III. Mission Operations: Experimental Systems

Introduction
A lunar science and technology facility is needed to create a scientific, space transportation, and industrial infrastructure to support exploration of space and the other planets. Research on the moon can also provide new information about human behavior, the formation of the solar system, and evaluation of potential use of lunar resources for supplying a lunar base, space station, or spaceships destined for Mars and beyond, as well as a source of energy (helium-3). Scientific and technological benefits of a habited lunar base include:

1. Surveys of lunar resources and extraction/processing methods: Lunar surface mining and production analysis.

2. Construction technology testbed.

3. Plant growth: Closed system ecological life support system experiments.

4. Planetological studies of the solar system’s origin and features, and physics/astrophysics/astronomical research in a high vacuum environment: lunar-far side observatory.

5. Human factors and environment-behavior systems research.

These science missions would take advantage of the moon’s unique environment: (a) high vacuum, (b) low gravity (1/6 of Earth), (c) regolith composition, (d) isolation, (e) low seismic activity (when compared to Earth), and (f) low magnetic field.

A. Laboratories: General Design Requirements
There have been basically two approaches to laboratory design for space missions: the dedicated facility approach and the open plan approach. In the dedicated facility approach, a specialized facility is provided for each general field. This approach provides a number of advantages (Batelle, 1987): (a) dedicated space to allow a series of focused experiments, (b) availability of dedicated facilities and equipment which are tailored to the discipline of interest, and (c) physical separation from other science experiments and base operations (Batelle, 1987).

The open plan approach has been most commonly used, since space and manpower is limited.

Design Recommendations:
The dedicated facility approach would seem to be the most suited to lunar applications, not only for the advantages listed above, but also for the simple reason of controlling dust from geochemistry and petrology experiments and construction technology research.

1. Laboratory Facility Breakdown
The general laboratories for this base would be:

a. Lunar surface mining and production analysis: geochemistry/petrology lab
This laboratory would provide facilities for the study and experimentation of lunar resources and extraction/processing methods (mining and resource utilization), as well as for the study of the origins of the moon and the solar system.
b. Space construction technology testbed
   This facility would test materials, both lunar and earth-based, and methods for advanced space construction.

c. CELSS testbed
   Experiments would take place focusing on plant growth and closed-loop ecological system development. Capabilities in biochemistry, analytical chemistry, cell biology, plant physiology and microbiology would be needed.

d. Far-side lunar observatory and astrophysics station
   Workstations may be required to monitor the performance and collect data from a Lunar Far-side Observatory. A solar observer, which would monitor solar flare activity, should be given high priority as a safety measure protecting the lunar base inhabitants from extreme radiation.

e. Human factors/environment-behavior systems monitoring research facility
   Experiments focusing on the adaptation of humans to isolation and reduced gravity would be an early part of mission operations activities. In addition, this facility would monitor cardiovascular de-conditioning, bone calcium loss, and muscle atrophy in crew members, as well as monitoring habitat environmental factors such as radiation, water quality, microbiology, toxicology, and barothermalsar physiology.

2. General Design Criteria
a. Volumetric requirements:
   The required volume for specific laboratories will depend on the equipment used and the scope of the investigations taking place.
   1. Equipment
   2. Workspace
   3. Circulation
   4. Design recommendations
      Area is to be provided as a workspace for note taking, analysis of tests, sample preparation, and the setting up and tearing down of equipment.
      A 4"-6" minimum clearance for circulation should be allowed, plus additional area for starting and stopping in 1/6 gravity (SICSA, 1989).

b. Anthropometrics
   1. Workspace height/configuration
   2. Design recommendations
      Standard anthropometric sizings should be followed, such as those found in NASA STD-3000.

c. Coding:
   Should be used such that it will facilitate the quick identification of elements under both normal operational and emergency conditions.
   1) Design recommendations:
      (i) Identify the facility
      (ii) Identify experimental apparatus and location
      (iii) Identify if possible dangers exist
      (iv) Identify emergency systems and exits
      (v) Coding should be readily identifiable without need for reading
      (vi) Either color or graphic symbols or a combination of both should be used
d. Proximity
   Facility arrangement, grouping, and layout should promote efficient and safe operation. Proximity relations can be determined by the crew tasks and operations in the labs, including:
   1. Frequency
   2. Duration
   3. Sequence
   4. Volume required
   5. Special environmental requirement
   6. Design recommendations
   Minimize transit time between related activities, accommodate the expected levels of activity at each area, isolate areas when necessary for crew health, safety, performance, and privacy.

e. Wayfinding
   Geometrical arrangement of spaces within the habitat may influence its legibility and the ease or difficulty one experiences finding one’s way within it; health and safety concerns dictate the need for clear orientation, especially in areas where possible dangers exist.
   1. Location of facilities
   2. Locations of exits/entrances
   3. Location of equipment and work spaces
   4. Location of emergency systems
   5. Design recommendations: Logical location of elements with respect to historical or hierarchical arrangements should be preserved.

f. Color/decor
   1. Color and decor are important visual and tactile stimuli which affect crew morale.
   2. Aesthetic and psychological requirements
   3. Flexibility
   4. Design recommendations: Color and decor should not be overly complex nor should it be overly simple; decor which can be modified would be an added amenity, and wherever possible the decor should also serve as a location coding, noise reduction (texture), or glare reduction function.

g. Materials
   Material selection is especially important in laboratory facilities, where they must resist the wear and tear associated with experimentation.
   1. Cleaning
   2. Contamination
   3. Repair
   4. Texture
   5. Durability
   6. Design recommendations:
      Materials should be durable enough to withstand abrasion, scratching, and corrosive contaminants, and be easily cleaned and maintained; they should also provide for added traction, noise reduction, and glare reduction where possible.

h. Atmosphere control
   Certain experiments may require special atmospheric conditions, as well as provisions for dust control or a seal-off ability.
   1. Temperature
   2. Humidity
   3. Circulation
4. Filtering
5. Seal-off ability
6. Design recommendations:
   Each facility should have its own atmosphere control capability, to insure experimental
   response and crew safety.

i. Light requirements
   Thermal and lighting provisions should be responsive to the needs of scientific experi-
   mentation:
   1. Color of light source
   2. Intensity
   3. Placement of source
   4. Distribution of light
   5. Character of task
   6. Design recommendations:
      A general lighting system should be provided, as well as task lighting for specific
      functions.

j. Sound transmission
   Experimental apparatus such as a thin section maker and polisher may produce noise which
could be subversive to other experiments or irritating to humans, therefore a special steps must be taken
to control noise from both entering and emanating from the facility:
   1. Extreme noise
   2. Extended exposure
   3. Communication inference
   4. Task interference
   5. Intermittent noise
   6. Psychological effects
   7. Design recommendations:
      Materials which dampen noise should be used, and apparatus which produce high noise
      levels should be given special provisions to control sound transmission.

k. Health/safety
   Experiments may take place, or materials used, which may cause harm to crewmembers should an
   accident occur:
   1. Mechanical hazards
   2. Contamination
   3. Fire
   4. Pressurization failure
   5. Thermal touch
   6. Auditory
   7. Electrical
   8. Locomotion in 1/6 g
   9. Design recommendations:
      Since any harm to crewmembers could be potentially catastrophic, every precaution should be
taken with experimental equipment. Facilities should have a seal-off ability, back-up
lighting systems should be provided, safeguards installed near heavy equip ment, and safety
systems such as fire suppression systems installed.

Project Genesis: A Lunar Outpost
B. Lunar Surface Mining and Production Analysis Facility

1. Size
The facility should be large enough to house a flow bench, a scanning electron microscope, storage sample racks, counter space sufficient for experimental apparatus and note taking.

Two smaller rooms, an acoustically isolated sample preparation room large enough to house a thin section maker and a "clean" room which can provide a pristine environment for the study of lunar samples, should also be provided within the facility.

A small pilot plant for the extraction of oxygen from lunar soil will most likely be present, necessitating storage space for raw lunar material.

Processing experimentation will be varied, and may include fluidized bed reduction, sintering using microwave plasma, and solar melting. Apparatus will likewise range from superconducting magnets and microwave generators down to particle size sorters. Therefore the size and overall configuration of this facility must meet storage requirements for equipment, as well as be flexible enough to allow for efficient and safe set-up and tear-down of experiments.

2. Atmosphere
Dust control will be extremely important within this area, since not only will large volumes of regolith be present, but experimental apparatus and sample preparation may produce dust in their operations, contaminating not only the atmosphere but also other experiments. Therefore, each piece of equipment should provide some means of dust filtering, and the larger dust-producing machines should be placed within an environmentally isolated room.

Humidity should be very low, since the presence of moisture in the atmosphere may affect the results of some experiments.

3. Day-to-Day Operations
Various experiments may be occurring simultaneously and available staff will be limited, therefore tasks such as sample preparation and experiment monitoring should be automated to the highest degree possible. In addition, tasks which produce dust or pose possible dangers should be automated wherever possible for safety reasons.

4. Lighting
An overall illumination system which is adjustable is recommended, supplemented by high degrees of specialized task lighting.
5. Health and Safety
Both mechanical and chemical hazards exist, thereby necessitating the presence of first aid capability within the lab to treat cuts, contamination, or possible eye injuries.

6. Location
To minimize the transport of regolith samples through the habitat, this facility should be located near an airlock, or perhaps have an interface large enough for the transfer of samples to an airlock.

C. Construction Technology Testbed

1. Size
The testbed may be comprised of a number of facilities, ranging from a material development laboratory to a material testing and deployment area.

Facilities for the development and production of materials in this initial base should be coordinated with the Lunar Surface Mining and Production Analysis Facility, since the two may share similar apparatus and processing techniques.

A facility for the testing and deployment of products will require an interior pressurized facility free of obstructions to allow for the erection of members, as well as a small isolated chamber in which to initially stress test and monitor materials under controlled conditions.

A nearby exterior area isolated from traffic should be provided for the testing of the lunar environment upon structural materials.

The geotechnical testing of various siting strategies will be an EVA task.
2. Health and Safety
Provisions should be made to monitor the possible outgassing of processed materials within a controlled environment before they are exposed to the atmosphere of the habitat.

Injuries caused by sharp members, accidents with tools and chemicals, or the unexpected failure of an experimental structural member pose serious threats to crew health. First aid within all testing areas should be provided, as well as fire suppression equipment.

3. Location
The testing facility would most efficiently be placed near the Lunar Surface Mining and Production Analysis Facility, to minimize traverse distance between development and testing areas, as well as near the Maintenance Facility, for the sharing of tools and related equipment.

D. CELSS Research Facility

1. Size

A. Test Facility
The facility should be large enough to house at least one complete set of plants in table

In the initial phases of the Biosphere, the scale of the facility should start and remain small until plant productivity, contamination safe-guards, and human safety are proven.

The facility should have a non-toxic atmosphere for easy human operations.

Aeroponics should be the method the facility would use to grow the plants. This method moves plants on a conveyor belt through areas where they would be sprayed with a fine nutrient solutions (Polette,1988)

B. Full Scale (Food Source)
The facility must be large enough to supply the entire crew with their daily dietary requirements.

The facility must also be large enough to produce an emergency supply of food. and must be large enough for the separation from the warm and cool crops to maximize plant productivity.

Cells Design Components (Polette,1988)
The facility must include a growth chamber, systems equipment module, mechanical processor, and storage areas.

The facility must have several complete sets of plants to ensure against contamination that could destroy the entire crop.

The facility should have both plant and aquatic organisms.

The facility should have automatic or robotic systems to maintain day-to-day operation to allow the crew to run other base operations.

The facility should have the capabilities of either method; hydroponics or aeroponics. This should depend on if there is any differences on plant productivity and/or overall labor hours involved.

2. Plant Productivity

The plants should meet or exceed their edible weight per plant in Table 1 in a normal atmosphere.

Plants that are grown in altered atmospheric, temperature, carbon dioxide, and humidity levels must exceed their productivity levels under normal conditions to warrant the change.

3. Atmosphere

A. Non-Toxic

The facility must be sealed off from the rest of the base due to the different levels of humidity, and temperature.

The facility must have an airlock to guarantee against plant contamination from the habitation or laboratory module.

The facility must have its own HVAC so it will not overload the habitation or laboratory module’s HVAC.

B. Toxic

The temperature, carbon dioxide, atmospheric, and humidity levels are changed to maximize plant productivity.

The facility must have an airlock to guarantee against plant contamination from the habitation or laboratory module.

The facility must have its own HVAC so it will not overload the habitation or laboratory module’s HVAC.

The facility must have a EVA/preparation area for those with lower atmospheric pressure or higher levels of carbon dioxide.

The facility must have detection system to guard against leaks into the laboratory or habitation modules and mechanical failure.

4. Organisms

A. Plant Type

The plant used are in the following table and were chosen for their dietary considerations and edible weight per plant.
**Table 1. Plant Growth Characteristics**

(Polette, 1988)

B. Aquatic Form

The aquatic stage will be implemented in the later phases of the biosphere due the amount of water that is required.

5. Lighting Systems

The facility should use cool fluorescent lamp lighting, as the main lighting source, that would provide an illumination of 7,000 lux on the plant (Polette, 1988).

The facility would also use fiber optics to utilize natural sunlight.

6. Configuration

A. Expansion Capabilities

The facility should have ability to expand with the addition newer phases of the biosphere and the overall base growth without any major reconstruction. (See figure)

B. Plant Redundancy

The facility/facilities must separate the sets of plants to ensure against total crop failure in case of an emergency.

7. Phasing

A. First Phase

The first phase should consist of a small inflatable test facility with a small number of plants to ensure growing techniques.
B. Second and Third Phase
The second and third phases would include many facilities to produce enough food to support the entire crew over long a duration.

Longitudinal Section Through an Advanced Stage Inflatable Facility

(Eolette, 1988)

E. Far-Side Lunar Observatory

1. Size
Design recommendations: Since information from a far-side observatory would most likely be transmitted directly to Earth, a single workstation would most likely be adequate. This workstation may also be monitoring solar flare activity.

2. Location
Design recommendations: Since the most pertinent information would be regarding solar flare activity, and this would be a base concern, this workstation would most likely be located in the base operations area.

3. Lighting
Design recommendations: Any astronomical workstation should be provided a dark environment so as to maximize the display capability of the visual images.
F. Human Factors and Environment-Behavior Systems Monitoring Research Facility

1. Purpose
The purpose of a human factors (HF) and environment-behavior systems (EBS) monitoring and research facility is derived from the essential mission of a lunar habitat — as a later Martian exploration. Thus it will be critical to monitor and test human reactions to all aspects of the base, to the functions, to the habitat, to the command module and functions, to EVA, etc. The HF/EBS Research Facility will be the heart of these monitoring and research functions.

2. Location/Proxemics
The HF/EBS Research Facility should be near both the habitat, the other research areas, the command module, and EVA doff/don areas. It thus should be relatively centralized in the total lunar base. As it will primarily be a telecommunications research facility, it could be adjacent to or a part of other research facilities and/or the command center.

3. Size/Configuration
The HF/EBS Research Facility will monitor all base human-environment interfaces through five primary research methods:
1. Telecommunication monitoring (e.g., from the exercise or health maintenance areas).
2. Systematic observation (e.g., of social interactions in different types of spaces).
3. Surveys (e.g., ongoing time/space logs and electronic data processed questionnaire formats of activities and reactions in the recreation areas, eating areas, etc.).
4. Open-ended interviews (e.g., of reactions to different arrangements of the private quarters).
5. Focus groups of the whole (e.g., in the group recreation area).
Most of the research will be conducted in situ, where the actual environment-behavior transactions are taking place.

The primary needs for the research "facility," therefore, will be one telecommunications workstation (equivalent to one SSF workstation rack) with sufficient monitoring devices to record all of the research being conducted, a hook-up to the central computer for real-time analysis, and storage for any materials which might be administered as questionnaires (though it is assumed most of this will be computer driven and stored).

A standard 1.35m clearance for circulation should be allowed around the workstation.

3. Anthropometrics
Standard anthropometric and ergonomic design considerations should be given to this workstation as the operator may be there for significant periods of time coding and analyzing data to give timely feedback to the base and to Earth control about ongoing base activities and human reactions.