Tip Position: <.004 inches with respect to robotic coordinate system
  - Arm Tip Torque: 30-35 inch-pounds
  - Arm Tip Force: 20-25 pounds
  - Two manipulator arms and two stabilization arms
  - Each of the four arms will have six (6) degrees of freedom
- [35:97].

The LTS will be capable of being operated in an autonomous mode or in a teleoperated mode. The teleoperated mode would be used by astronauts in the habitation module or by crewmembers of the nearside base to conduct specific tasks. At all other times, the LTS will operate in autonomous mode, carrying out its functions without human interference. Teleoperated mode will always override autonomous mode. The LTS is powered by hydrogen-oxygen fuel cells which are independent of the fuel cells used by the LCUV.

#### **6.2.1.2 Foreman Robot**

The foreman is a stationary robot which assigns jobs to the LCUV and the LTS/LCUV units. This robot was developed by the PHOBIA design team at

the Department of Aerospace Engineering and Engineering Mechanics at the University of Texas at Austin. Since the foreman is stationary, the exposure of the unit to dust and potential damage in the work environment is reduced. [36:71] The foreman will be capable of making decisions when a construction robot encounters a problem which it cannot solve.

### **6.2.2 Robot Software**

#### **6.2.2.1 Foreman Programming**

As shown in Figure 6.4, the foreman robot is programmed with an artificial intelligence (AI) mission code. This code will be the primary driver which will enable the foreman to make independent decisions about how to solve a problem which an LCUV is facing.

Another software program which the foreman will have is the PICON (Process Intelligent Control) expert system. PICON is a real time control system for the space station.[36:78] An expert system is a software routine which gives the robot the capability to solve difficult problems—like an expert. PICON constructs, alters, and initiates rules; these rules form the basis of any action or reaction of the system being controlled. PICON responds to questions or problems by returning a suggestion for a solution. These suggestions are developed by applying the rules contained within the knowledge base of the robot.[36:79]

#### **6.2.2.2 LCUV Programming**

The Lunar Construction Utility Vehicle (LCUV) will be programmed with a low level of intelligence. This may include a "smart" algorithm which will alter itself to allow adaptation to problematic situations. This "smart" algorithm would be capable of dealing with a situation where it could not find the right tool for a specific task. The LCUV would not be able to make independent decisions about how to solve major problems which it may encounter such as getting stuck in the regolith or falling over a crater rim.

The LCUV software will also include a rudimentary AI code called PARPLAN. This code is designed to efficiently distribute tasks to the members of a multi-arm robot. PARPLAN is not an expert system but rather a program

written in Quantus Prolog. The program monitors and controls the state vectors of a robot manipulator system through the use of primitive instructions such as

Hand #3 place gear #2 in slot #4 during the interval  $T_1$  to  $T_2$ .

These software programs are shown in Figure 6.4. [36:79]

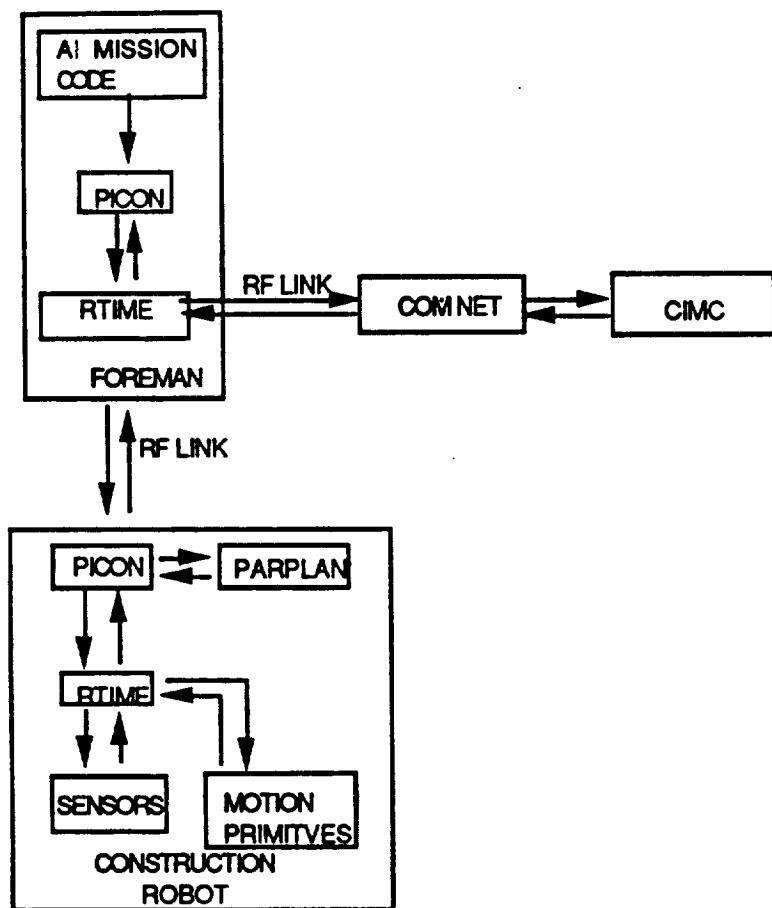


Figure 6.4 Robotic Software Interfaces

### **6.2.2.3 LTS Programming**

The telerobotic servicer is programmed to a higher level than the LCUV. Its software package includes a version of PICON and PARPLAN as in the LCUV; however, the level of programming in both software routines is higher than those in the LCUV. This allows the telerobotic servicer a greater degree of freedom than the LCUV plus, it allows the servicer to perform complex tasks on its own. The only time that the LTS will call back to the foreman is if it finds either a major problem with the system it is operating on or if the LTS is disabled or malfunctioning in some manner.

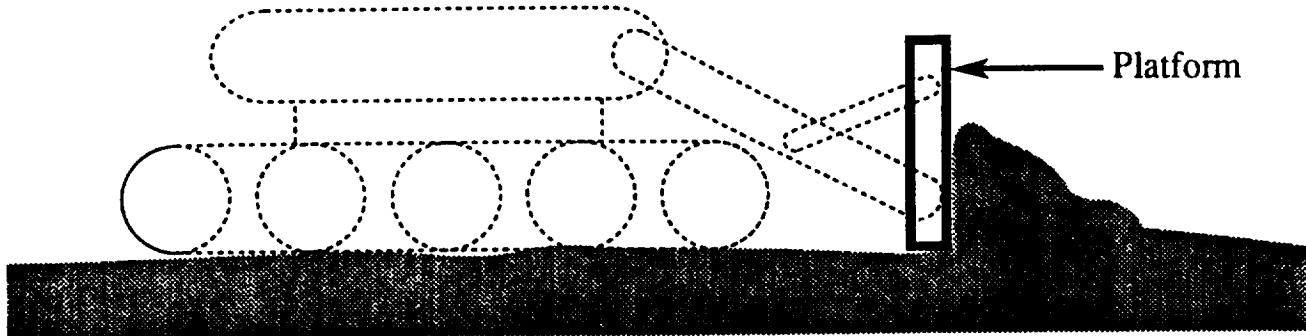
### **6.2.3 Robotic Duties**

The robotic duties include construction around the observatory site prior to the set-up of the habitation module and other observatory equipment, maintenance of the observatory equipment during untended periods, and long range lunar surveys and experiments.

#### **6.2.3.1 Construction**

Robots will be sent to the LFO site with the first unpiloted mission. The tasks of the LCUV is to prepare the site by excavating holes and trenches, removing large rocks and boulders, and to pave trails leading to the various parts of the LFO.

To excavate holes and trenches, the LCUV will use blasting charges shaped specifically for the type of hole that is desired. After the hole is created, it will be smoothed out in preparation for the equipment to be placed into it [37]. For the removal of large rocks, the LCUV will either remove the obstacle physically by picking the rocks up and moving them to another location or, in the cases of rocks too large to be moved, the LCUV will drill a hole into the rock and place an explosive charge inside. The charge will be used to break the boulder into smaller fragments thereby facilitating the removal of the boulder. To pave trails around the LFO site, the LCUV will use an excavating blade to smooth out and pack down the lunar soil as shown in Figure 6.5.



**Figure 6.5 Lander Platform Use as Excavating Blade [26]**

#### **6.2.3.2 Maintenance**

During the period when the LFO is unmanned, the LCUV and the LTS will be used to maintain and repair equipment. The equipment at the LFO will be designed with modular components. When a unit fails, an LCUV or LTS will remove the faulty unit, bring it back to the habitation module and take back a new unit to replace the old one. This simple procedure can also be used when there is a crew at the LFO. The robot can be used to eliminate the need for a crewmember to risk injury during an EVA by bringing the faulty module to the habitat. This procedure would not be used only in the case where the dexterity and delicacy of the human touch is required.

#### **6.2.3.3 Selenological Surveys**

The LCUV may be used to perform long duration selenological surveys. This task would involve such operations as drilling for core samples, scooping surface samples for analysis, and other tasks. By being used for this capacity, the LCUV eliminates the need for the crew of the LFO to undertake a hazardous EVA operation. Furthermore, the LCUV can perform extended selenological surveys since it is not limited by air and food reserves.

#### **6.2.4 Construction Operations**

The first unmanned missions to the LFO site will include robots to begin construction of the observatory. One of the lunar cargo landers will bring the

habitation module, another will bring the lunar crane, and other landers will bring the rest of the robotic construction team as well as other parts of the observatory. This section describes the tasks which the robots will conduct in setting up the LFO.

#### **6.2.4.1 Protection of Equipment**

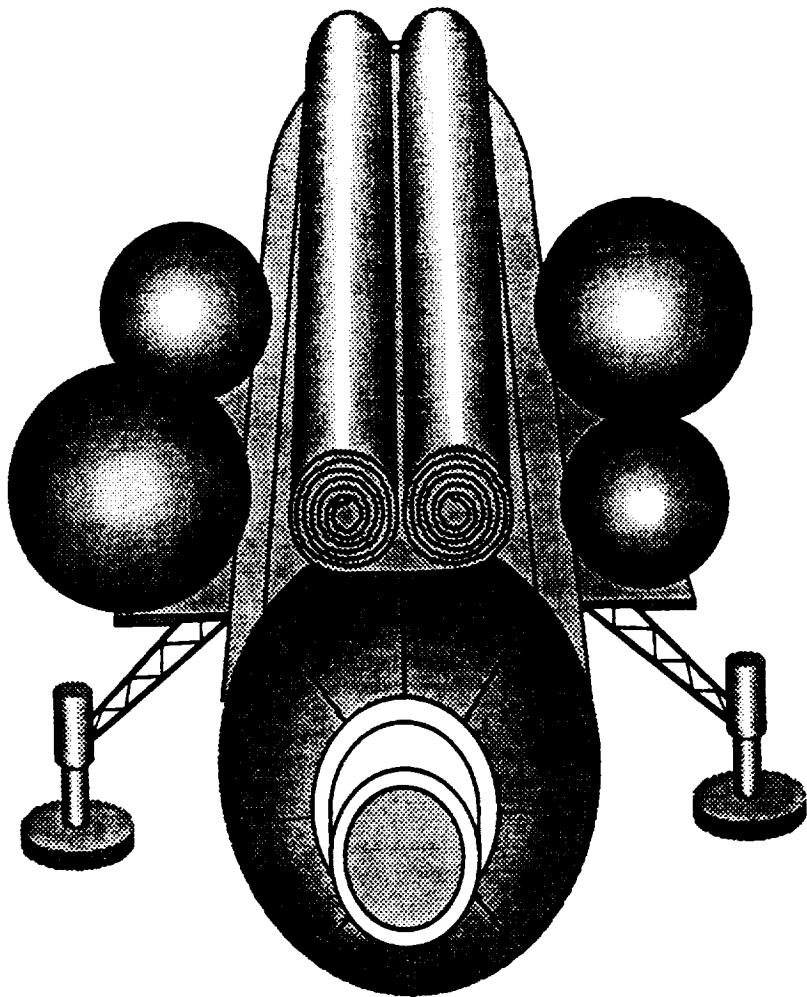
To protect equipment on the lunar landers on the surface of the Moon, OUTLOOK recommends the usage of the thermal and micrometeorite blanket developed by the students at the Department of Mechanical Engineering at the University of Texas at Austin. The blanket is shown in a stored configuration in Figure 6.6 and in a fully deployed configuration in Figure 6.7. The material chosen for thermal protection was a multilayered thermal insulation (MLI) blanket.[28:19] The blanket also provides adequate protection from micrometeorite impacts.

#### **6.2.4.2 Habitation Module Set-up**

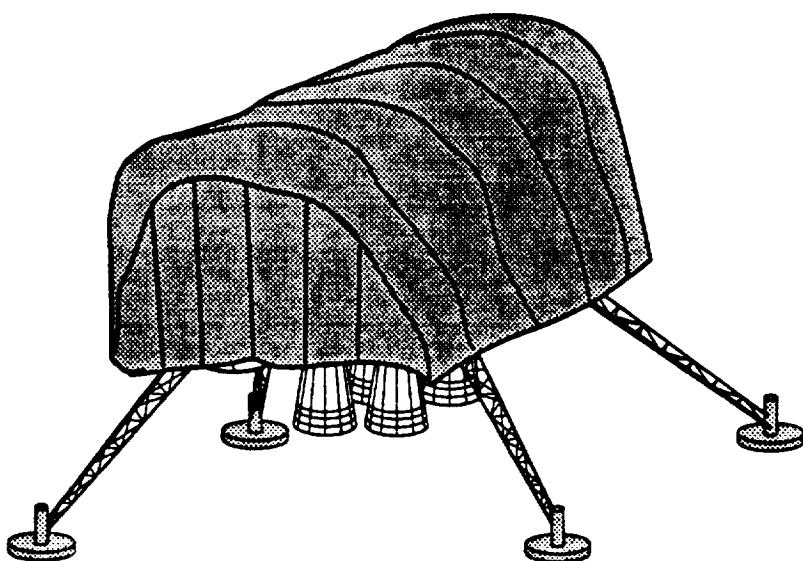
The first job which must be completed in the set-up of the LFO is the initialization of the habitation module. In order to do this, the lunar crane must be activated first. Since the foreman and the other robots will not be active during their flight from the earth to the lunar site, the crane will be teleoperated by crewmembers from the lunar nearside base.

The first task is to bring the crane down from the lunar lander platform. This will be accomplished by having the crane lower itself (through teleoperation) down a light weight ramp connected to the lander. This concept is shown schematically in Figure 6.8. The crane will use its robot arm to push the crane to the ramp while the tag lines of the crane control the descent down the ramp. After reaching the surface of the moon, the crane will disengage the tag lines from the lander and await the arrival of an LCUV.

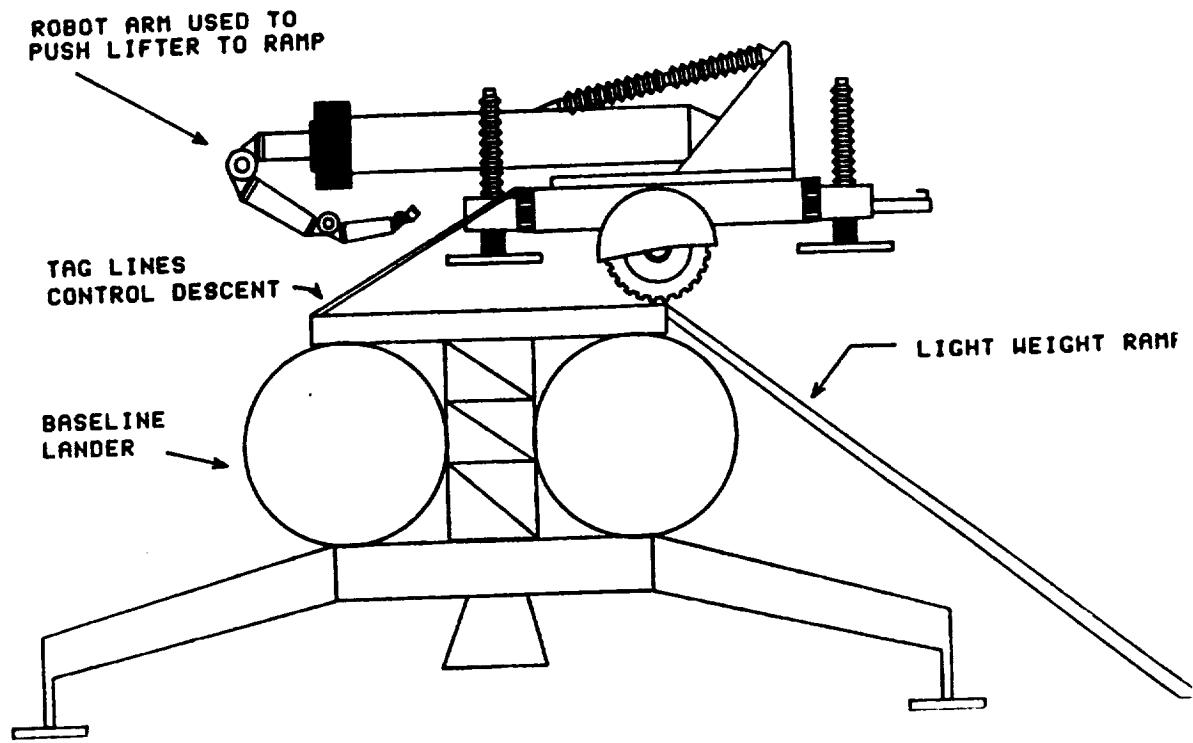
The LCUVs will reach the lunar surface using a similar ramp as the lunar crane. The LCUVs will place the foreman on the lunar surface, ensure that its placement is stable and safe. After receiving a signal from the nearside base, the foreman will activate and take over control of the construction of the farside observatory.



**Figure 6.6 Protective Blanket in Stored Configuration [38]**

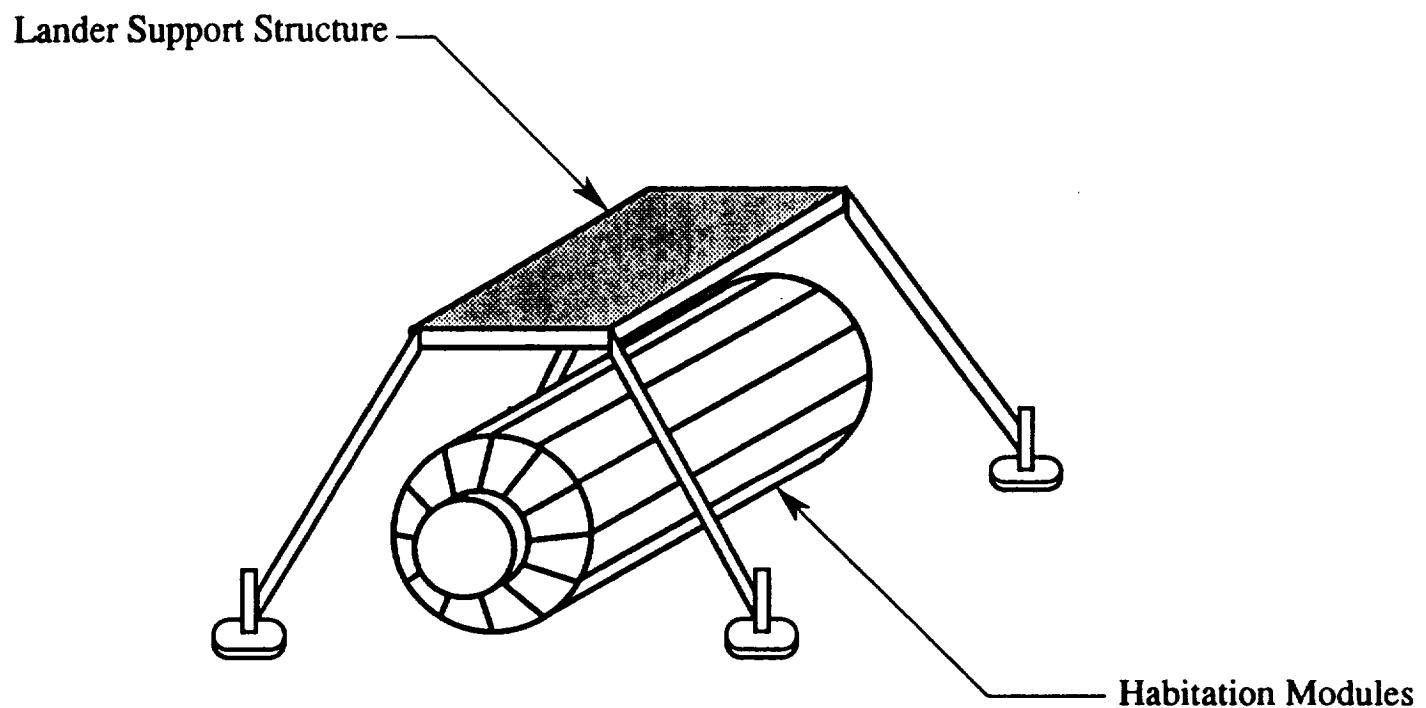


**Figure 6.7 Protective Blanket in Deployed Configuration [38]**

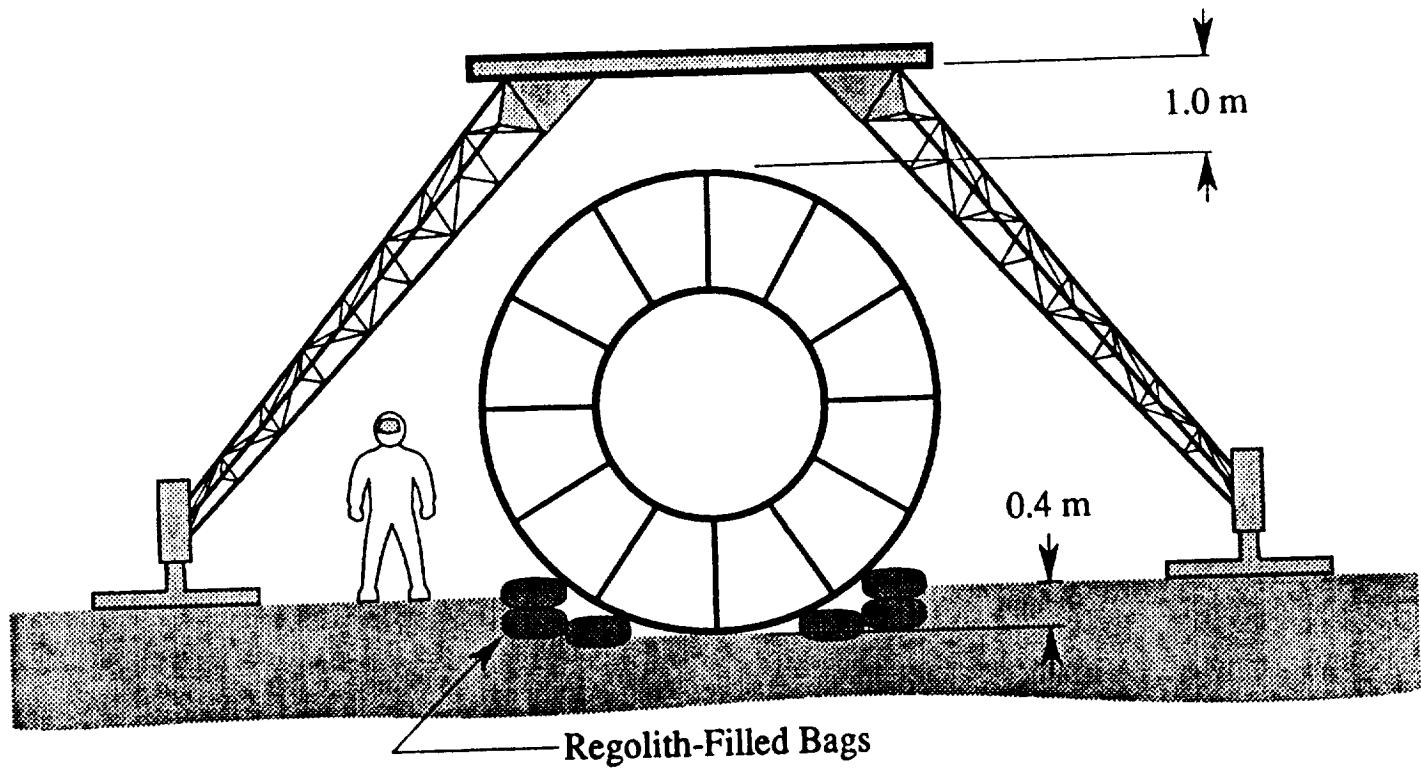


**Figure 6.8** Crane Deployment from Lunar Lander

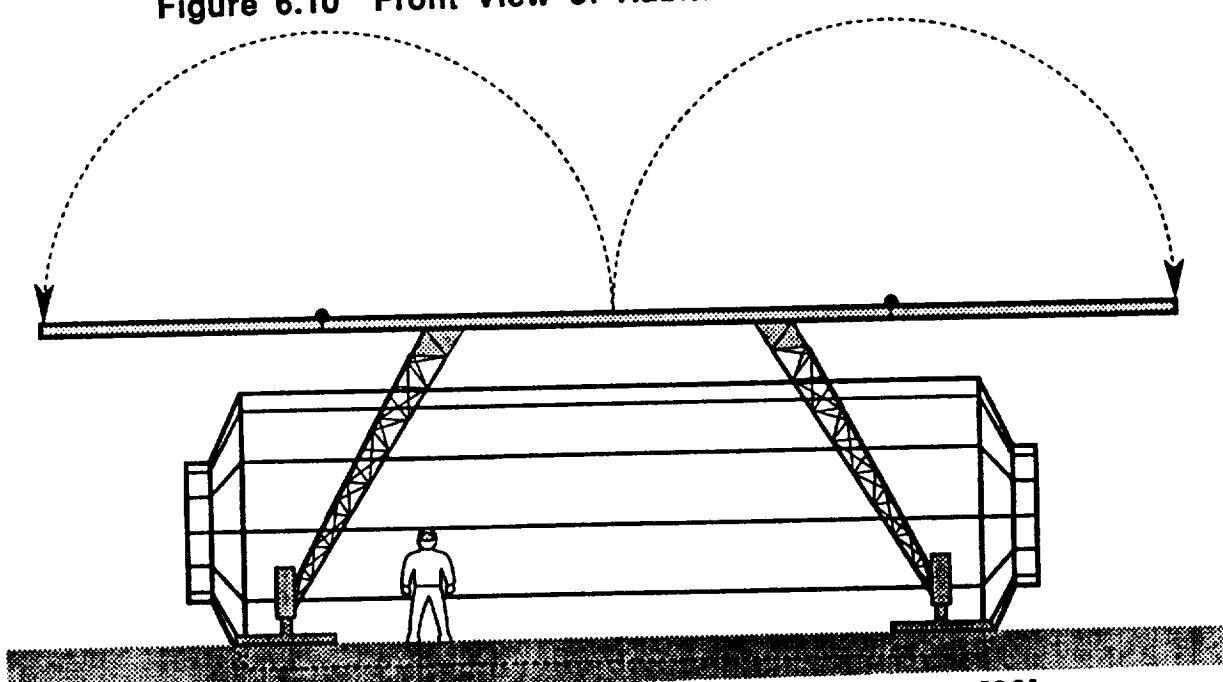
An LCUV will connect itself to the lunar crane and tow it to the lander containing the habitation module. The LCUV will instruct the crane to lift the module using its cable and hook lifting mechanism. Should any instability arise due to the lifting of the module, the crane's robot arm will be used to stabilize the module. The LCUV will then tell the crane to place the module down on the lunar surface. After placing the module down, the robots will begin the task of disassembling the lander which the module came down on. The lander support structure will then be placed over the module as shown in Figures 6.9 and 6.10; this structure will support the regolith covering which will be used for radiation protection. The lander's platform can be unfolded to extend the coverage of the module as shown in Figure 6.11.



**Figure 6.9 Isometric View of Lander/Habitation Structure [26]**

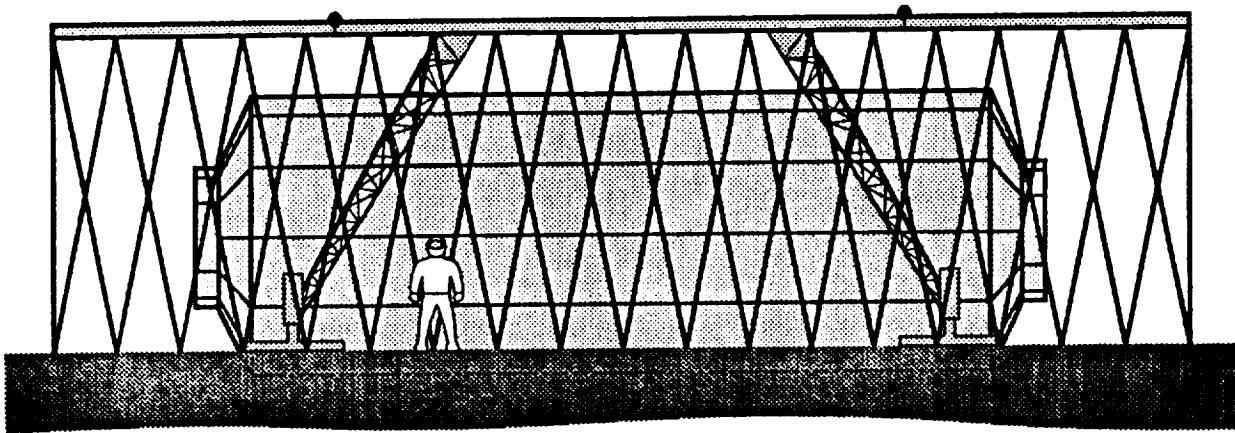


**Figure 6.10** Front View of Habitation Structure [26]

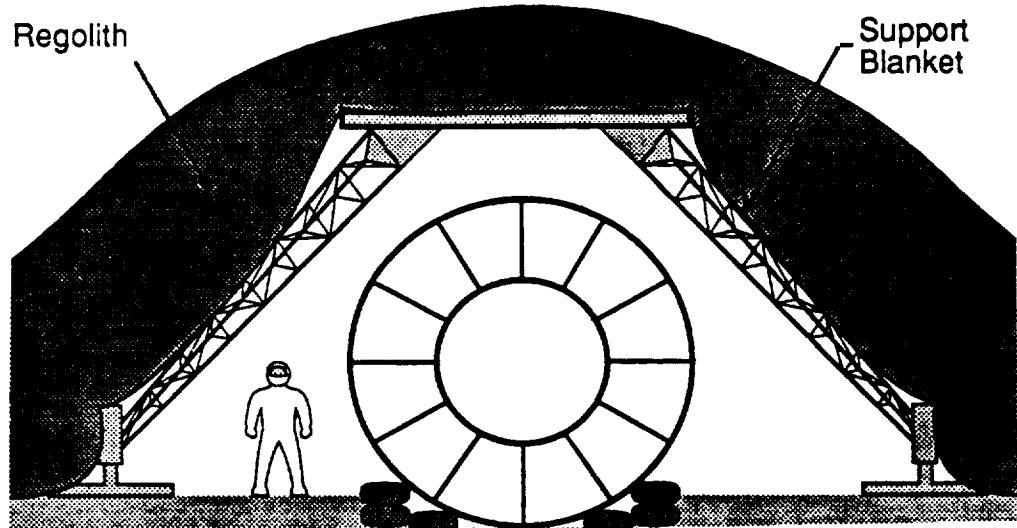


**Figure 6.11** Side View of Habitation Structure [26]

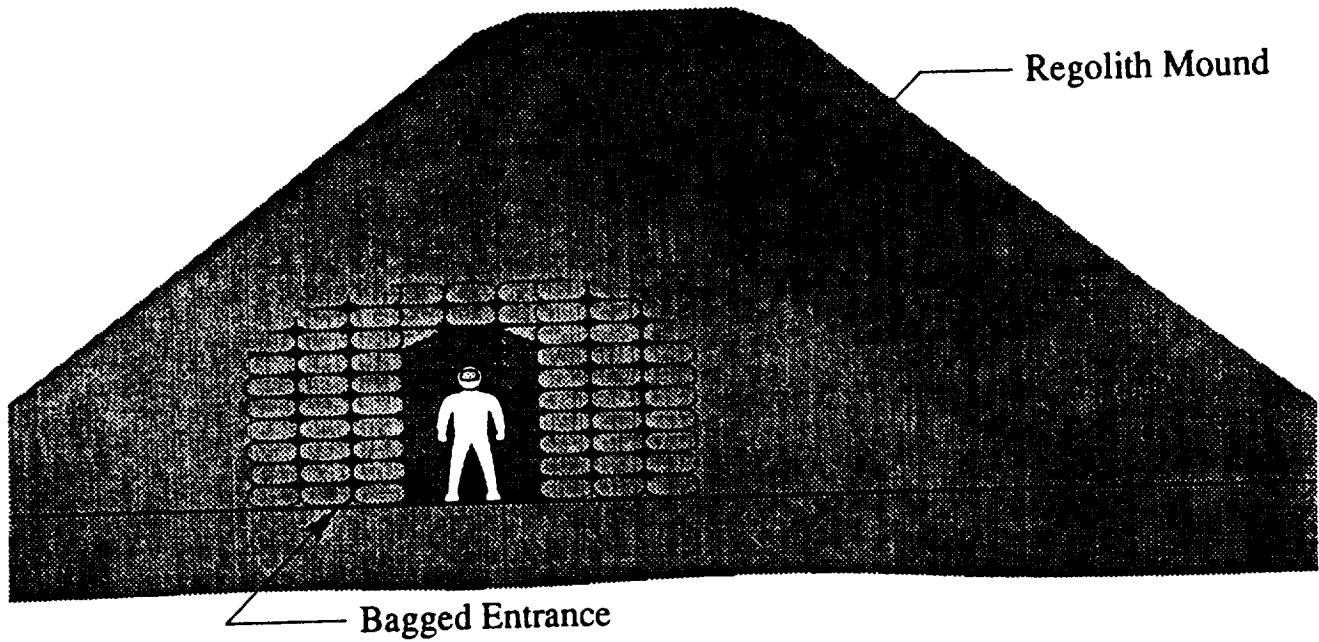
After placement of the lander support structure over the module is complete, a folding lattice will be deployed over the support structure as shown in Figure 6.12. This lattice will help support the thermal and micrometeorite blanket which will be placed over the lander support structure. The micrometeorite blanket in turn will support the lunar regolith which will be place on top of it; this concept is shown in Figure 6.13. Finally, after the shelter is covered with regolith, a bagged entrance will be constructed to permit easy access to and from the lunar surface. Figure 6.14 shows the completed habitation shelter.



**Figure 6.12 Deployed Lattice Structure [26]**



**Figure 6.13 Buried Habitation Module [38]**



**Figure 6.14 Completed Habitation Shelter [26]**

#### **6.2.4.3 Other Construction Tasks**

After completing the habitation shelter, the robots will then turn their attention to setting up other aspects of the LFO. These include set-up and initialization of the SP-100 nuclear reactor, construction of the Very Large Baseline Array (VLBA), setting up the optical telescope, setting up the secondary communication system, and other tasks necessary before astronauts can be brought to the observatory.

## **7.0 Recommendations for Further Study**

The following areas are recommended by the OUTLOOK Design Team for future study:

- The interface of the Lunar Farside Observatory with the nearside base must be investigated to determine the most efficient way to support the operations on the lunar farside and minimize the launches required from Earth. Servicing missions, crew rotation, resupply, and future construction operations could be performed by personnel stationed at the nearside base.
- The materials to construct the equipment must be studied to find the necessary combination of minimum weight, high strength, and resistance to the harsh lunar environment. Ease of repairability must also be considered.
- The study of assigning robotic and human tasks should be expanded as robotic capabilities increase with technology. Human EVA must be kept to a minimum, while still allowing the observatory to be constructed within a reasonable timeframe.
- A system to manage the vast amount of data which would be generated by the observatory must be developed. Such a system should have the capability to provide local data compression and analysis, as well as the ability to send the data to Earth.
- The design of a communications satellite or platform to be stationed at L5 must be investigated. Due to the limited lifetime of any satellite, a communications system must be expandable to survive for the entire lifetime of the observatory.
- The use of the observatory to replace or augment future missions such as the Mars Explorer should be considered. The quality and accuracy of the information expected to be obtained by the farside equipment could make the sending of a probe to the other planets unnecessary.

## **8.0 Management Report**

The following section describes the management status of OUTLOOK and the responsibilities of each group. The task scheduling for the project is also presented.

### **8.1 Management Structure**

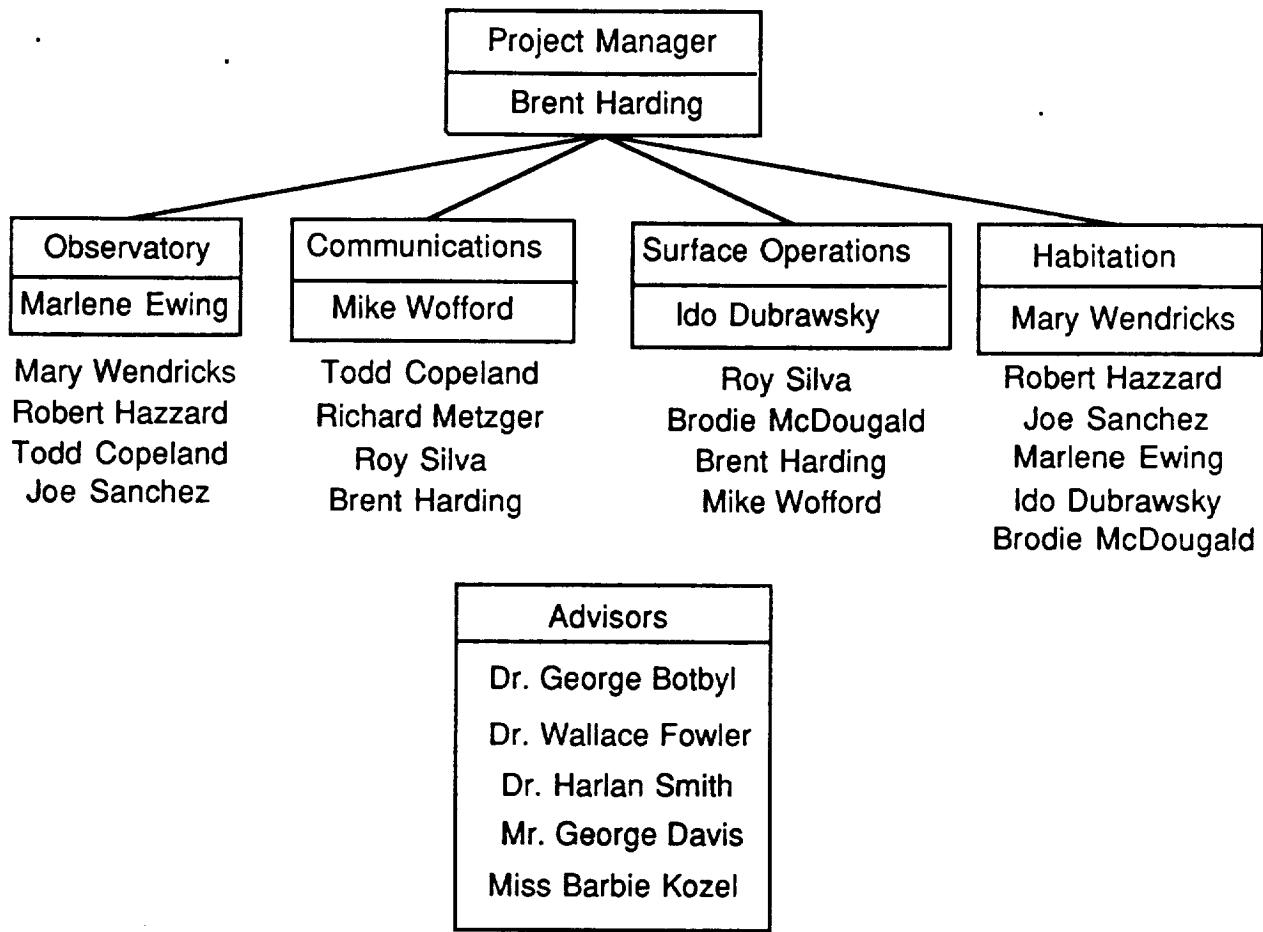
OUTLOOK Design Team management structure is depicted in Figure 8.1. The program manager oversees administrative and planning functions. The four group managers are responsible for assuring that research and design requirements are completed. The managers also report all problems encountered by engineers in their groups to the appropriate team members. Each member is involved in two technical groups to provide better communication between areas.

### **8.2 Group Descriptions**

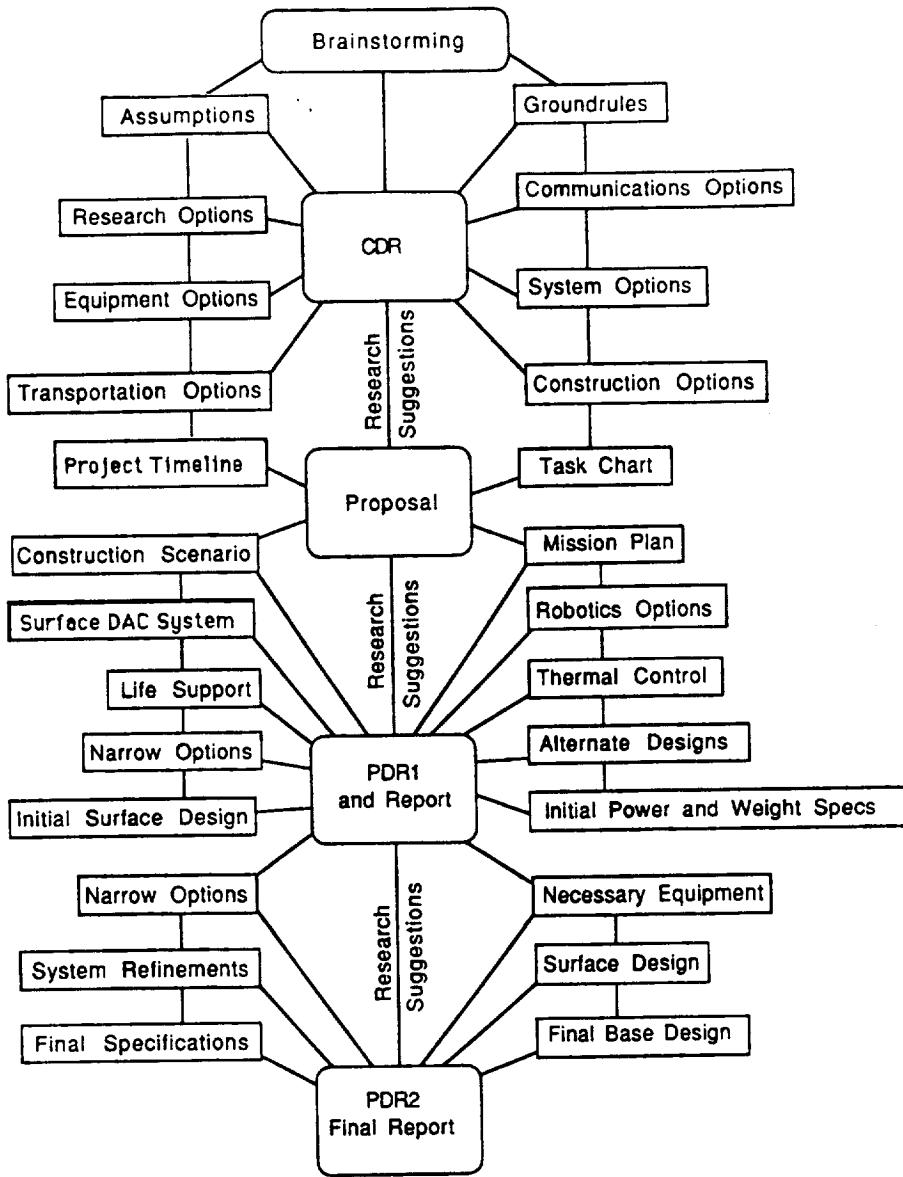
Each of the four technical groups is responsible for a separate aspect of the lunar farside base design. The Surface Operations group is responsible for astronomy equipment, surface systems, shielding of equipment, and surface and launch vehicle requirements. The Construction group is devising a base construction scenario. Human habitation requirements are the responsibility of the human factors group. Due to the importance of communication to the farside project, a group has split away from the Surface Operations group, to form the Communications group.

### **8.3 Task Scheduling**

Critical design paths for completion of the lunar farside base on schedule are depicted in Figure 8.2.



**Figure 8.1 OUTLOOK Management Structure**



**Figure 8.2 Critical Task Scheduling for Meeting Project Milestones**

#### 8.4 Personal Profiles of the OUTLOOK Design Team

The following section provides brief descriptions of each member of the OUTLOOK Design Team, including the areas each worked on throughout the project, individual interests, and future plans.

<b>Team Member</b>	<b>Areas of Work</b>	<b>Interests</b>	<b>Future Plans</b>
Todd Copeland	Communications	Guidance, Navigation, & Control	Air Force Pilot
Ido Dubrawsky	Surface Ops Habitation	Fluid Mechanics	Graduate School for PhD
Marlene Ewing	Scientific Equipment	Orbital Mechanics	Achieve a M.S.in Orbital Mechanics
Brent Harding	Project Manager	Trajectory Analysis	Work for a NASA Subcontractor
Robert Hazzard	Power, ECLSS	Aeronautics	Work for GD and get an MBA
Brodie McDougald	Robotics, Construction	Aerospace Engineering	Attend UT after high school
Richard Metzger	Communications	Comm. System Design	Enter Navy
Joe Sanchez	Habitation, Radiation	Space, atmos. Flight	Work for an Engineering firm
Roy Silva	Transportation	Space Operations	Navy Nuclear Power Program
Mary Wendricks	Thermal Control, Support Facilities	Guidance, Navigation & Control	Work on design of GNC Systems
Mike Wofford	Communications	Orbital Mechanics	Work for an Engineering firm

July 25, 1990:

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funding information.

  
PHILIP N. FRENCH  
Document Evaluator

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**Appendix A**

**Sketches of Earth-Based Observation Equipment**



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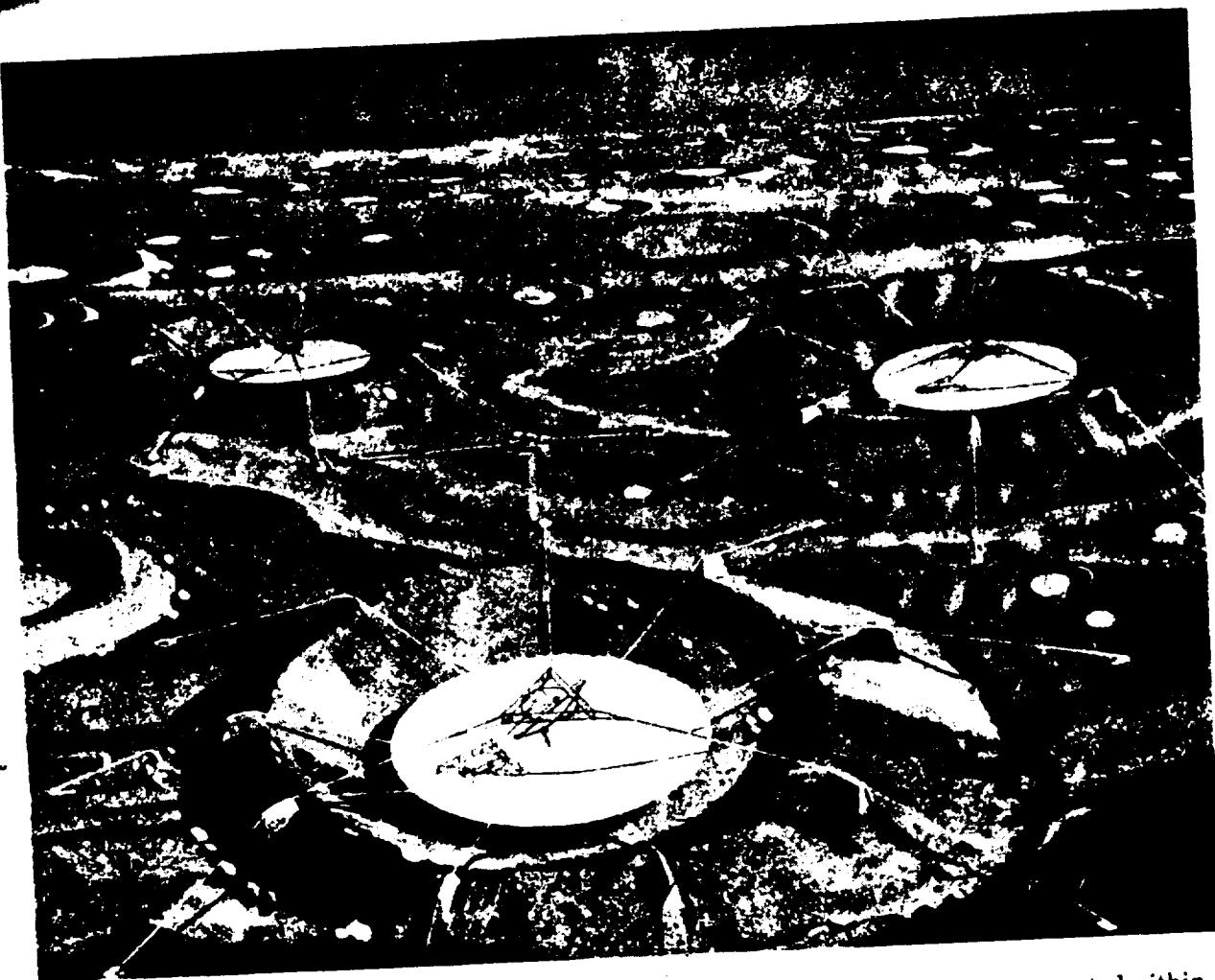
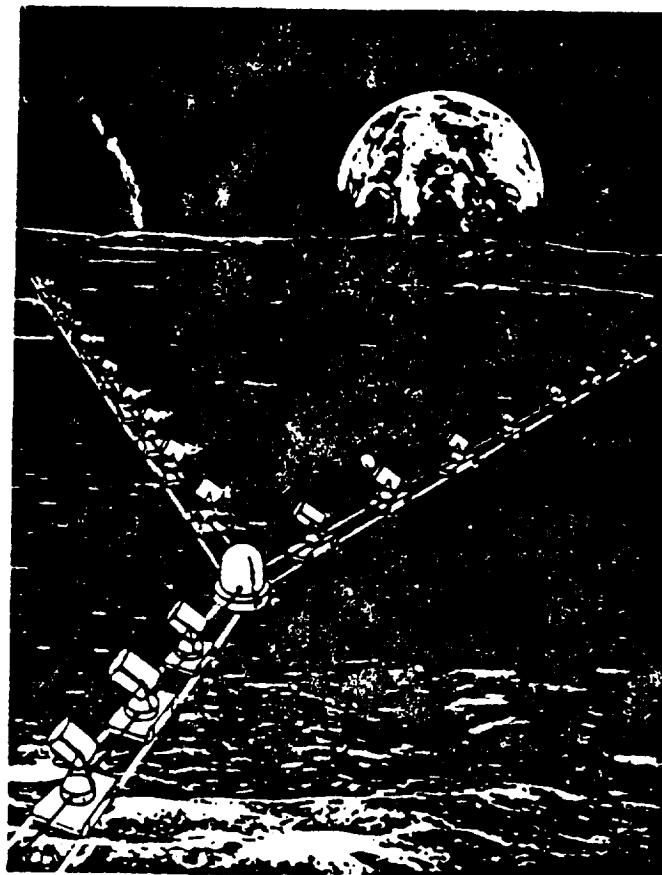


Figure 3 - Artist's concept of an array of three Arecibo-type spherical antennas constructed within natural craters on the far side of the Moon.



**Figure 3.-** Schematic view of an optical aperture-synthesis array on the Moon. The individual elements could assume forms very different from the versions shown.

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