2.0 DESIGN ISSUES AND REQUIREMENTS

2.1 SITE SELECTION AND SITE PLANNING REQUIREMENTS

The site for any future lunar base will be chosen in response to two considerations. The most important requirement is that the site support scientific research. Local minerals, optimal location for telescopes and communication systems will support scientific placement. It is assumed that precursor missions will have investigated the surface of the Moon, aided in locating the optimal site, and use past Apollo missions to further determine the First Lunar Outpost (FLO) location. The second consideration is that a predesigned base configuration can be successfully implemented. We will need to be familiar with the local topography and use that knowledge to either deliver existing equipment to the surface, or design machinery that will respond to the exceptional environmental conditions. Construction methodology will follow a similar pathway.

There will be four major elements to the base: the solar panel collection fields, nuclear power facility, the habitat, and the launch and landing site. Permanent landing pads should be located between 3 and 5 km from the habitation zone, and no further than 5 km away from FLO. The base should have a north-south axis, the habitat centrally located within this axis, with the power and landing areas on opposite ends of the axis. This will allow a protective envelope for the habitat guarding against spacecraft fly-over and potential hazard. The nuclear power facility should be located 1 km from the habitat, accessible by road along the axis. This allows for a measure of safety while limiting the distance current must travel. The solar fields should be located where little exploration is expected, limiting dust contamination. Future field operations and lunar scenery should be taken into consideration.

2.2 FIRST LUNAR OUTPOST REQUIREMENTS

According to the latest NASA thinking and requirements (Carpenter, 1992; Perkinson, Adams, et al., 1992), FLO will consist of the following components:
- lander
- crew module or habitat
- astronomy telescopes
- in-situ resource utilization demonstration unit
- additional cargo landers/research laboratories
- integral rovers
- furnishings and equipment

The lander, crew module, and return stage should remain functional for return to Earth from the Moon. The requirements for each of these components will be covered briefly in the following sections.

2.2.1 LANDER

The lander should provide the capability to deliver 5 mt (E) of cargo and a nominal crew of four from lunar transfer orbit to the lunar surface. This is an estimate of the resupply and science equipment mass needed to support the nominal mission specified for revisit to an established lunar outpost.

2.2.2 CREW MODULE OR HABITAT

The crew module should be able to be depressurized while the crew is living in the surface habitat. Given a limited number or repressurizations, the requirement to provide ingress/egress between the piloted crew module and the lander is best met by depressurizing the entire crew module rather than providing an airlock. The current NASA working assumption is that it is cheaper to require the return vehicle to remain functional when depressurized than to repressurize the crew module following egress.

General requirements for the crew module/habitat include the following:
- the architecture should be configured to accommodate evolution of the outpost, e.g., potential additional volumes include airlocks, logistics containers, other habitats, etc.; growth should accommodate spatial adjacency between similar activity centers and not jeopardize crew well-being
- the architecture should be designed for simple interfaces, modularity, and replacement; this modularity should provide quick disconnect for hardware and electrical equipment
- the habitation volume should allow future integration of an additional pressurized volume to provide for outpost expansion
- to overcome the stresses induced by the mission environment, "mental health is preserved by providing: appropriate design, appropriate crew selection, training, and psychological support"
- the concepts for the habitat should not be limited to currently available or designed hardware, and should include options utilizing pressure-stabilized structures
- internal access to the pressure shell of the habitat shall be provided within 30 minutes of a warning, to allow sealing of leaks, rerouting of wiring, removal of dust, etc.
- the architectural layout should insure that adjacent volumes are set aside for similar or compatible activities and that interfering activities be separated, e.g., compatible activities such as hygiene and waste management functions can be adjacent, while interfering activities such as food preparation and waste management should be separated
- the architecture should provide a marked emergency route for contingency operations
- the habitat should support internal operations by space-suited crewmembers, e.g., emergency cases will require suited crewmembers to operate inside habitable elements
- the architecture should accommodate unimpeded translation and circulation paths within the habitat; traffic paths should be sized according to activities, location of crew stations, and size of cargo/crew; a range of scenarios focusing on the equipment size and crew moving through the habitat need to be addressed
- the intra-vehicular activity (IVA) architecture of the habitat shall provide a minimum of 10.0 cubic meters of habitable volume per crewmember (by habitable volume is meant free volume that the crew can access for working, sleeping, eating, personal hygiene, recreation, exercise, etc.)
- external viewing shall be provided for the crew; windows or video are essential for crew use in observing their external environment
- the architecture should provide multipurpose/flexible activity centers and volumes; multipurpose utilization will increase the efficiency of the habitat, e.g., the wardroom can fold away to create an open area for exercise equipment
- the architecture should provide a consistent orientation throughout the habitat, to provide a familiar and comfortable living and working environment for the crew
- the habitat shall provide two independent paths for crew egress; in the event of fire or other emergency which may block crew access to the airlock, an emergency exit (hatch) must be provided for crew egress

2.2.2.1 Airlock

Airlocks function as a dust-off, pressurization, and ingress/egress point for the crew to transfer between the lunar surface and the habitat. While crew ingress/egress is the primary function of the airlock, lunar dust is both very fine and abrasive, potentially causing medical problems for the crew and impairing the operations of habitation systems, and must be removed before entry. Specific requirements include the following:

- the airlock must isolate the two environments: EVA and IVA
- the airlock shall provide transitions between pressurized and unpressurized environments
- the airlock also provides a space for dust and contamination clean-up before entering the habitat; a method for removing dust from the airlock shall also be provided
- the airlock shall also provide the capability for cargo ingress and egress for retrofitting, resupply, maintenance, or repair, e.g., habitat laboratory equipment, consumables, sample containers, maintenance equipment, EVA suits, and logistic replacement units
- the airlock shall provide the capability to accommodate ingress/egress of an injured crewmember wearing a spacesuit, i.e., a hatch size no less than 2 m vertical by 1 m horizontal for a vertically-mounted hatch, or 1.4 m by 1.4 m for a hatch mounted 45 degrees from horizontal
- the airlock should have sufficient room for two crewmembers to don/doff suits by themselves or aided by a third crewmember
- all hatches shall be operable from either side by pressure-control valves by a suited crewmember without the use of tools
- the airlock should be able to function as a hyperbaric chamber with sufficient high-pressure oxygen and nitrogen bottles
2.2.2.2 Safe Haven

A “safe haven” is a desirable into which to retreat in case of a fire or other hazard. The use of an airlock is possible, but has not yet been fully evaluated by NASA (D. Perkinson in Carpenter, 1992).

2.2.2.3 Command and Communications Center

There shall be a centralized command and communications center to serve as a Base Command Center and as the Earth Communications Center.

2.2.2.4 Mission Operations Workstations

At the present time (Carpenter, 1992), it is expected that the primary mission operations for a First Lunar Outpost will consist of four research functions:

- space physics
- engineering research
- life sciences
- geosciences

In all phases of the mission, the crew will be interacting with various workstations. Designing these stations around crew capability maximizes productivity (Brown & Bond in Carpenter, 1992). Crew size, and therefore viewpoint, reach, and restraint should be considered. The gravity environment, required visual data, room to use tools and equipment, and location of task should be considered to maximize crew capability.

2.2.2.5 Health Maintenance Facility

Capability for emergency surgery and critical care shall be provided at the lunar outpost, including evaluation and treatment of significant, normally survivable injury and illness including dental care with standard immediate and ongoing care (cf. Brown/Waligora v Petri in Carpenter, 1992). The Health Maintenance Facility shall provide space for clinical medical procedures and storage of clinical medical equipment and supplies. The habitat shall also provide the capability to monitor crew health and physical conditioning.

2.2.2.6 Exercise Facility

Programmed exercise on exercise devices shall be provided as a countermeasure to loss of muscle mass and as a possible countermeasure against loss of bone mass and other physiological consequences of reduced gravity.

2.2.2.7 Galley/Wardroom

The galley/wardroom will serve for all eating, meetings, and passive recreation. The following requirements apply:

- capability to store food, including environmental control (e.g., refrigerator and/or freezer), for 4 crewmembers for 45 day stays
- capability to provide warm food products, the type of heating to be dependent on gravity environment, cabin pressure, and food packaging material

2.2.2.8 Sleeping Quarters

The habitat element shall provide crew sleeping accommodations to maintain the health, safety, and productivity of the crew.

2.2.2.9 Personal Hygiene Facility

The capability for personal hygiene shall be provided to the crew for improved productivity, prevention of skin diseases, reduction of transmission of harmful microorganisms, removal of debris, and control of body odor. This facility should provide for hair grooming, skin care, body deodorizing, nail care, brushing teeth, and hair removal, including cleaning the body post-urination/defecation, post-exercise, during medical/health maintenance, pre/post meals, and pre/post experimentation or other work requiring specialized washing. At a minimum, this should include a toilet and lavatory (the provision for a shower for 4 crew, 45-day missions is being debated; cf. Petri v Brown/Bond in Carpenter, 1992).

2.2.2.10 Trash Management Facility

Other habitat hygiene includes housekeeping activities which include dust removal, clean-up following meals, and waste management/disposal.
A method and space shall be provided for preparing trash for disposal by packaging, compaction, and/or recycling. It is estimated that a 4-person crew for a 45-day stay will consume over a ton (English) of matter (ca. 25 cu m) per 45 days, all of which becomes trash except for small quantities of water and carbon dioxide (Perkinson in Carpenter, 1992). This volume cannot remain inside any habitat and so must be disposed of or recycled in some way, such as being used for radiation shielding.

2.2.2.11 Logistics-Stowage Area

Consumables (oxygen, nitrogen, water, food, refrigerated/frozen food, etc.) and equipment (suits, tools, filter, scientific equipment, spare parts, seals, etc.) required to support lunar surface activities and the crew during a nominal lunar surface mission must be able to be stored and replenished.

Storage must also be provided for 200 kg of geologic and biomedical samples (including containers) for transfer to the crew module and return to Earth, including space to package and pack these samples.

An organized and accessible stowage system shall be provided that accommodated stowage of all look equipment including scientific instruments assigned to the mission. Such a stowage system shall include well-defined and logically packed system of lockers, drawers, trays and appropriate retention and packaging accommodations. Stowage volumes shall be standardized and modular throughout the habitat to accommodate logistics resupply of items and packages of various sizes and shapes. Such a system shall withstand environments from micro-g to hyper-g.

2.2.3 Astronomy Telescopes

At the present time (Carpenter, 1992), it is expected that the total FLO environment will include three astronomy telescopes for space physics and astronomy situated sufficiently far from FLO to be protected from launch/landing blast-off and debris and yet close enough for EVA deployment and operation.

A Lunar Ultraviolet Transit Telescope (LUTT) will have an approximate mass of 200 kg, require an approximate power of 100 watts, occupy an approximate packed volume of 2.7 cu m, and have an approximate data transmission rate of 200 kilobits per second (Eppler in Carpenter, 1992).

A Small Research Telescope (SRT) will have an approximate mass of 200 kg, require an approximate power of 500 watts, will occupy an approximate packed volume of 2.5 cu m, and have an approximate data transmission rate of 100 kilobits per second (Eppler in Carpenter, 1992).

A Small Solar Telescope (SST) will have an approximate mass of 100 kg, require an approximate power of 50 watts, will occupy an approximate packed volume of 1 cu m, and have an approximate data transmission rate of 256 megabits per second (Eppler in Carpenter, 1992).

2.2.4 In-Situ Resource Utilization Demonstration Unit

To conduct in-situ resource utilization (ISRU) surface operations, an ISRU demonstration unit will be deployed and set up by a two-person crew to a position near the side of the habitat within power cord reach of a power connection to the habitat. It will require active participation by the crew to load samples and recover materials more convenient to the crew and eliminates the need for an additional power supply.

The geosciences research function shall support this unit by delineating lunar resources local to the outpost, operating the resource utilization projects, and test the use of space resource utilization products.

The ISRU demo package will have an approximate 750 kg, require an approximate peak power of 2900 watts, and occupy an approximate packed volume of 0.6 cu m (Eppler in Carpenter, 1992).

2.2.5 Additional Cargo Landers/Pressurized Research Laboratories

Provision should be made to unload rovers and science payloads from additional cargo landers on the lunar surface, and to reuse the landers as pressurized research laboratories. Present thinking (Carpenter, 1992) is that in addition to the astronomy telescopes and ISRU demonstration unit there will be three pressurized remote laboratories in proximity to the lander/habitat:

- engineering research laboratory - for engineering tests on the lunar surface, evaluation of subsystems and prototypes of future equipment, and demonstration of prototypes for future lunar surface processes
• life sciences laboratory - for life sciences research on the lunar surface including acquisition of samples, for IVA life sciences research relating to human parameters including the monitoring of human performance and biomedical parameters, and for operating experiments in human physiology, exobiology, and gravitational biology

• geosciences laboratory - for initiating and conducting environmental characterization and regional exploration of the lunar surface, monitoring geophysical activity (including remote monitors of an approximate mass of 216 kg and approximate packed volume of 0.5 cu m and other geologic field equipment of approximate mass of 336 kg and approximate packed volume of 1.8 cu m), support a team of two astronauts for geologic and geophysical EVAs, space for geoscience instruments and analysis including basic composition and description of lunar materials, sample identification, and sorting (ca. 200 kg for return to Earth)

2.2.6 FURNISHINGS AND EQUIPMENT: GENERAL HUMAN FACTORS REQUIREMENTS

• all equipment shall accommodate crew size and reach, including visual cones and eye points, switch positions, and reach envelopes for 5% American female to 95% American male

• items shall be stowed adjacent/near the area where they are to be used

• IVA furnishings shall be reconfigurable for temporary stowage when not in use (e.g., wardroom seating and table when not in use to provide a larger volume for other uses, e.g., for exercise)

• IVA furnishings shall be reconfigurable to accommodate a range a crew sizes (e.g., partial gravity seats should have seat height, angle, etc. adjustments just like a 1-g chair)

• IVA furnishings shall be provided that optimize partial-g human postures (predicted to be somewhere between 1-g and 0-g normal postures; Carpenter, 1992)

• living and working furnishings such as sitting, sleeping, working, and eating accommodations shall be provided, with consideration given to the partial-g aspect of each item - trade studies shall insure that partial-g implications for each such device have been addressed in its design

• the crew module shall provide crew couches to support the crew during prelaunch, launch, partial-g, and hyper-g phases

• the IVA architecture shall provide a location coding system that is consistent throughout the crew module

• The IVA architecture shall provide translation non-slip surfaces with a friction co-efficient of 1 or better (Brown/Bond in Carpenter, 1992)

• lighting levels shall be tailored for designated operation to allow either direct visual viewing by crew members or indirect viewing by monitoring devices such as cameras

• the IVA architecture shall provide mobility aids and restraints/ handholds within the habitat (preliminary observations from lunar partial-g testing (cf. Brown/Bond in Carpenter, 1992) indicate that translation devices may be required; the control or lack of control during translation may be dependent on physiological degradation, mission workload, nutrition, rest, and sleep; trade studies of prolonged exposure to partial gravity and its effects on human performance require further examination; for example, access to ceiling compartments may be easy at the beginning of a mission, but as the body adapts or degrades to partial-g, crew members may require a stool or platform to access overhead stowage; similarly reaction aids may be required if sufficient force cannot be generated to move or open objects in the partial-g environment (Brown/Bond in Carpenter, 1992)

2.3 INITIAL OPERATING CONFIGURATION DESIGN REQUIREMENTS

Spatial and volumetric requirements for functions within the lunar habitat should be based upon a variety of factors. For example, critical will be the weight at liftoff. Those restrictions are then applied resulting in space allotted for science and experimentation, crew support and housing, maintenance and logistics. These should reflect habitability and behavioral issues related to the human response to isolation and confinement: sleep, exercise, medical support, personal hygiene, food preparation, group interaction, habitat aesthetics, communications, recreation, privacy and personal space, and waste disposal and management (Stuster, 1987). Mission directives will streamline the technical necessities, further sophisticating the profile of the base concept.
2.3.1 Quantitative Spatial Requirements for All Functional Areas

The commencement point for the determination of appropriate volumetric sizing is the human form. Architectural Graphic Standards (Ramsey & Sheper, 1989) directs the use of 97th percentile values to determine space envelopes, 2.5 percentile values for the maximum "kinetospheres" (reach areas by hand or foot) and the 50th percentile values for control and display heights. This numerical data must then be augmented by the change in body alignment resulting from the gravitational delta. This is adjusted to reflect unusual requirements in the body envelope as a result of necessary attire, e.g., translation in corridors with a crewmember fully space-suited. The body envelope dimensioning can be applied to each specified function within the habitat. Final sizing requirements and recommendations can then be evaluated against other sets of recommendations.

It should be noted that there is a lack of hard empirical data to support the recommendations of the suggested volumetrics at this point in time. These values are suggestions that will be altered and augmented as the time approaches to commence the construction of the lunar base.

2.3.2 Design Requirements for All Functions and Activities

2.3.2.1 Research Activities

Any science-related discipline requires research laboratories. This portion of the lunar base should be designed for a 24-hour per day mission schedule. There should be adequate circulation within and amongst the laboratory workstations. The science area must address not only physical, but human sciences as well.

Every laboratory on Earth has its own specific set of requirements for equipment, method of examination and testing, sample stowage and retrieval, and communication and delivery of physical experiments to outside locations. To design one generic laboratory suitable for all disciplines is not practical. As the space community determines which of the scientific areas will be included in future lunar bases, specific sets of requirements will be drawn. Certain functional spaces that serve all labs can be determined and included now:

- stowage
- easy accessibility to all equipment
- furnishings responding to 1/6-g anthropometrics
- functional circulation pattern
- acoustic control and abatement
- ventilation
- water supply

The following are a sampling of the suggested areas of research that have been considered for future use: microbiology — a subdivision of biological research that addresses the research of microscopic forms of life; life sciences — to study the physiological effects of reduced gravity and the psychological implications of isolated and confined living; health maintenance — a medical facility to monitor and attend to the physical condition of each crewmember; physical sciences — studies will be conducted in nonliving materials; geomorphology — investigation of the surface and subterranean relief features of the Moon, then interpreting the features genetically; botany and plant growth — a subset of biology, this area examines the potential of growing plants in new environments; telerobotics — this research will focus on using robotics to aid in surface operations, alleviating unnecessary EVA time for the crewmembers.

2.3.2.2 Command and Communications

The general requirements needed to be met for command and communications are the following:

- ability to operate all vital function on the lunar base
- backup systems available
- manual override available
- interconnection to all other base terminals
- communications access
- compatible to other systems

By meeting these general requirements, command and communications will not only serve as the main control area, but also function to serve other needs of the crewmembers within the lunar base.
2.3.2.3 Crew Functions

Crew quarters are essential in providing the crew privacy, a place for retreat, and additional personalization necessities. The quarters must be equipped with a hygiene facility and sleeping quarters to accommodate 12 crewmembers. The goal is to provide a comfortable and functional atmosphere while addressing both lunar and Earth requirements:

- crew quarters should include a horizontal sleeping space
- should provide an area for face, hand, eye and body wash
- provide controls for communications and caution/warning system
- should provide a personal work space
- provide stowage for personal belongings
- should utilize hand holds for translation

2.3.2.4 Crew Support Activities

- shower and full body cleansing
- mirror
- stowage for general supplies
- ventilation for humidity control
- adequate volume to allow donning and doffing of clothing, drying off after shower
- lighting system for proper visual acuity for personal hygiene

2.3.2.3.1 Sleeping and Privacy

Single and double crew quarters should consist of full habitat accommodations for each crewmember. Single crew accommodations will provide maximum privacy; double quarters will provide space for two crewmembers. The selection of which crewmembers will occupy the single/double quarters will be based upon the crew selection process, while allowing a crewmember a measure of personal choice. Each quarter, both single and double should contain:

- controls for communications and caution/warning system
- personal work space
- personal stowage compartments
- horizontal sleeping space (bed)
- accessibility to hygiene facility

2.3.2.3.2 Personal Hygiene

The crewmembers will require facilities to accommodate full body cleansing, and should consider waste management as well. Each facility should include:

- hand, face, eye cleansing capability
- toilet

2.3.2.4.1 Eating and Meeting

The wardroom will be promoted as a gathering arena for the crew. The volumetric requirements should contain adequate space for 12 crewmembers to be seated and conduct briefings as well as celebrations. This space should also be conducive to sharing meals. Requirements should include:

- seating for 12 persons
- table accommodating 12, yet can be reconfigured to seat fewer numbers, especially 6 at one time
- communication system for teleconferencing
- lighting to allow for task and general illumination
- materials to permit easy maintenance and cleaning

2.3.2.4.2 Food Preparation

A galley should be provided to function not only as a space for food preparing, but also for stowage of consumables, cleanup post-mealtime, and for waste management. This volume should allow for more than one crewmember to prepare food. Included in the galley should be:

- food stowage compartments
• refrigerator/freezer
• microwave/convection oven
• food preparation equipment
• food consumption utensils
• sink
• trash management container
• cleanup supplies
• material surfaces conducive to easy maintenance
• illumination for tasks and general activity

2.3.2.4.3 Recreation

This area should be dedicated to crew relaxation and communication, not only within the base, but with Earth as well. Many of the activities the crew will perform for relaxation can take advantage of dual-functioning spaces. Included should be:

• audio/visual projection system
• stowage compartments for video or audio tapes, compact discs
• seating for smaller groups of crew members
• seating to accommodate quiet activity e.g., reading
• space reserved for game playing
• space allotted for small group casual conversation
• stowage for hard-copy printed books for leisure

2.3.2.4.4 Exercise Countermeasures

Due to the physical degradation of the human in a lesser gravity field, exercise will be an important portion of the daily routine. To promote the use of exercise equipment and to make the rigors of physical activity a more enjoyable experience, it is suggested that the area dedicated to exercise be closely associated with group gathering:

• space should be allocated to furnish at least two dual-function machines
• machines should be compactable to allow for closure and stowage during nonuse periods

• provide visual stimulation with the use of audio/visual projections, scenic pathways, or Earth-based panoramas
• provide personal hygiene function with limited hygiene facility

2.3.2.4.5 Limited Hygiene Facility

This facility should provide limited functions of quick cleanup post-exercise, and the placement of this facility should be adjacent to the exercise area. Included in the functions should be:

• toilet
• handwashing and facewashing area
• mirror
• stowage compartment for general supplies

2.3.2.4.6 Laundry

The cleaning and maintenance of personal clothing, bedding, etc. may be accomplished pending the invention of a satisfactory method of accomplishing the task in 1/6-g. At present, one particular method has not been defined. The laundry should be adjacent to other functional areas of crew support requiring similar components e.g., water or power. Requirements for a laundry facility should include:

• washer and dryer
• stowage for supplies
• surface for sorting or folding of clothing

2.3.2.5 Ingress and Egress

Airlocks will provide efficient ingress/egress of the habitat. Dust suppression devices will be used to prevent contamination of the habitat and laboratories. It will be necessary for the airlock to have the capacity to dual function.

2.3.2.5.1 EVA/IVA Movement

For the ease of translation from the interior environment of the habitat to the exterior surface of the Moon, the following should be considered:
• use a close surface access point as a safe haven
• permit equipment transfer through the airlock to the habitation area
• entry or exit of the habitat without having to depressurize or reduce the normal internal operating pressure
• provide smaller chamber for complete depressurization
• provide dust-off capability at the entrance to the airlock
• support EVA operations, e.g. tools, equipment stowage, power supply
• allow crew transfer from the lander to the habitation module
• serve as a hyperbaric chamber and contain hyperbaric equipment
• dust exclusion from habitation area from lunar surface operation

2.3.2.5.2 Suit Stowage

Each crewmember will need to have a separate EMU, with the availability to reach that suit quickly in the event of a failure within the habitat. Suits should be stowed as separate pieces, readily accessible for each crewmember. Additional considerations are:

• provide stowage facilities for suits
• provide compartments for additional suit parts, e.g., gloves, visors, and boots

2.3.2.5.3 Suit Maintenance

The EMU will need servicing each time it is used on the surface or in the event of an emergency. To maintain the suit, space must be allocated for repair and cleaning, power regeneration, or replacement of damaged portions. Requirements that should be addressed are:

• work surface to physical handling of the EMU
• supply of power for regeneration of life support system
• stowage or hanging capability for the suit as a unit
• stowage for tools and equipment necessary for maintenance
• illumination provided for task or general activity
• stowage for additional EMU spare parts

2.3.2.5.4 Suit Donning and Doffing

Each crewmember must have physical volume to put on and take off an EMU. The suit is bulky and may require the assistance of a fellow crewmember. Ease of donning is required in the event of an emergency, and the space allotted for this function must permit this activity. Required is:

• sufficient volume for donning and doffing EMU
• hand holds to provide support

2.4 Interior Design Components

2.4.1 Computer System and Workstations

At the heart of the lunar base lies the central processing unit. Without its use, monitoring all the environmental controls and other needed functions would be extremely difficult. The computer must supply all the vital needs for the lunar base, and it must be able to fit into a standard rack or workstation. Computer systems needs to be analyzed to determine what type computer system is to be used. Then the workstation should be designed around the computer system for ease of use and reparability.

2.4.1.1 Computer System

Before a workstation in a lunar base is designed, it is essential to know the physical size of the processing unit, monitors, printers, disk drives, and discrete components which will be used within the workstation design. Determining the size of the computer system requires a knowledge of the internal and external working of the computer. Some of the issues that need to be addressed are:

• information systems
• human factors issues and computers
• functions needed for the lunar base
• additional functions required by the computer system
2.4.1.1 Information Systems

Laudon & Laudon (1991) state the formal definition of information system is the set of components working together to collect, retrieve, process, store, and disseminate information for the purpose of facilitating planning, control, coordination, and decision making. The basic components that make up an information system are the following:

- input
- processing
- output
- feedback

For the lunar base, the following devices should be used to satisfy these needs:

- satellites
- cables
- monitors
- computers
- hard copies such as books, printouts
- voice messages

NASA makes use of satellites to relay information to and from Earth. The space shuttle uses the orbiting Tracking and Data Relay Satellite (TDRS-1 and TDRS-4) and the Data Relay Network controlled ground stations for communications and information relay to and from the shuttle (Internet, Tracking and Data Relay Satellite System). For the lunar base, it will be assumed that a similar system for input and output to the base from Earth will be utilized.

Cables are used on Earth as well as in space to transmit data across a conducting line. For the lunar base, it is important to know which cables will be used for interconnections so it can be determined how much chaseway space is needed for cables. Tanenbaum (1976) states the RS-232-C cables have a standardized 25-pin connector on them, and the RS-232-C standard defines the size and shape of connector and cable. The RS-422 is another cable being utilized for space application. Note that the cable might need shielding to prevent any stray AC signals that may enter the cable.

Monitors visually show the information to be used by the system. To save space and cost, flat-screen technology is used; however, since the flat screen provides more distortion than a cathode-ray tube (CRT), CRTs are used to show data which is needed to vital operations. The shuttle uses 12-inch diagonal CRT screens providing a 22-line display (47 characters per line) in three colors (green, red, yellow). In addition to 128 alphanumeric symbols, the unit can display vector graphics (1024 different lengths and 4096 angles). A high intensity green flashing mode is also provided (Internet, Multifunction CRT Display System). The shuttle type CRTs will more than likely be used on the lunar base, but more research is needed to determine what kind of flat screen monitors are to be used.

The computer is the brain which does the processing of information. Based upon shuttle technology, the AP-101S by IBM was selected for all processing. The AP-101S should satisfy the processing needs of the lunar base because of the success of use in the space shuttle. More research is encouraged for a processing unit due to constant technology changes and upgrades. It should be noted that included with the processing unit would be electronic storage by means of RAM, ROM, and external drives.

Hard copies of data may be provided upon request. Laser printers will jet out information which may be to be examined carefully. Utilizing hard copy, corrections can be made by hand and allow an overview of the data.

Lastly voice messages are relayed by using speakers mounted next to the monitors. A small microphone will be enclosed to pick up the operator's voice and transmit it to other parts of the base. Still experimental, the Voice Command System (VCS) is used to control shuttle television cameras with verbal command (Internet, Voice Command System).

2.4.1.2 Human Factors Issues

Sanders and McCormick (1987) define human factors as focusing on human beings and their interaction with products, equipment, facilities, and environments used in work and everyday living. Some human factors issues that should be dealt with for the computer system are the following:

- speed
- accuracy
- reliability
- compatibility
- size
Although many other human factors or ergonomics issues could be dealt with, the previous mentioned factors are relevant to the cause.

Speed is the response time of the computer versus the time the user wants to process the information. It will be assumed that the user wants the information to be processed as quickly as possible so that he/she may continue other work. Speed may be measured in bits per second, miles per hour or cycles per second. For the computer, hertz and bits per second are the two measures of speed that will be used. Translating this to the computer hardware, the control unit should generate signals fast enough to utilize the bus structure most efficiently and minimize the instruction execution time. Shiva (1991) states the speed of the microprocessor may be enhanced by minimizing the execution time of each instruction or minimizing the execution time of a sequence of instructions. These speed requirements are needed for a fast processor for the lunar base since time may be a matter of life or death.

Accuracy involves the precision to which the calculations have to be made. The more precise the calculations, the more memory and circuitry will be needed to hold significant digits and their calculations. Accuracy may also be applied to how the data actually appears on the computer screen (visual acuity). Accuracy may be measured in terms of bits and/or bytes. It will be assumed that the more bits a computer uses, the greater the amount of information can be processed. For the computer, the ASCII or EBCDIC code is used in which each character is one byte long. Shiva states the maximum length of a character string is a design parameter in a particular machine.

Reliability has much to do with probability and statistics. The computer should be running without failure for an infinite time, without breakdown. Since the study of probability and statistics requires complex mathematics, this topic will not be discussed in detail, but by using machines that have been in existence for several years, the reliability of the machine may be increased. Also, fault checking may be used by the addition of extra hardware. Table 2.4.1.2-1 shows techniques in increasing the reliability of the computer by the concept of redundancy.

When a machine needs to be interfaced to the external world, compatibility becomes an issue. Compatibility refers to the ability for the machine to interact with another machine or a transducer of some type. Most computers can be adapted to fit or synchronize with another computer with the addition of interface cards, a change in pin configurations, or a change within the program itself. For the lunar base, the computer should be able to communicate easily with Earth-based computers and lunar base subsystems.

The physical size of the computer is an issue relevant to allotted space requirements. With the advent of the microchip, the processing units are becoming ever smaller; however, the hardware for the computer to run, including the power supply, will take up physical space. Obviously if the computer system were too small, the crewmember could not input information or read the output from a screen. The size of the computer therefore, will be determined mainly by the components inside, and by the input and output needed by the person. For the lunar base, it will be assumed that the hardware is already available; therefore, this factor will be limited for control due to preexisting parts.

2.4.1.3.3 Needed Functions for a Lunar Base

The computer must be able to handle the following lunar base functions:

- pressure control
- telerobotics
- fire suppression
- communications
- health monitors
- future needs

Since the lunar base is pressurized, it is important for the computer to monitor any pressure changes within the habitat, and make the necessary corrections. Pressure control in space is still in the experimental stages with NASA (Internet, 1993).

Telerobotics will be used to do research work, repairs, and explore the land on the outside of the habitat. The computer and workstation should have provisions for controlling the telerobotics from the inside of the base.

If a fire should break out within the habitat, the computersystem needs to activate a warning system and take the necessary steps to isolate or extinguish the fire. The fire suppression system will contain Freon-1301 extinguisher bottles for the automatic fire suppression, and the hand-held fire extinguishers will contain Halon-1301 (Internet, 1993). Communications will be utilizing a separate screen to observe the person being spoken to, or use television cameras to monitor activities of the robotics. A closed-circuit TV type system will be installed to monitor activities within each.
section of the lunar base. The computer will control the frequencies of communications and what appears on the screen while the interaction is being performed.

Health monitors and related health equipment will be controlled with the central processing unit to insure crew health. Health monitoring equipment would include such items as thermometers, pulse rate machines, diet control machines, exercise monitors, and other necessary equipment to check vital signs. After all the information from a crewmember has been gathered, the computer will process this information, and determine whether the crewmember is healthy.

Lastly, the computer should be able to handle future needs such as expansion of the base or the addition of equipment.

2.4.1.1.4 Additional Functions for a Lunar Base

Additional functions a computer should be equipped to address are the following:

- e-mail
- training
- inventory and management
- caution and warning system
- manual override

E-mail is not a necessity for the system, but it can be utilized to communicate with other users when the communication system may be down. E-mail is simply electronic mail, and it allows the user to type in a message on the computer and send it electronically to another user.

If a crewmember is new to the system, the computer should have a training program installed. This program will teach the basics of the lunar base computer system.

The caution and warning system should contain different types; of sounds and lights to indicate what and where the problem is. Three colors of light, red, yellow and green, are suggested to be used for the base, placed next to doors or protruding from walls to indicate the malfunction. The caution and warning system would advise the user to take the necessary steps to correct the problem and contact an Earth-based station automatically.

If the computer system should fail completely, there should be a manual override for each necessary function. The manual override panel would contain discrete components needed to operate the base until the computer system was repaired.

2.4.1.2 Workstations

To design a workstation, the components that will be placed on the workstation must be analyzed. The workstation can then be designed around the components and made so that a crewmember can easily perform his/her necessary tasks. Some of the issues which will be analyzed for the design include:

- workstation function
- workstation ergonomics
- the purpose
- location of workstation controls

2.4.1.2.1 Purpose

For the lunar base design, four basic workstation design must be analyzed. These four include: the central command center, laboratory units, wall-mounted units, and backup units.

The central command center should contain enough room for three monitors, a keyboard, telerobotics controls, communications, and other discrete switches and displays that may be used. The purpose of the three monitors is to be able to simultaneously interact with the computer, perform telerobotics with a remote camera, and talk to someone or send email messages. It is for practicality that the command center fit within three standard racks. Each rack should contain one monitor and associated controls for functions such as warning systems, fire suppression, and telerobotics.

The laboratory unit should be two standard racks in width. While performing experiments, it is necessary to have a table to write on, a keypad to enter information into the computer, a separate memory and storage device to eliminate the use of the main frame, a printer for raw data and measurements, and a storage place for the hard data and software; therefore, a two-rack system should be used for the laboratory racks. Two types of laboratory units needed to be designed are for areas of possible contamination and areas where there is no contamination. For the former, regular keyboards and components may be used; however, where
contamination is possible, components with minute gaps easily cleaned are necessary.

The backup unit is an extension of the command center. It should consist of two monitors, a standard keyboard, and space for a variety of discrete controls. Two monitors allow the user to simultaneously control the computer and communications in the event of an emergency. The backup center uses components from the rack and is designed to fit into the commander's crewquarters.

Wall-mounted units may be used in the event of emergency. These controls should be mounted upon the walls at various locations, perhaps at safe haven points, to allow the user to communicate with the computer at point locations.

2.4.1.2.3 Workstation Ergonomics

Human factors issues to be dealt with in the design of a workstation are the following:

- gravity of the environment
- user population
- movement
- musculoskeletal tension

The gravity level deals with the physical dimension and layout of the workstation to conform to a particular user in a g-level which the station is being used. For example, the body posture is different at 1-g rather than at 5-g.

The workstation should be designed to conform to the characteristics of a specific population of users for whom the system is designed. The station should be design to fit the anthropometric range of the lunar base crew.

Workstations should be configured so that body movement, when operating the controls is kept at a minimum. As well, priority and time movement will determine the location of certain functions within the workstation.

The workstation should be designed to minimize the musculoskeletal tension required to maintain a posture or position required for a particular operation.

2.4.1.2.4 Control Locations

The controls of the workstations include everything needed to provide electronic information to and from the computers, cameras, and sensors both inside and outside of the lunar base. Some of the controls which will be used are monitors, lights, switches, and keyboards.

With regard to the monitors, the following requirements should be analyzed when selecting the type of monitor to be used: glare reduction, surround luminance, viewing distance, font, character size, and mathematical tables (NASA STD 3000, 1987).

Assuming the light located on the panel are LEDs, or light emitting diodes, the following requirements are to be met:

- intensity control LEDs capable of being dimmed
- color coding - use of LED color coding should conform to the NASA STD 3000
- lamptesting - LED indicator lights with less than 100,000 hours mean time between failure (MTBF) should require lamp testing capability (NASA STD 3000, 1987)

The advantages and disadvantages of different types of switches are listed in Tables 2.4.1.2.4-1, 2.4.1.2.4-2, and 2.4.1.2.4-3. Using this general criteria for switches, the kind and type may be selected and placed according to NASA STD 3000.

The keyboard and/or keypads have requirements for the function key types, reduction of errors, and non-ASCII key locations. Figure 2.4.1.2.4-1 shows the standard keyboard layout which is to be followed in designing a specialty keyboard.

2.4.2 Furnishings and Equipment

NASA currently provides pertinent information on space-related interiors and equipment to accommodate a range of body configuration. This range includes from the 5% Japanese female to the 95% American male. Approximate heights considered are 1.6 m to 1.9 m. This range addresses the international partnership that is anticipated between the United States, Russia, Japan, the European Space Agency and Canada.
### Rack Components

A rack will be a standard measured unit that will contain functional equipment, monitors, stowage, workstations, laboratory work areas, computers, and all general and specific products necessary for the operation of the lunar base. The rack should consider the following:

- a kit of parts
- compactability
- lightweight for transportability
- designed for 1/6 gravity
- address human factors and anthropometrics
- should dual function
- address survival levels as well as more “luxurious” levels

### Requirements for all Functional Areas

For all the functional areas of the lunar base, racks should be designed for the following needs:

- research laboratories
- crew quarters: single, double arrangements
- hygiene facilities, both full and limited

### Materials, Colors and Finishes

The general criteria for materials, colors and finishes is not very different from those in Earth-based environments. The most pressing concern will be for the specific material and its outgassing qualities. The materials used within a lunar base should address not only a functional requirement, but should suggest attention to the human element. From a functional perspective, materials should be sensitive to the following:

- outgassing minimal, preferably accomplished prior to occupation of the habitat by human crewmembers
- provide minimal maintenance for cleanability
- materials should be durable
- materials must be nonflammable
- materials must not impart chemical, mechanical or any other hazard to the crew
- materials must be resistant to abrasion, scratching, or corrosive contaminants

From the perspective of psychological benefit, materials can add aesthetic qualities to a space, can assist in task performance under illumination, and can abate acoustic reverberations within the habitat.

Color selection must be accomplished carefully within an isolated and confined environment. It should be accomplished simultaneously with the design of the illumination system. Colors should:
- enhance the human element within the habitat
- provide a variety of visual stimuli
- be selected to augment the spatial confines of the habitat
- be selected to promote ease of task performance
- allow the crewmember his/her own personalization of specific territories

Finishes of surfaces addresses most specifically the reflectances that may occur. With light absorption and scatter being minimal, there will be greater contrasts. Finishes generally should be selected so as not to produce glare or unwanted reflections. Matte or satin finishes will assist in illumination. There may be unusual spaces within the habitat that might warrant the use of a highly reflective surface, e.g., to perceptually expand a space. Those intentional uses should be kept to a minimum. Utilizing panels that can be reversed or changed-out, a crewmember will have design flexibility to suit his/her taste as well as assist in the easy maintenance of the environment.

2.4.4 Illumination

Lighting will play a key role in the success of the lunar mission objectives from both a psychological viewpoint as well as the productivity viewpoint. Illumination will address from general to specific task requirements. People have a biological need for visual information. When sensory data is ambiguous, astronauts can become uneasy or distracted and may not be able to work efficiently (Lam, 1977). The crew will need to be aware of the following:
- location, with regard to destination and escape routes

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedals</td>
<td></td>
</tr>
<tr>
<td>Use when both hands are occupied</td>
<td>Cannot use with foot restraints can induce forces to move operator out of position if not restrained</td>
</tr>
<tr>
<td>High force capability</td>
<td></td>
</tr>
<tr>
<td>May be used where pedal has created a stereotyped expectancy</td>
<td></td>
</tr>
<tr>
<td>Rocker switches</td>
<td>Susceptible to accidental activation</td>
</tr>
<tr>
<td>Efficient use of space</td>
<td>Can be difficult to read three-position rocker switches</td>
</tr>
<tr>
<td>Will not snag clothing</td>
<td></td>
</tr>
<tr>
<td>Status is obvious</td>
<td></td>
</tr>
<tr>
<td>Push-pull controls</td>
<td>Difficult to determine positions when used for multiple position control</td>
</tr>
<tr>
<td>Used for 2 position control</td>
<td>Susceptible to inadvertent activation</td>
</tr>
<tr>
<td>Efficient use of panel space</td>
<td></td>
</tr>
<tr>
<td>May be used in a multi-mode fashion (e.g., on-off and volume control) to save space</td>
<td></td>
</tr>
<tr>
<td>Slide switches</td>
<td>Continuous slide switches susceptible to mispositioning</td>
</tr>
<tr>
<td>Can be discrete or continuous</td>
<td>Can be difficult to position</td>
</tr>
<tr>
<td>Good for large number of discrete or positions</td>
<td>continuous sled switch precisely</td>
</tr>
<tr>
<td>Provide easy recognition of relative switch setting</td>
<td></td>
</tr>
<tr>
<td>Legend switches</td>
<td>Not recommended for more than tow positions</td>
</tr>
<tr>
<td>Good in low illumination (if self illuminated)</td>
<td>State of activation is not always obvious</td>
</tr>
<tr>
<td>Fast activation</td>
<td></td>
</tr>
<tr>
<td>Effective way to label switches</td>
<td></td>
</tr>
<tr>
<td>Efficient use of panel space</td>
<td></td>
</tr>
<tr>
<td>Printed circuit (DIP) switches</td>
<td>Slow</td>
</tr>
<tr>
<td>Very space efficient</td>
<td>Usually require stylus to set</td>
</tr>
<tr>
<td>Key operated switches</td>
<td>Small size makes switch difficult to read</td>
</tr>
<tr>
<td>Prevent unauthorized operation</td>
<td>May require stabilized hand to set and avoid excess force</td>
</tr>
<tr>
<td>Permits flush panel for seldom operated switches</td>
<td>Slow to operate</td>
</tr>
<tr>
<td>Key slot susceptible to contamination if not shielded—especially in microgravity</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.4.1.2.4-2. Control Devices Advantages, Disadvan. (from NASA-STD-3000).
<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Knob, discrete position rotary</strong></td>
<td>Used when 4 or more detented positions are required</td>
</tr>
<tr>
<td></td>
<td>Resistant to accidental actuation</td>
</tr>
<tr>
<td><strong>Knob, continuous position rotary</strong></td>
<td>Good for precise settings</td>
</tr>
<tr>
<td></td>
<td>Single- or multi-turn capability</td>
</tr>
<tr>
<td></td>
<td>Not recommended for 2 position functions</td>
</tr>
<tr>
<td></td>
<td>Relatively slow</td>
</tr>
<tr>
<td><strong>Knobs, ganged</strong></td>
<td>Efficient use of space</td>
</tr>
<tr>
<td></td>
<td>Relatively slow</td>
</tr>
<tr>
<td></td>
<td>Not recommended for gloved use</td>
</tr>
<tr>
<td></td>
<td>Susceptible to erroneous settings</td>
</tr>
<tr>
<td></td>
<td>Not recommended when frequent changes are required</td>
</tr>
<tr>
<td></td>
<td>One knob may move if inter-knob friction exists (may require two handed operation).</td>
</tr>
<tr>
<td><strong>Thumbwheels</strong></td>
<td>Compact</td>
</tr>
<tr>
<td></td>
<td>Not recommended for fine control</td>
</tr>
<tr>
<td></td>
<td>Slow, not recommended for high traffic functions</td>
</tr>
<tr>
<td></td>
<td>Can cause intermediate and inadvertent inputs</td>
</tr>
<tr>
<td></td>
<td>Susceptible to inadvertent activation</td>
</tr>
<tr>
<td></td>
<td>Position or selection may be difficult to assess in dim light</td>
</tr>
<tr>
<td><strong>Cranks</strong></td>
<td>Used when multiple rotation are required</td>
</tr>
<tr>
<td></td>
<td>Fast</td>
</tr>
<tr>
<td></td>
<td>Can handle high forces</td>
</tr>
<tr>
<td></td>
<td>Can be used for coarse and fine adjustments</td>
</tr>
<tr>
<td></td>
<td>Requires space</td>
</tr>
<tr>
<td></td>
<td>Susceptible to accidental movement</td>
</tr>
<tr>
<td></td>
<td>Tempting hand hold or grasp under microgravity conditions</td>
</tr>
</tbody>
</table>

- time, to orient biological clocks
- physical security and enclosure, regarding the safety of the structure
- territory, crew member boundaries and opportunities for personalization
- places of refuge, shelter in time of perceived danger

These needs for visual information can be addressed with lighting by creating the subjective impressions of visual clarity, visual relaxation, privacy, spaciousness, crew control and personalization, time and space orientation, and safety.

Visual clarity refers not to how well lit an area is, but to its lack of haziness or visual gloom. The lighting in a space may be sufficient to see the task at hand, but may still be flat and shadowless. The failure to meet user expectation for visual information is more likely cause for gloominess than inadequate light (Lam, 1977). Visual clarity is especially important in the laboratory where the crewmembers will be working for extended periods and the need to recognize color codes accurately will be important. Visual clarity is reinforced by:

- higher luminance on work and ceiling plane
- higher luminance in central part of the room
- cooler-toned continuous spectrum light sources (Steffy, 1990)

A sense of relaxation is needed in casual spaces such as the crew quarters, passive recreation and the wardroom. Visual relaxation is reinforced by:

- non-uniform lighting to provide darker areas to look to
- interior windows
- warm-toned surfaces (Steffy, 1990)

The laboratory areas can also benefit from these design criteria. By combining relaxation with visual clarity, a comfortable yet highly productive environment can be created (Steffy, 1990). The impression of privacy is appropriate for more intimate casual spaces such as the crew quarters and passive recreation. Privacy can be reinforced by:

- non-uniform lighting
- wall lighting
- low luminance in the zone of the user

Table 2.4.1.1.2-1. Control Devices Advantages, Disadvan. (from NASA-STD-3000).
higher luminance surrounding the user (Steffy, 1990).

A feeling of spaciousness is important in areas of circulation and in cramped spaces. Spaciousness is reinforced by uniform lighting and uniform wall lighting to make the wall surfaces appear lighter in value in comparison to the ceiling and the floor.

For crew control and personalization, each area should have moveable or adjustable fixtures to accommodate furniture rearrangement and dual functions. Excluding circulation, each area should allow crew control of light brightness with dimming switches or ceiling fixture independence.

Time and space orientation should be reinforced by lighting because of the habitat's lack of inherent environmental information and Earth-like sensory stimulation. Lighting can help in defining spatial and surface changes. Changes in brightness and hue throughout a 24-hour day in the habitat might be used as stimulation for daily rhythms.

For safety, lighting should be used to articulate circulation paths. An emergency lighting system should be available in the event of a temporary power supply failure. The status of the structure should be indicated with lights spaced throughout the habitat. This gives objective information and reinforces the subjective impression of safety.

2.4.4.1 General Illumination Requirements

The habitat lighting system should optimize viewing conditions for all crew activities. Ambient light should be placed to enhance the interior volume of the habitat and emphasize its spatial functions. Brightness, direction, color, and concentration of task lighting should be determined by the task and the amount of time spent on the task. Task lighting should reinforce the visual information required for the area by not obscuring the task with shadows, glare, or veiling reflections.

2.4.4.2 Human Factors Requirements

The following issue should be addressed when considering an illumination scheme for a lunar environment:

- privacy: non-uniform lighting and low illumination in the zone of the user/high illumination surrounding the user
- visual relaxation: non-uniform lighting (darker areas to look to), interior windows, and warm-toned surfaces
- spaciousness: uniform lighting, uniform wall lighting
- crew control/personalization: fixture moveability, adjustability, variable brightness, ceiling fixture independence
- time orientation: simulated sunrise and sunset
- safety: exit lighting and status or emergency lights

2.5 Building System Requirements

To provide a conceptual proposal for a lunar base, it is necessary to review what has been considered by the aerospace community to date. Included in this investigation are methods of construction and the use of particular materials that may prove appropriate for the lunar environment. In addition, given the vacuum and the intensity of what impacts the surface, attention needs to be paid to methods of protection from a number of environmental elements.

2.5.1 Materials

All materials chosen should be expected to last a given lifetime. Replacement of components will be costly and, depending on the type of failure, possibly endanger human life. The ability to function as intended for a specific service-life depends upon the resistive qualities against surface fatigue, abrasive wear, chemical reaction, contamination, depletion (off-gassing) and punctures. The severe climate of the Moon's temperature gradient (-171 degrees C to 134 degrees C) changes quickly and remains for
extended periods of time. Materials in contact will need to have similar coefficients of expansion over this wide temperature range. Radiation from the sun and galactic cosmic radiation (an isotopic flux of protons, alpha particles, and heavier nuclei) pose a constant threat to materials. Radiation, in the form of solar flares, ultraviolet radiation and galactic cosmic radiation (GCRs) will be to lunar equipment as oxidation is to Earth-based elements. Solar particle events (SPEs) are a wind of high-energy protons with fluxes up to 100 cm per sq. s resulting from explosions in the sun’s chromosphere. “Because of the Moon’s very small magnetic field and nearly absent atmosphere, space radiation bombards lunar base structures directly with negative consequences for both biological and material systems” (Sherwood & Toups, 1992). Radiation is very detrimental to organic compounds and polymers; deterioration happens very quickly. The Moon has no atmosphere, resides in a hard vacuum which also poses design problems. “Most organic materials and some inorganic material evaporate or outgas volatile substances. In a vacuum, certain materials begin to offgas which on Earth do not. The importance of preventing contamination of life support systems and equipment from outgassing will restrict the materials available for use. Many metallic surfaces rapidly form a protective oxide layer which prevents seizing and galling. In space, such protective films do not form, possibly leading to microwelding of asperities and rapid adhesive wear of components. Graphite, a powdered lubricant commonly used on Earth, becomes abrasive in the vacuum of space due to the loss of water at the edge of molecular slip planes” (Ramsey, 1991). Materials must be lightweight, high in strength and easily cared for.

2.5.3 Structural System

The habitat needs a structural system which satisfies the following needs:

- internal pressure of 101.4 kPa
- sustain load from regolith cover or ability to withstand radiation exposure
- survive impact of micrometeoroids
- be able to support internal rack systems
- ability to handle live loads
- support entrance and exit points
- withstand radiation exposure
- be flexible
- be easily erected and retrofitted

The first lunar outpost may be brought intact from Earth, ready for use with little preparation. The habitat which will be used for long-term stays needs to house additional crewmembers for longer periods. This demands innovative structures that will meet requirements costs effectively.

2.5.4 Connections

Connections must provide locking, airtight seals between two objects. It is critical that the connection must allow the easy translation of a fully-suited astronaut. Equipment, supplies, and racks must pass through as easily, without the extensive assistance of a second crewmember. The following considerations must be addressed:

- internal door placement — enclosed crew stations shall have entrances or exits to permit unrestricted flow for all anticipated traffic, and shall be located so personnel ingressing or egressing will not interfere with surrounding operations or traffic flow
- emergency passate — capability shall be provided to allow emergency egress and rescue entry into a compartment
- external pressure hatches — hatches opening directly to the vacuum of space shall be self-sealing and inward opening
- windows — airlock hatches shall incorporate windows for visual observation of all airlock operations with a minimum of blind spots inside the airlock
• EVA operation — all opening/closing mechanisms shall be operable by a pressure-suited crewmember
• operation shall be accomplished from both sides of the connection
• connections may be operated by a single crewmember
• connections shall be self-aligning
• connections should have provisions against dust contamination

2.5.5 HAZARD SHIELDING

As extended duration lunar missions are envisioned, environmental parameters such as high-energy, charged particle radiation from solar flares and GCRs become critical. Large solar flares can release great quantities of high-energy nuclei for time periods as long as several days. As well, very high-energy GCRs bombard the Moon steadily from sources outside the solar system. Unlike Earth, lunar inhabitants will not have the protective cover of an atmosphere against this radiation; therefore, health and safety may be endangered. Allowable dose limits for crewmembers have been set and therefore shielding must provide adequate protection. The lack of a significant atmosphere on the Moon will allow the tiniest particles to strike the surface with their full velocities, as high as 20 km/sec. (Sherwood & Toups, 1992). No damage can be caused by micrometeoroids striking the habitat. The depth of protective cover depends upon the material used. In the case of radiation, the exposure will most likely vary throughout the habitat. The design should take advantage of equipment that provides protection by placing sleeping quarters or other high occupancy rate activities behind them.

2.5.6 ENERGY CONSIDERATIONS

The energy needs of the lunar base have to be met by utilizing some sort of power generation system. To obtain this energy, there are several requirements that must be addressed:

• determination of electrical energy needs
• determine the source of the energy
• methods of power transfer needed
• resistive losses determined
• location of supply sources

Though these requirements may be necessary, more research need to be done to determine if certain criteria for establishing power is feasible.

2.5.7 CONSTRUCTION SEQUENCING

A smooth construction progression is necessary and must be fully delineated prior to launch. Presently, there is no roadway system on the lunar surface to use in the transport of materials, nor are there transportation materials themselves. Both of these issues need to be resolved. The sequencing should incorporate resources, time, energy and equipment. precursor missions will have accurate mapping of the site location. Dependent upon the method of construction, equipment may have to be transported to the surface prior to arrival of FLO. Any surface preparation might be accomplished by telerobotics, if technology is available at the time. It would be prudent to deliver necessary components to the surface; components that could self-deploy would be beneficial. When the crew arrives, a cost benefit in EVA time on the surface would be realized when as much construction as is permissible by robotics could be accomplished.

With the use of a FLO site, the crew could commence construction of the habitat portion of the permanent site. Again, minimal EVA time is desirable, especially if any construction can be accomplished from the FLO lander. Once the habitat is erected, it will need a hazard protection system deployed above it. This is an area that needs further investigation and design. Considerations have been made with regard to the ease of deploying the system - erecting it prior to or post-construction of the habitat. Methods of containment of the lunar regolith and the depth to which the regolith must be placed over the habitat are still under investigation. Current thought directs the design of regolith protection to minimally be at a depth of 0.5 - 1.5 m.

As the habitat exterior volume is completed, a power supply should be connected to the shell to aid in the interior configuring of the structure. A solar array field should be the primary system of choice. A redundant system under consideration will be a nuclear power generator. Once the exterior is constructed, airlocks must be attached to allow ingress and egress of the crew. Redundant points of egress are mandatory. Provisions for this requirement must be made early in the construction progression.

Launch and landing facilities can be constructed as well as roadways linking vital portions of the base. Required is the linear axis of the base configuration. This corresponds with the launch and landing flight
patterns, with provisions being made so that no spacecraft directly passes over the habitat or power sources.

2.5.8 Expandability and Retrofit

The possibility of expansion is desirable as the lunar base matures into a self-supporting entity. Expansion may occur in three ways: within the same site, or adjacent to an existing site, or in an altogether new area. It should be considered that as the base functions expand, there may be a need for additional personnel to inhabit the facility. As well, laboratories may expand, add new abilities, and raise the level of sophistication of the science being performed. This will result in the demand for additional space. The lunar base must be designed at the outset to incorporate this possibility.

With the passage of time, there will be an expected lifespan for the equipment, materials and structure of the habitat. The design must address the need for future replacement or remodeling of the structure. Components that can easily be replaced, such as the rack systems, will be beneficial. This ease of retrofit will alleviate the necessity to abandon the base when it has lived out its life. Cost economy demands that the habitat and surrounding facility have the capability of being expanded, repaired or components replaced, again with minimal EVA time required for the crew.