NASA-CR-195551

NASW-4435

IN-37 C
3836
174P

Lunar Surface Operations

Volume I:
Lunar Surface Emergency Shelter

Dr. William Shields
Dr. Salah Feteih
Dr. Patrick Hollis
and
Mechanical Engineering Students
FAMU/FSU College of Engineering
Tallahassee, Florida

NASA/USRA University Advanced Design Program
Annual Report
July, 1993

(NASA-CR-195551) LUNAR SURFACE OPERATIONS. VOLUME 1: LUNAR SURFACE EMERGENCY SHELTER Annual Report (Florida State Univ.) 174 p

N94-29354

Unclas

G3/37 0003836

Table of Contents

Volume I:
Lunar Surface Emergency Shelter

List of Student Participants

Lunar Surface Emergency Shelter:

Michael Render
Patrick Bilek
Robert Howard
Chris Keen
Gregory Kercher
Keith Kobetitich
Kay Mehr
Kim Melvin
Kory Reeves

TABLE OF CONTENTS

LIST OF ACRONYMS

4BMS	Four Bed Molecular Sieve
ACLSS	Automated subsystem Control for Life Support Systems
DEC	Dynamic Energy Conversion
DIPS	Dynamic Isotope Power System
ECLSS	Environmental Control for Life Support Systems
EU	Electrolysis Unit
HLVV	Heavy Lift Launch Vehicle
LARTS	Lunar Articulated Remote Transportation System
LEO	Low Earth Orbit
LSES	Lunar Surface Emergency Shelter
MCA	Major Constituent Analyzer
MCC	Multipurpose Control Console
MeV	Megaelectron Volt
ODP	Overall Data Processor
PCM	Particle Control Monitor
PFC	Primary Fuel Cell
PV	Photovoltaic
REM	Roentgen Equivalent Man
RTG	Radioisotope Thermoelectric Generator

SD	Solar Dynamic
SSF	Space Station Freedom
TCM	Trace Contaminant Monitor
TCS	Thermal Control System
TES	Thermal Energy Storage
TLI	Trans Lunar Injection
TLS	Temporary Lunar Shelter
WVE	Water Vapor Electrolysis

PROBLEM STATEMENT

A shelter is to be designed to provide survival-level accommodations for up to four astronauts for a maximum of five days. Protection against ionizing radiation, and life-support must be provided. It would be used by astronauts who were caught out in the open by a solar flare event, or whose vehicle or other shelter was unable to support and protect them.

Requirements:

House four people for five days.

Provide 20gm/cm^2 surface density shielding against ionizing radiation.

Provide life-support assuming that astronauts are wearing EVA suits that provide up to six hours of life-support with a two hour extension.

PROJECT ORGANIZATION

DESIGN OVERVIEW

The lunar shelter design was largely based on adaptations of systems currently proposed for Space Station Freedom. Whenever possible, existing technology was considered when selecting subsystems to satisfy each requirement.

The overall design requirement was broken down into eight major sections. Each of these was then analyzed separately:

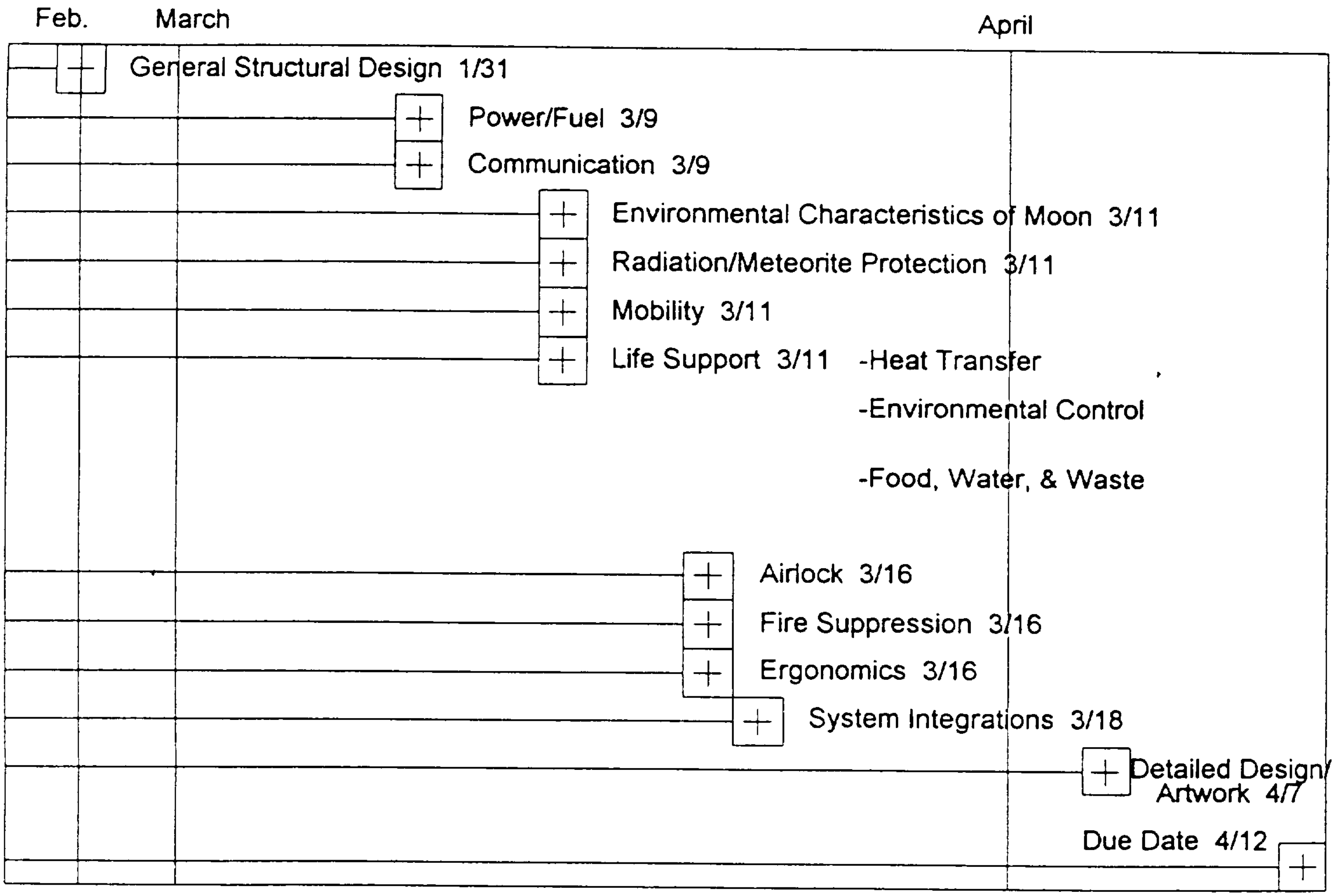
Major Subsystem Requirements

General structural design
Power
Radiation and Micro-meteorite protection
Lunar environment
Communications
Life support
Mobility
Airlock

An individual or small design team was assigned to each of these subsystems. Consistency in design philosophy and compatibility of components was ensured by frequent group meetings and monitoring by a project integration manager.

The large number of subsystems made it impractical to study them concurrently. The following schedule was therefore used:

DESIGN SCHEDULE



MAJOR SPECIFICATIONS

The LSES shall be designed to provide survival-level accommodations for four astronauts for up to five days.

It shall be ready for use at short notice and be transportable to a working site.

Protection shall be provided against solar radiation produced as a result of a 200MeV solar event, based on a 15 REM maximum dose.

The shelter shall be mobile, compact and self-contained such that astronauts on long-range excursions will have constant access to it. Accordingly, it will be swiftly deployable and accessible with the minimum of preparation.

The structure must be able to withstand the lunar environment, notably the steep temperature gradients that exist between sun and shade, micro-meteorite bombardment and lunar dust particles.

The shelter shall be self-contained with an independent power supply and communication system. The astronauts will therefore not be required to leave the shelter during a solar event to obtain equipment from the primary lunar vehicle.

Storage shall be supplied for all necessary supplies and equipment.

Communication ability shall be provided with EVA suits in the near vicinity, the lunar base and, via the base, Earth.

Life-support and the ability to pressurize the living space shall be included to conserve EVA suit supplies. This will also allow helmets and suits to be removed, if necessary, for eating, drinking and first-aid.

The design shall be based on minimal use of Earth materials and minimum construction and maintenance time.

ASSUMPTIONS

The investigation and design of each subsystem of the TLS required that several assumptions be made concerning the technology and equipment that will be available at the time of use:

> A lunar base exists which has communication with Earth and can act as a relay station for communications from the shelter. This equipment is fully operational, serviceable and independent of TLS operation. Also, a lunar vehicle exists which is capable of towing the shelter.
>
> Equipment at this base includes lifting machinery capable of removing the shelter from the lunar lander upon its arrival at the lunar surface. Excavation equipment and a regolith conveyor will also be required to provide lunar soil for shielding.
>
> Maximum required range of the shelter is set at 1000km in any direction from the lunar base.
>
> Satellites and/or space stations exist for relay of communications signals. Linking with these platforms is readily available and fully adaptable. Initial audio and telemetry data rate is set at 250 kbps. This rate is supported by all communication links comprising the system.
>
> Launch from Earth will be aboard the proposed Heavy Lift Launch Vehicle (HLLV). The internal payload dimensions are 10m diameter by 8.5m in length. Maximum mass is 33,000kg. A trans-lunar booster and lunar lander stage will be provided.

DESIGN PHILOSOPHY

Each subsystem analysis required that decisions be made between a number of possible alternatives. These decisions were based on a design philosophy that was decided upon by all members of the design team. Each separate section required unique guidelines to be adopted for that particular application. However, any decision had to agree with the following:

> The over-riding design consideration was safety. Multiple redundancy, use of proven equipment and non-complex mechanisms were used whenever possible.
>
> Existing technology was used whenever possible to minimize the need for technological innovation and the related expense. Similarly, equipment will be suitable for adapting and upgrading.
>
> Maintenance requirements were kept minimal to decrease the time required to service the shelter and the additional parts that would be required from Earth.
>
> Provisions and equipment were based on the minimum required for comfort and safety. The shelter is for emergency use only and will therefore not warrant 'additional extras'. This minimized cost, reduced complexity and contributed to reliability.

LUNAR ENVIRONMENT

INTRODUCTION

The lunar environment is a serious obstacle to overcome in order to have a successful emergency shelter. Environmental characteristics, such as the temperature characteristics, soil properties and radiation intensities are important facts to consider, so that the design of the lunar shelter can withstand these lunar elements. This section provides environmental information, relevant to the construction of a mobile, lunar emergency shelter.

LUNAR CHARACTERISTICS

Gravity (1/6 of Earth's gravity at Equator): 1.62 m/sec^2

Escape Velocity: 5000 miles/hour

Inclination of equator: 6 41'

Albedo: 0.073 (spherical)

The moon reflects up to 70% of sunlight

Mass (1/81 that of Earth's mass): 7.3458x10^{25} gm (5.0344x10^{21} slugs)

Mean Diameter: 2160 miles (3476 kilometers)

Mean Density: 3.3402 gm/cm^3 (6.4822slugs/ft^3)

Surface Area: 37.9x106 km^2

Moment of inertia: 0.395 /kg m^2

Heat flow (average): 29 mW/m^2

Lunar rock types: Ferroan Anorthosities (most common),
Kreep (High potassium and rare earth elements) and Mare Basalt

The lunar seas (Maria) occupy about 40% of the lunar disc

LUNAR ATMOSPHERE

$2x10^5$ molecules/cm^3 (at night)

$1x10^4$ molecules/cm^3 (at day)

Constituents: H_2 , ^4He, ^{20}Ne, ^{36}Ar, ^{40}Ar

DAYTIME LUNAR ATMOSPHERE

Species	Density (molecules/cm^3)
H_2	$0.12x10^5$
H_2O	$1.4x10^5$
CO_2	$1.4\text{-}3.4x10^5$
Various	$0.1x10^5$
Total	$3.0\text{-}5.0x10^5$

Hydrogen is constantly blown off the surface- $3.9x10^4$ Hydrogen atoms/cm^3

Water Vapor: As a result of each solar wind proton shower, 0.036 H_2O molecules are released from the lunar surface. Escape rate to space is $1.4x10^5$ molecules/cm^3.

ABSTRACT

The Lunar Surface Emergency Shelter (LSES) is designed to provide survival-level accommodations for up to four astronauts for a maximum of five days. It would be used by astronauts who were caught out in the open during a large solar event.

The habitable section consists of an aluminum pressure shell with an inner diameter of 6ft. and a length of 12.2ft. Access is through a 4in. thick aluminum airlock door mounted at the rear of the shelter. Shielding is provided by a 14.9in. thick layer of lunar regolith contained within a second, outer aluminum shell. This provides protection against a 200MeV event, based on a 15 REM maximum dose.

The shelter is self-contained with a maximum range of 1000km. Power is supplied by a primary fuel cell which occupies 70.7ft^3 of the interior volume. Mobility is achieved by towing the shelter behind existing lunar vehicles.

It was assumed that a fully operational, independent lunar base was available to provide communication support and tools for set-up and maintenance. Transportation to the moon would be provided by the proposed Heavy Lift Launch Vehicle.

Major design considerations for the LSES were safety, reliability and minimal use of Earth materials.

THERMAL ESCAPE TIMES FROM MOON TO e^{-1} OF INITIAL CONCENTRATION

Gas	T = 150 K (cold side)	T = 400 K (hot side)
H	5100 seconds	3600 seconds
H_2	10^4 seconds	4100 seconds
He	200 hours	9700 seconds
O	10^{10} years	1.4 years
O_2	10^{26} years	10^6 years
H_2O	10^{11} years	60 years
CO_2	10^{37} years	10^{10} years

Due to the lack of atmosphere there is no light scatter, absorption or thermal convection.

LUNAR TEMPERATURE

104 - 390 K at equator

80 K at the poles (dawn)

Mean temperature at a depth of 35 cm is 45 K higher than at the surface

Change in temperature between atmosphere and ground is 50 K.

Thermal Conductivity of lunar soil:

1.5×10^{-5} W/cm^2 for top 1-2 cm

5-7 times greater below 2 cm

LUNAR SOIL

The dust that covers the surface of the moon is called regolith. The coverage is estimated at an average depth of 4 meters.

Regolith grain sizes: 45 - 100 um

Soil adherent characteristics on specific surfaces:

Painted Surfaces: 10^4 dynes/cm^2

Metallic surfaces: $(2-3)\times10^3$ dynes/cm^2

Permeability of soil to 25 cm: $(1-7)\times10^{-12}$ m^2

RADIATION ENVIRONMENT

Solar Wind: 1 Kev/amu

Penetration Depth: 10 cm

Proton Flux: 10^8/ cm^2/ sec

Solar Flares: 1 - 100 Mev/amu

Penetration Depth: 1 cm

Proton Flux: 10^2/ cm^2/sec

Cosmic Rays: 10^2 - 10^4 Mev/amu

Penetration Depth: 300 cm

Proton Flux: 1/ cm^2/ sec

Impact velocities of micrometeorite bombardment: 2.4-72 km/sec

OVERALL STRUCTURE

DETERMINATION OF GENERAL SHAPE AND STRUCTURE OF SHELTER

Before subsystems were designed to satisfy the given requirements, a general consensus amongst the design team had to be reached concerning the overall shape and structure of the shelter. Determination of shielding techniques and materials would have a large effect on the final design. However, it was necessary to reach agreement about the basic format of the shelter before the suitability of a system could be considered.

To satisfy the given requirements, the shelter could be either permanent, temporary or fully mobile. A permanent shelter would be constructed, in advance, at the anticipated site where it would be required. It would then act as an outpost which, although constantly available, would have limited use within a wide range. A temporary shelter would be constructed at each work-site and then dismantled when the site was abandoned. A fully mobile shelter would require no assembly but would either have to be towed or independently powered.

The decision of mobility was decided upon using the following factors:

Set-up time
Versatility to surroundings
Suitability for pressurization
Suitability for shielding

MOBILITY			
Criteria	Permanent	Temporary	Mobile
Set-up time	D A T U M	+	+ +
Versatility		-	+
Pressurization		-	S
Shielding		- -	-

The suitability of a particular shape for the shelter was decided upon using the following parameters:

Suitability for pressurization
Useful volume
Ease of transportation to the Moon
Mobility on the lunar surface
Ease of assembly
Proportion of surface exposed to radiation for a given habitable volume
Ergonomics

Four alternatives were considered: Cubic, cylindrical, spherical and wheels (using hollow wheels as one-man shelters). A cubic shelter was used as the datum.

OVERALL SHAPE				
Criteria	Cubic	Cylindrical	Wheels	Spherical
Pressurized	DATUM	+	-	+
Useful volume		+	-	+
Transportation		+	+	-
Mobility		S	+	-
Construction		S	+	-
Exposed surface		+	+	+
Ergonomics		S	-	S

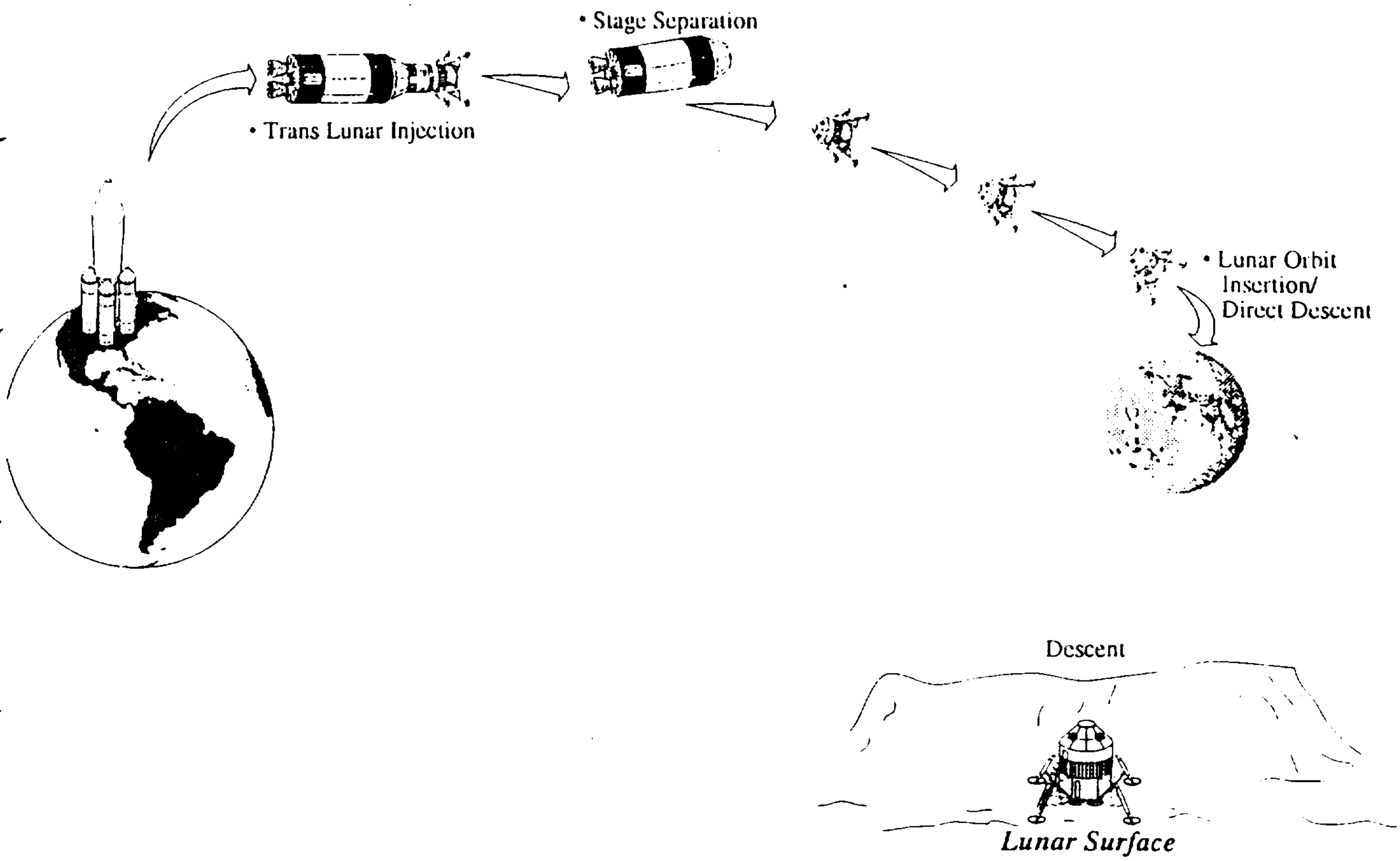
As may be seen, a cylindrical shelter was superior or equal in suitability to the datum. The wheels were found to be unsuitable for pressurization, have little useable volume and be impractical for the required duration. A sphere was the most suitable shape for pressurization and had the minimum surface area but was found to be difficult to construct and adapt to mobility.

Therefore, it was decided to make the shelter cylindrical and fully mobile.

EARTH-TO-MOON TRANSPORTATION

IN-SPACE TRANSPORTATION MISSION SCENARIO

It was assumed that the LSES would be launched from Earth aboard a single stage heavy lift launch vehicle (HLLV) such as that currently under consideration by NASA. After reaching a low Earth orbit (LEO) a trans-lunar injection (TLI) stage would provide the thrust to move out of orbit and head towards the moon. The burned-up TLI stage would be disposed of en-route, leaving a lunar lander stage which would perform the final descent to the lunar surface.



Earth-to-Moon transportation scenario

Size, weight and shape of the shelter were therefore based on approximations of the maximum capabilities of the proposed HLLV and lunar lander [1]. The large available diameter of the HLLV allows the shelter to be launched and landed on the moon in a horizontal position. This eliminates the need for excessive strengthening in the axial direction and also simplifies deployment once on the lunar surface. The cradle interface to the lunar lander will also serve as the structural interface to the mobility system. Points of attachment on this cradle will allow it to be hoisted off of the lander using equipment already at the lunar base.

Assembly of the shielding will then have to be completed by filling the exterior aluminum shell with fine regolith from the lunar surface. This, too, will be achieved using equipment already in place at the lunar base such as a conveyor and shovels. The regolith will be raised to the top of the shelter where regularly spaced openings will allow it to be poured into the cells of the honeycomb polymer structure within the outer aluminum shell.

SUBSYSTEM DESIGN

RADIATION AND MICRO-METEORITE PROTECTION

RADIATION AND MICRO-METEORITE PROTECTION CONTENTS

Radiation Terminology

Solar Flares

General Requirements on Radiation and Micro-Meteorite Protection

Status of Requirements on Radiation Protection

Design Synthesis

RADIATION TERMINOLOGY

The problem definition states that the lunar shelter must protect the astronauts from 25 rem per month. The rem is defined as Roentgen Equivalent Man where one rem is the dosage of any ionizing radiation that will cause the same amount of biological injury to human tissue as one roentgen of X-ray or gamma-ray dosage. The rem is obtained by multiplying the physical radiation dose (rad) [the amount of energy deposited per unit mass of material] by an energy-dependent quality factor. In this study, the quality factor used in the conversion of physical dose to dose equivalent is that recommended in reference [2].

The use of the megaelectron volt (MeV) is also used extensively in the report. The MeV is a unit of energy and is equivalent to 1.602×10^{-13} Joules.

The required thickness of the radiation shielding for the lunar shelter was expressed in inches. However, shielding is sometimes expressed in terms of its areal density. For example, a shielding requirement may suggest the use of 20 g/cm^2 of water to effectively protect the crew.

SOLAR FLARES

Unlike on Earth, lunar inhabitants will not have the protective cover of an atmosphere or magnetic-field regions as shields against radiation from outer space. More precisely, the two primary sources of radiation exposure in space are:

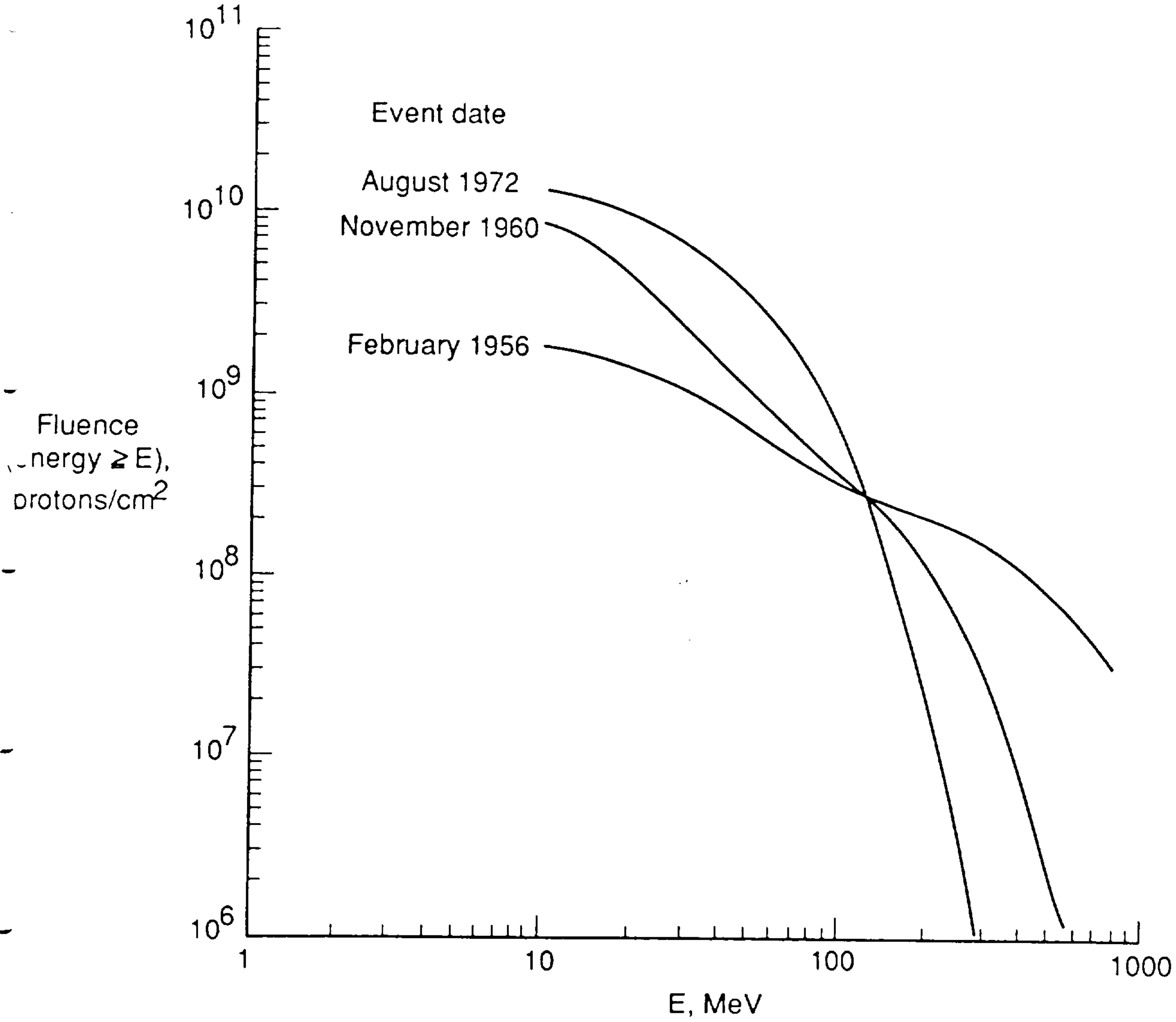
1) Galactic Cosmic Rays
2) Solar particle events which consist of high energy protons, X-rays, gamma rays, electrons, and neutrons.

Galactic cosmic rays must only be considered for missions 4 to 6 months or longer, Ref [2]. Observations have also shown that if the shielding against the high energy protons is effective, the absorbed doses from other solar radiation are not significant.[3] Therefore, full attention has been placed on protecting the astronauts from solar flare events composed of high energy protons.

In order to protect the astronauts from solar flares, data had to be acquired on the energy possessed by protons in large solar flare events. The three largest solar flare events recorded in the last half century are:

1956:	produced one tenth the protons as the 1972 flare, but delivered far more protons than other flares.
1960:	exhibited characteristics intermittent to the others.
1972:	produced the most protons but had fewer protons with energies greater than the other two events.

In order to protect the astronauts from the possibility of such a large scale solar flare, the lunar emergency shelter should be designed to provide shielding against events like those described above. A graph of the time-integrated proton flux spectra for the three listed solar flare evens can be seen in the following



Time-integrated proton flux spectra for three anomalously large solar proton events

GENERAL REQUIREMENTS ON RADIATION AND MICRO-METEORITE PROTECTION

Statement of Need

An emergency lunar surface shelter is to be designed to house up to four astronauts for up to five days. The astronauts would seek refuge inside the shelter when there was an occurrence of a solar flare event or their vehicle or other shelter was unable to support and protect them. In addition to radiation protection, the shelter structure would help protect against the unlikely event of micro-meteorite impacts. The basic problem for the radiation protection team was to design a lunar shelter capable of protecting astronauts from a large solar flare event like those stated on the previous page. Design specifications and specific requirements are outlined and listed below.

Design Requirements

Due to the high cost of transporting materials into space, the radiation shield should be designed as compact and light weight as possible while providing maximum radiation and thermal protection.

The radiation shield should be kept simple thereby making it reliable.

The radiation shield should be capable of providing the astronauts with protection at any given instant. The shield should be able to be deployed quickly because high energy protons from the sun can reach the moon in less than ten minutes.

The shield should be designed so that it will be ready to protect the astronauts from the possibility of a solar flare event when they are away from the permanent lunar base. Therefore the shield can not depend on machinery to ready it for a proton shower thereby increasing its simplicity.

The radiation shelter should minimize the need for new technology by using existing designs when possible.

The shield should not interfere with mobility. Therefore a very large and massive structure should not be used. A design with has a relatively low center of gravity should be used to minimize the possibility that the shelter would tip over while in transport over the rugged lunar surface.

From an economical standpoint, the use of lunar materials should be utilized instead of material that needs to be transported to the Moon from Earth.

The radiation shelter must be designed to withstand pressurization so that the astronauts can take off their space suits.

The shelter should be designed so that it is simple to operate under emergency conditions.

The radiation shield should have low maintenance because the astronauts will not be able to exit the shelter during a proton shower.

Due to extreme temperature changes that occur on the lunar surface, the shielding material and design must be able to withstand the induced thermal stress and strain encountered in such an environment.

Structural materials should be selected with corrosion protection in mind, along with strength and durability characteristics.

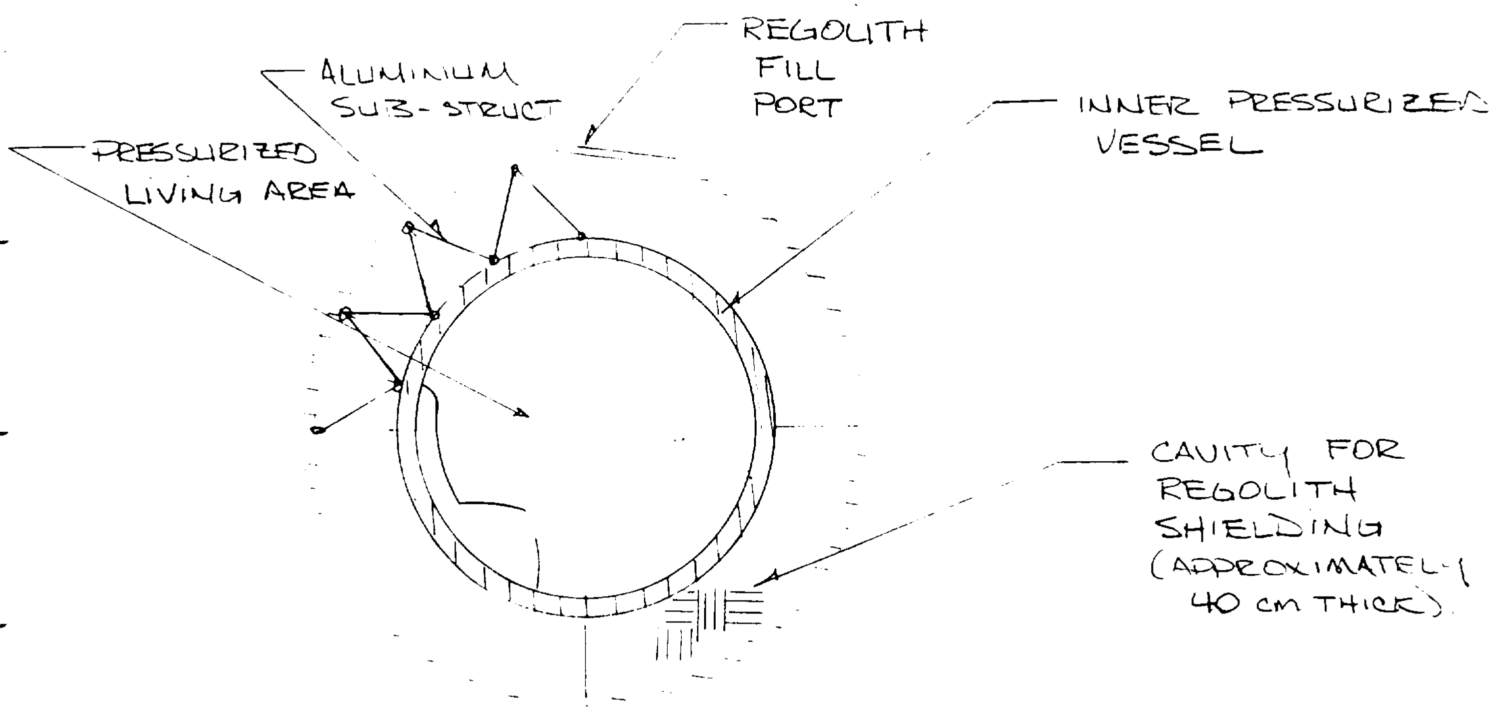
STATUS OF THE REQUIREMENTS ON RADIATION PROTECTION

Requirement	Status
25 rem/month protection to BFO	Use of Al and regolith as shielding
Four person habitable environment	300 ft^3 habitable volume
Minimize cost	Use existing technology and regolith
Minimize weight	Use of regolith, has a density $=1.5 g/cm^3$
Thermal protection	Use of regolith and carbon felt to insulate crew compartment from temperatures ranging from -200°F to 200°F (shade vs. direct exposure to sun)
Simple in design and construction	Shield consists of few, non-moving parts
Dependable	Shield always ready to protect since the shield is pre-furbished at the permanent lunar base.
Quickly deployable	Shield is pre-furbished at the permanent lunar base.
Minimize the need for new technology	Shield consists of Al and regolith
Allow mobility	Size and weight has been minimized, low center of gravity has been achieved using a cylinder.

Requirement	Status
Use of lunar materials	Regolith supplies some radiation and thermal shielding.
Allow for pressurization	Aluminum structure will be capable of withstanding the 101 kPa cabin pressure.
Simple to operate in emergency	Shelter requires no initial setup by the astronauts since it has been pre-furbished at the lunar base.
Low maintenance	Shield does not depend on any machinery or moving parts which must be periodically checked and maintained.

Design 2:

The second design basically consisted of an thin outer aluminum cylinder which contained a second, thick walled, aluminum cylinder inside of the first, as shown in the figure below.



Design 2 - Mobile Shelter

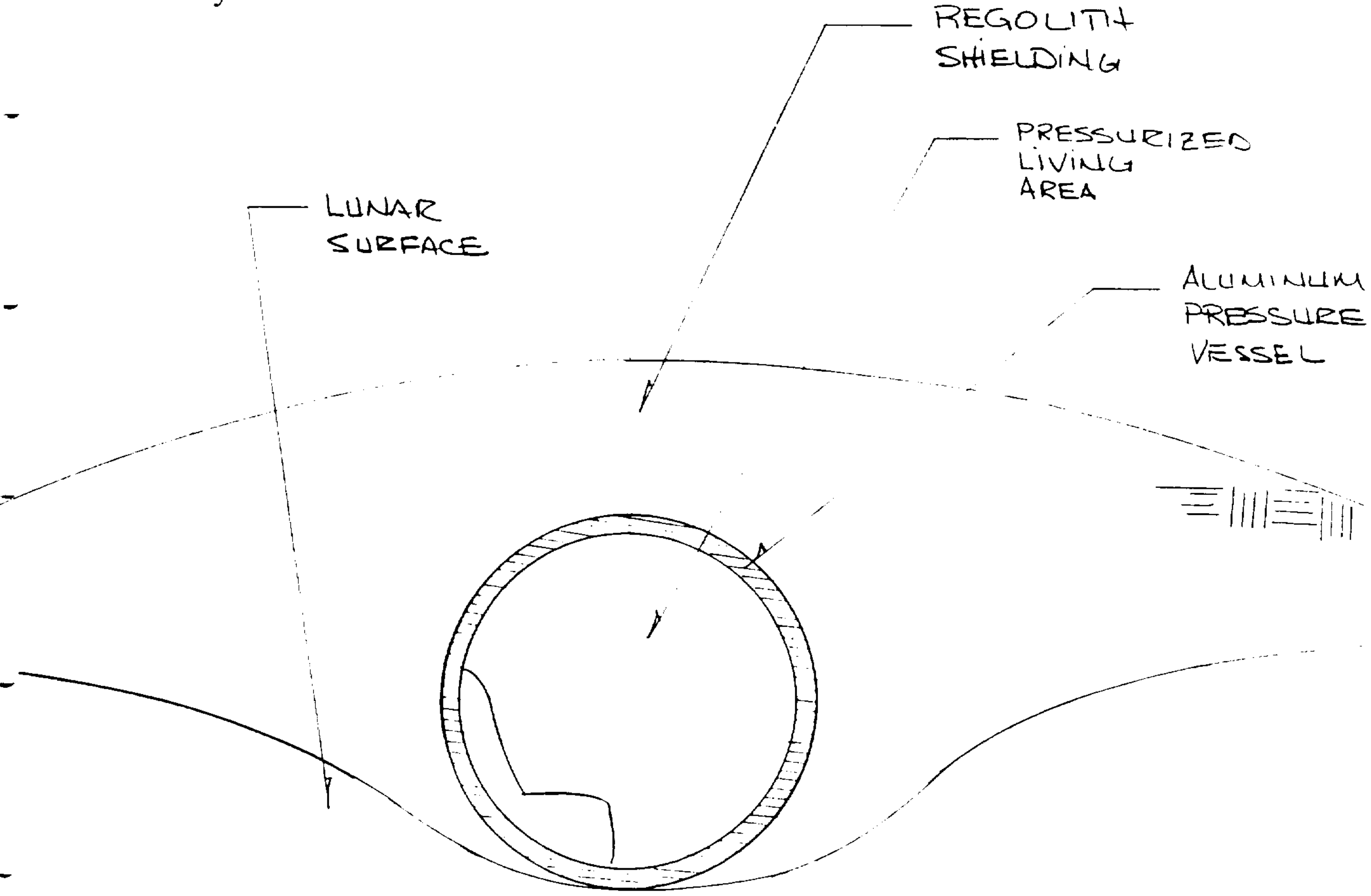
The smaller cylinder would serve as the living quarters for the four astronauts. It would be supported by an aluminum truss substructure placed at equal distances along the length of the emergency shelter. Sifted regolith will be placed between the outer and inner cylinders as the primary shielding material. Regolith can be placed in position by fill ports at the top of the shelter. The regolith will not only provide the necessary radiation shielding, it will also serve as a thermal insulation medium and shock wave attenuation material. An objective behind the use of regolith was to minimize the number of materials that had to be transported to the Moon. In order to protect the astronauts from radiation exposure larger than 25 rem/month (produced by the three largest solar flares recorded in the last half century), a regolith thickness of approximately 44 cm will be required. See appendix A for specific design calculations.

DESIGN SYNTHESIS

Four designs were considered for radiation shielding against the three largest solar flare events in the last half century. The incorporation of ideas from the first three proposed designs led to the fourth and final design for the radiation shield.

Design 1:

The first design was a permanent shelter made of a thick aluminum cylinder buried by regolith, as depicted in the figure below. The thick layer of regolith is used as the radiation shielding material. This particular design posed questions as to the ability of the astronauts to use such a facility in the event they were on a mission that placed them at a great distance from the shelter. In this event, the astronauts would have to return to the shelter quickly. This design would be acceptable if it were not for the fact that the mode of transportation to the shelter could fail, thus leaving the astronauts in a situation of great peril. Because of this potential for disaster, this design was eliminated and replaced with one that allowed mobility.



Design 1 - Permanent Shelter depiction

The obvious problem with this particular design is the large mass of regolith required, as moving such a large and massive structure would be difficult. Possible problems with the substructure were also of concern because the connecting points will experience cyclic fatigue due to thermal expansion and contraction. Other shielding materials used in conjunction with regolith would reduce the required thickness of the shield. This concept was employed in the third design.

Design 3:

The third design utilized the basic structure of the second design except the aluminum truss structure would be replaced by a polyethylene honeycomb which is impregnated with TiH_2. The reason the for using such a material can be found in reference [5]. This report on <u>High Effectiveness Shielding Materials and Optimal Shield Design</u>, states that the shielding ability of the new polynated materials are found to be highly superior to that of the shielding materials in common use. The use of these new materials will allow for the reduction in shield thickness and total mass. Because polyethylene has a low density and is a hydrogenous material, it would serve as an ideal radiation shield. The honeycomb structure would have two primary functions: first, its geometrical shape would serve as a strong substructure and second, its cell shape design would provide an optimal shock wave attenuation barrier. The honeycomb cells would be filled with regolith on the Moon in order to maximize radiation protection and to add additional structural strength by filling the cell voids.

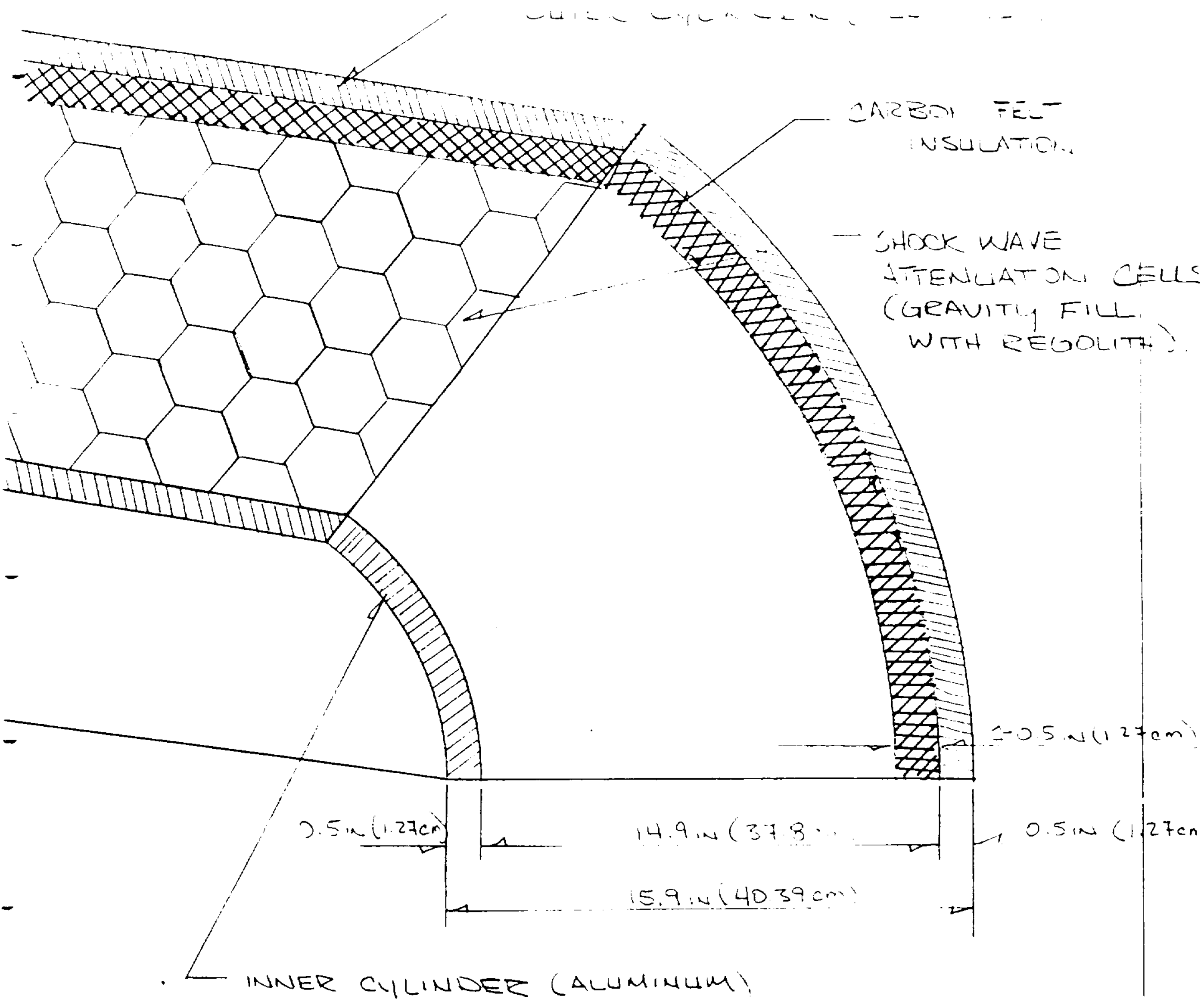
Questions were posed as to the strength of the polyethylene when considering the extreme temperature differences present on the Moon's surface. The surface temperature of the shelter facing the sun will average 200^0F (93^0C), while the shaded side will average -200^0F(-128^0C). Because the polyethylene is impregnated with another material, this caused concern as to separation of material and crack propagation. For these reasons, a different structural design must be proposed in order to guard against possible structural problems.

Design 4:

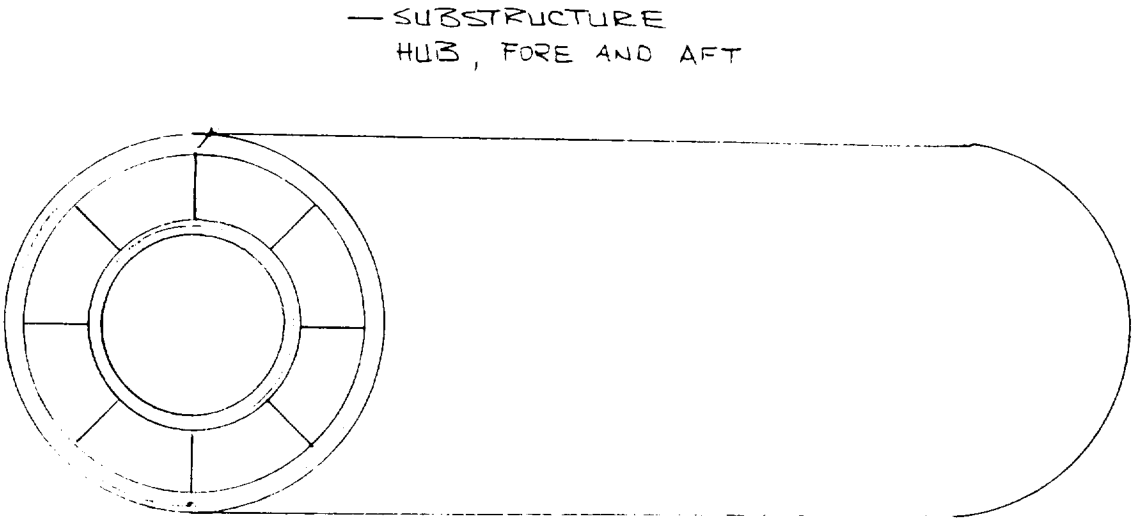
The final design incorporated ideas from the above three design proposals. The outer and inner shell will be 1/2 inch (1.27 cm) thick aluminum-titanium alloy (Al 2219). Between the two cylinders lies 14.9 inches of a regolith filled honeycomb structure. The typical shield section diagram shows these design parameters. The aluminum will provide a rigid structure while the honeycomb will act as a substructure and provide micrometeorite protection. With this configuration, the radiation shield will have a mass of 8402.99 kg; see appendices. (Note that this calculation does not include weight considerations for the end sections, suspension, furnishings, equipment, or supplies) The polyethylene should no longer be impregnated with the TiH_2 and will be a uniform material. The main reason for choosing this alternative is that the overall effectiveness of the TiH_2 is not clear for this type of application. The report mentioned is based on gamma ray absorption and not proton flux. Because of the potential of the loss of human life, a decision was made that the shielding would provide the proper protection without making unnecessary assumptions. The assumption that was avoided was the relation of shielding thickness to effective radiation protection on the part of the TiH_2 component. As stated in the report mentioned above, the results of the calculations presented should not be taken to represent realistic shield design and performance. When further research shows that titanium hydride is truly superior to conventional material, the final design can be changed to one that includes TiH_2.

To minimize the effects of thermal fatigue, an insulating material should be placed between the outer shell and the honeycomb structure. Thick carbon felt material (about 0.5 inches (1.27cm)) will provide the necessary thermal protection for the polyethylene structure. With this configuration, the polyethylene substructure will have protection from extreme thermal fluctuations. Regolith will still be used to fill the cell voids. The regolith can be installed into the shelter through fill ports at the top of the shelter. The process of installing the regolith would involve either a pumping method or a conveyor type transport to the fill ports at the top of the shelter. As stated earlier, the regolith will add to the effectiveness of the radiation shielding and strength of the structure. Because the regolith will not be in place during transport to the Moon, it will be necessary to add a supporting substructure at the ends of the shelter. The shelter substructure diagram that follows details the ends of the shelter. The design of the access door can possibly take care of the support at that end of the shelter. All calculations concerning the shielding and material thickness are contained in appendix B.

Radiation dose calculations were made by Reference [2] and Reference [3] using the BYNTRN computer codes. The BYNTRN code solves the Boltzmann transport equation, taking into account all energy dependencies and scattering interactions. This code is used when detailed dose calculations are required.



Typical shield section (not to scale)



Shelter substructure (not to scale)

The fourth design gives protection from the most pressing problems. Those problems are radiation, decompression, and hypervelocity (velocities above 5000 ft/sec (1524 m/s)) impacts. Even though meteorite impacts are highly improbable, they need to be addressed because the occupants of the shelter are many thousands of miles from safety.

The overall radiation shielding is a composite. This composite consists of the aluminum structure, regolith and polyethylene honeycomb. The combination of these materials reduces the mass of the structure while increasing the efficiency of the shielding. The honeycomb structure in combination with the regolith provides some protection, however minimal, against hypervelocity projectiles. The calculations concerning the shielding thickness and hoop stress evaluations are contained in appendix B.

MOBILITY

MOBILITY
CONTENTS

INTRODUCTION TO MOBILITY

The mobility of the LSES can be considered an important safety feature. This mobility allows the astronauts to leave the base on extended lunar excursions with the security of having full radiation shielding and life support systems within close proximity.

The following section is an analysis of the mobility options available for the LSES. Some of the design considerations are similar to those for an earth vehicle, but the Moon's environment presents some additional requirements. The main factors in mobility include terrain and soil mechanics, mobility objective, and vehicle load.

The mobility of the LSES can be separated into three main systems:

Tracking System
Suspension System
Transport System

Each system will be evaluated according to the requirements that shall be presented in the following section. The overall design summary appears at the end of this section.

INTRODUCTION TO TRACKING

A vehicle will move across the ground only if the ground can support its weight without much resistance to motion. This motion has a vertical component, "flotation", and a horizontal component, "traction". Too much traction creates a bulldozing effect, while not enough traction promotes free-rolling of the vehicle.[6] These two factors are particularly important in the mobility of the LSES.

It has been determined that the Moon's regolith can support a contact pressure of 7 to 10 kPa.[7] Therefore, the surface area of the tracking system must be large enough to support the weight of the emergency shelter.

REQUIREMENTS FOR TRACKING SYSTEM

The contact area of the tracking system must provide adequate flotation for lunar gravitational conditions to prevent sinkage into the loose regolith.

The tracking system must resist a free-rolling motion that is promoted by the uneven lunar terrain.

The vehicle will be required to traverse the uneven lunar terrain while maintaining control and remaining in contact with the ground as much as possible.

The tracking system must avoid accumulation of lunar regolith which could prevent normal functioning.

This system should be able to absorb a portion of the dynamic load created by the uneven terrain.

The overall design must be relatively simple and ensure ease of maintenance and repair.

The materials used must remain flexible throughout the temperature range of -240 to 220 F.

INTRODUCTION TO SUSPENSION

Since the shelter is going to be mobile, it is necessary to design a suspension system to prevent excessive jolting that could damage the interior equipment or the vehicle itself. The demands on a lunar suspension system are similar to those on earth. It needs to provide support for bouncing and a damping effect to compensate for the lower gravitation field on the Moon.

REQUIREMENTS FOR SUSPENSION SYSTEM

The suspension system must be able to absorb the dynamic load associated with the uneven terrain. This dynamic load will be partially absorbed (passively) by the tracking system.

Because of the uneven lunar surface, the suspension system should provide independent components to help maintain contact with the ground.

Lunar dust must be prevented from interfering with the system.

The suspension system is also responsible for preventing the vehicle from bottoming out during lunar excursions.

The materials and technology used must be compatible with the overall design goal of weight minimization.

INTRODUCTION TO TRANSPORT

The purpose of the transport system is to ensure that the astronauts can easily reach the LSES in the case of a solar flare or other emergency. In other words, this system defines the means by which the shelter can travel to any place the astronauts can travel.

REQUIREMENTS FOR TRANSPORT SYSTEM

This system will ensure that the temporary shelter is within the range for astronauts to reach in case of emergency.

The transport design should be light weight, relatively simple, and ensure ease of maintenance and repair.

The method of transportation should also minimize power usage for the LSES and be compatible with other lunar vehicles.

ALTERNATIVE SOLUTION PRINCIPLES

Each system was analyzed according to existing technology, and several alternatives were investigated to determine the best solution principle. The following is an outline of the alternative solution principles for each system.

Tracking System

- Wheels
- Jointed Legs
- Track

Suspension System

- Mechanical
- Magnetic

Transport System

- Internally Powered
- Externally Powered

ALTERNATIVE SOLUTIONS

TRACKING SYSTEM

WHEELS: Wheels are extremely reliable and mechanically efficient, making them the preferred mobility option for many missions. There are various wheel types and sizes that can be used, but they have a limited surface contact area.

JOINTED LEGS: Jointed leg locomotion systems are extremely complex in nature. They are plagued by large dynamic loads and non-uniform motion, making them inefficient in their energy usage. The potential for jointed legs lies in their ability to traverse extremely uneven terrain, such as a three foot vertical step.

TRACK: Track locomotion systems are well suited for use on the lunar surface. Their large surface contact area increases performance and flotation characteristics. Tracks on earth have a high frequency of breakdown, which can only be corrected by making them very heavy and sturdy. A tracked system is also complicated in design.

SUSPENSION SYSTEM

MECHANICAL: Mechanical suspension systems are the most commonly used systems because of their simplicity, dependability, and cost. A combination of one or more of the following make up a mechanical suspension system: torsion bars, springs, dampers, struts and shock absorbers.

MAGNETIC: Magnetic suspension systems are still in the conceptual design phase. Two examples of this complex technology are superconductive and permanent magnet cores.[8]

TRANSPORT SYSTEM

INTERNALLY POWERED: An active transport system has its own power supply and steering system. This type of system has the advantage of operating independent from any other vehicle.

EXTERNALLY POWERED: An externally powered transport system is a passive and relies on another vehicle for travel. The main design parameter for this type of system is the means of attachment of the two vehicles.

STATUS OF REQUIREMENTS FOR TRACKING SYSTEM

Requirement	Status
Contact Pressure less than 10 kPa	Met: With six wheels, each having a ground contact area of 0.43 m^2, the contact pressure is 9.4 kPa.
Maintain Ground Contact	Met: The flexure of the wheels will improve the level of control and help maximize ground contact.
Avoid Dust Accumulation	Met: The mylar cover that surrounds the wheel will guard against lunar dust buildup.
Absorb Dynamic Load	Met: A major purpose of designing flexible wheels is to absorb a portion of the dynamic load. This in a sense makes the wheels a part of the suspension system.
Simple Design/Maintenance	Met: Utilizing the existing technology for the tracking system increases simplicity and dependability.
Maintain Flexibility	Met: This factor influenced the material selection for the wheels. Kevlar 49 will maintain sufficient flexibility for the lunar temperature ranges.
Resist Free-rolling	Met: The wheel design accounts for sufficient contact area to resist a free-rolling motion.

STATUS OF REQUIREMENTS
FOR SUSPENSION SYSTEM

Requirement	Status
Avoid Dust Accumulation	Met: The protective sleeve around the suspension system will prevent lunar dust from entering the system.
Absorb Dynamic Load	Met: The torsion bar suspension system will enable the shelter to be towed over the uneven lunar terrain with minimal deflection of the chassis and internal components.
Maximize Ground Contact	Met: Having independent suspension for each wheel will improve the vehicle's handling and control by maximizing ground contact.
Weight Minimization	Met: Hollow shafts are used wherever possible.
Maintain Flexibility	Met: The material used will become more rigid in the colder temperature range but will maintain adequate flexibility.

STATUS OF REQUIREMENTS FOR TRANSPORT SYSTEM

Requirement	Status
Close to Astronauts	Met: Since the shelter can be towed by another lunar vehicle, the astronauts will have easy access to the LSES in case of emergency.
Light Weight	Met: The decision to design the shelter to be towed was highly governed by the weight minimization goal. The additional constraint, however, is that another lunar vehicle must be capable of pulling this additional mass.
Minimize Power Usage	Met: The LSES requires less power since the transport system is passive (being towed).

TRACKING DESIGN

Wheels were chosen as the best solution principle for the tracking system. In the past, they have proven to be an excellent mobility choice for lunar mobility systems. Wheels are mechanically efficient, can be designed into light weight systems, and provide excellent reliability.[9] Jointed legs were ruled out because of their mechanical complexity, and a tracked vehicle was ruled out to minimize weight and add simplicity.

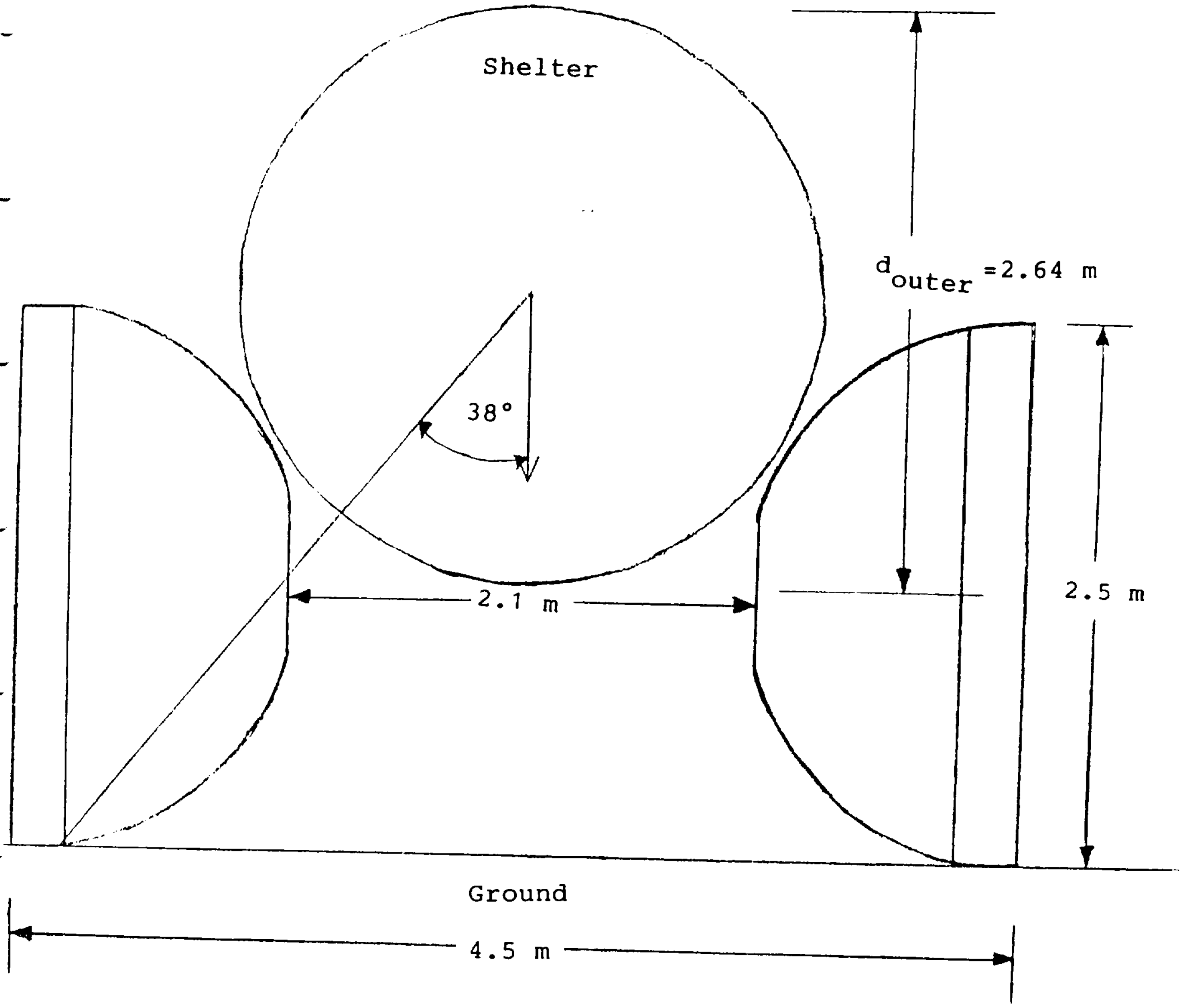
The wheels were modeled after the design for the 1990 Lunar Articulated Remote Transportation System.[10] This design was selected for its relative simplicity, improved ground contact for control, light weight, and dependability. The wheels are a hemispherical shell, supported on the inside by an array of curved ribs, as shown in the wheel diagram. Traction is accomplished by the stainless steel wire mesh and the fiberglass reinforced cleat.

The use of wire mesh reduces weight and increases the coefficient of friction to promote rolling as opposed to sliding. The cleats are in the shape of an inverted 'V' to further prevent the shelter from sliding in any direction. The wheel spacing and maximum roll angle were calculated by the scaled drawing below. The bottom of the chassis was assumed to be at the centreline height of the wheel base. This assembly provides a maximum roll angle of 38 degrees, well above the expected angles to be traversed. Both the shell and ribs shall be made of Kevlar 49 (with a protective radiation coating). This material is ideal for maintaining flexibility over the extreme temperature ranges of the Moon.

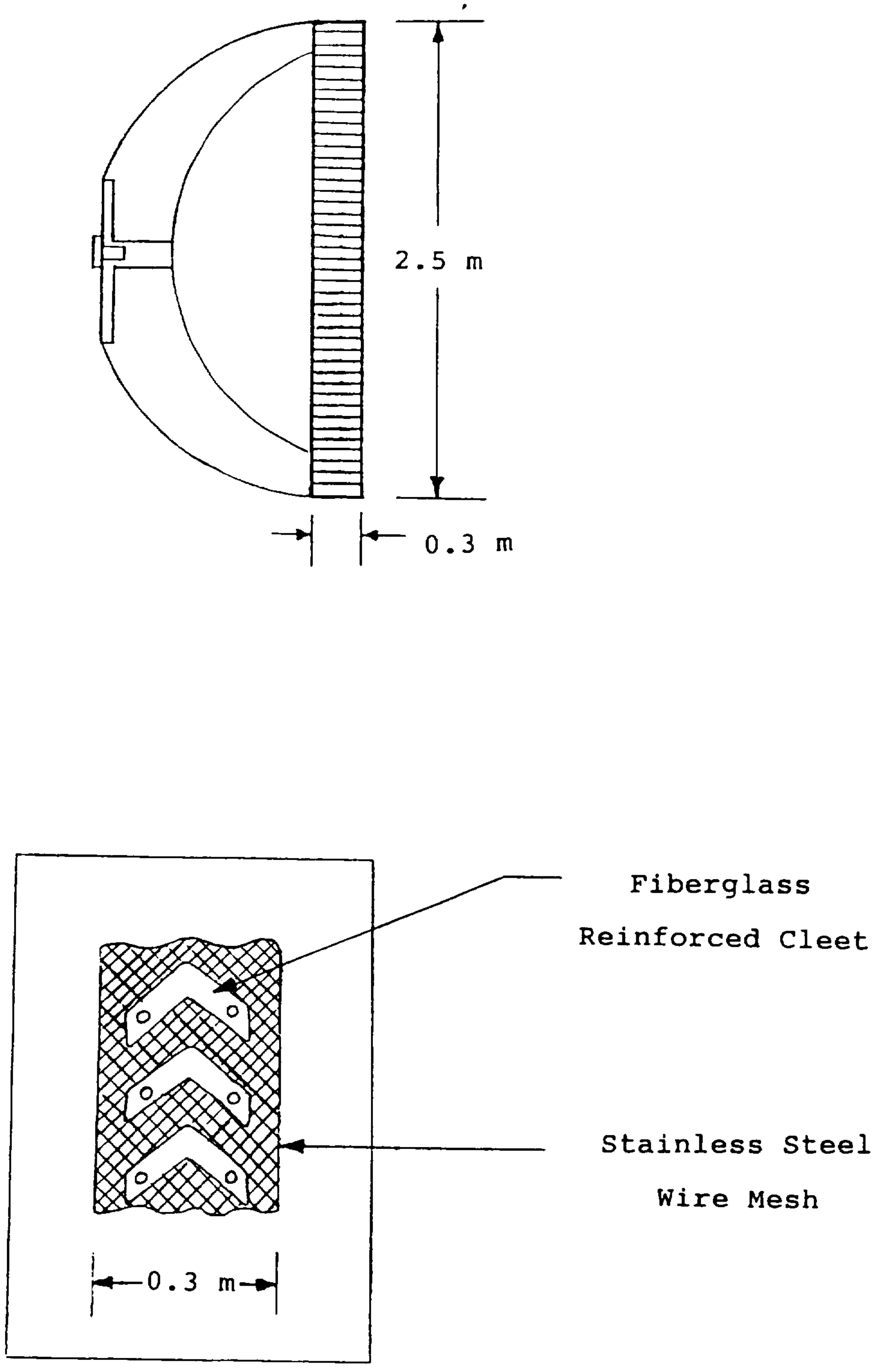
Protection from lunar dust will come from the Mylar cover. Since the buildup of this dust could interfere with the normal functioning of the system, the cover is an important safety factor in the design. Mylar was selected for its light weight, flexibility, and ability to coat other materials for protection.

Wheels have tremendous versatility, including size, configuration, and number. Because of the weight associated with the radiation shielding material, six hemispherical wheels are needed to best fit the design requirements. Both two and four wheeled systems were considered, but neither provided adequate contact area to support the shelter within reasonable dimensions. These calculations are shown in Appendix C.

The main problem with wheels in terrestrial, all-terrain applications is their small "footprint". The Moon's regolith can support a maximum contact pressure of 10 kPa. With the estimated shelter weight of 18 kN (3 kN per wheel), the optimal wheel dimensions were determined as shown in the wheel drawing. An increased contact area increases the rolling resistance, but lowers the bulldozing resistance. Therefore, the ideal contact area involves a balance between these two factors.



Wheel design



Wheel construction

SUSPENSION DESIGN

A mechanical suspension system was chosen over a magnetic type. The underlying factors in this decision include weight and power minimization, cost, and simplicity. Since the LSES will not be manned when in motion, the improved comfort level associated with the other two technologies is not a major constraint.

The primary functions of the suspension system are to absorb the dynamic load associated with the uneven terrain and to prevent the bottoming out of the vehicle. The flexible wheels will only take care of a small portion of these problems.

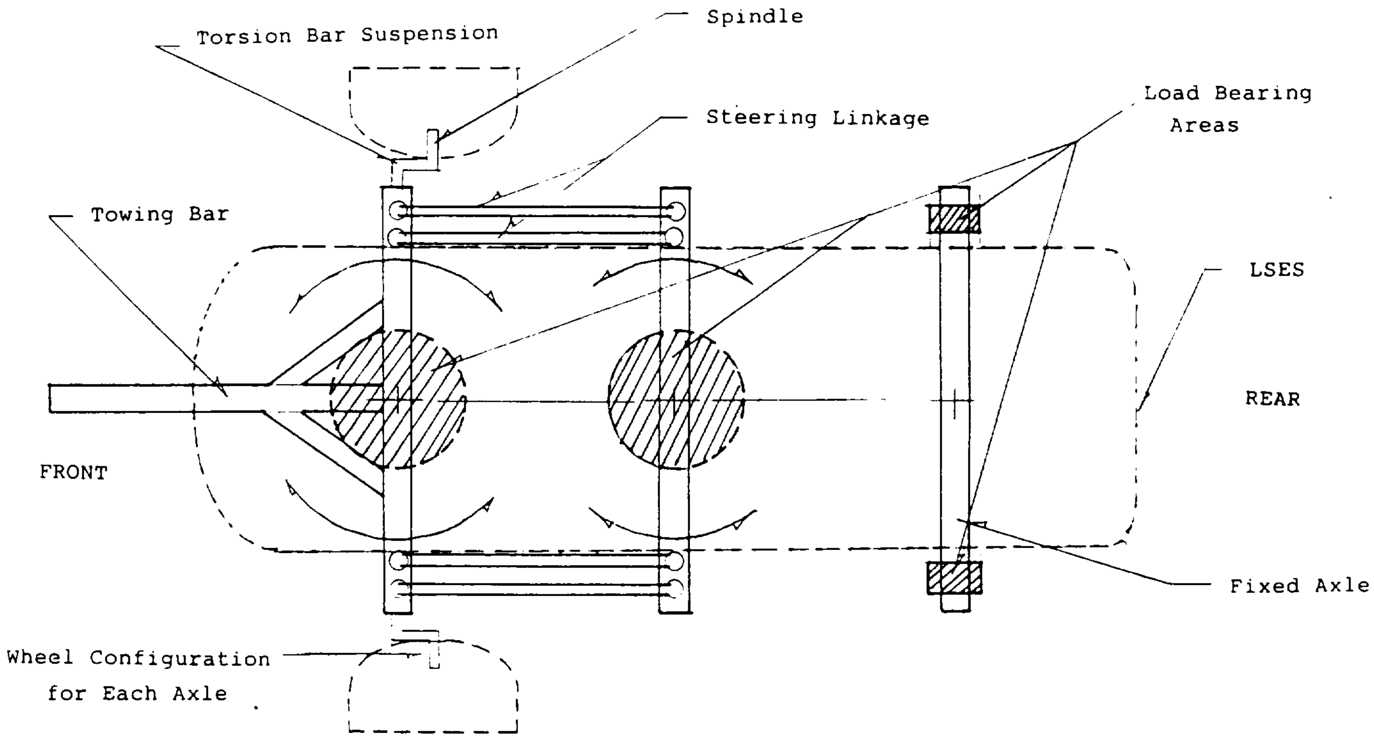
The chosen suspension system is a torsion bar mechanism. the reason for using this type of suspension is based on simplicity, ease of maintenance, reliability, and ease of implementation into the overall design of the chassis. In addition, this type of design will allow for simple and quick modifications according to the lunar terrain to be traversed. Furthermore, this system provides a low center of gravity which is necessary to help prevent roll.

The chosen six wheel configuration requires the suspension to accomodate a suitable towing system. This system requires that the rear axle be stationary and the front two axles pivot; one pivot point for each axle. A suspension system using coil springs or leaf springs would be impractical due to the complexity of the resulting system, in addition to multiple possible modes of failure. Refer to the suspension layout diagram for system outline.

Each of the six wheels will have its own suspension system. These independent components will provide maximum ground contact for the variable lunar terrain which, in turn, will maximize control and safety in lunar excursions.

A flexible mylar cover is designed to protect the torsion bar system from the accumulation of lunar dust. This device will not add any significant weight and will increase the lifetime and reliability of the suspension system.

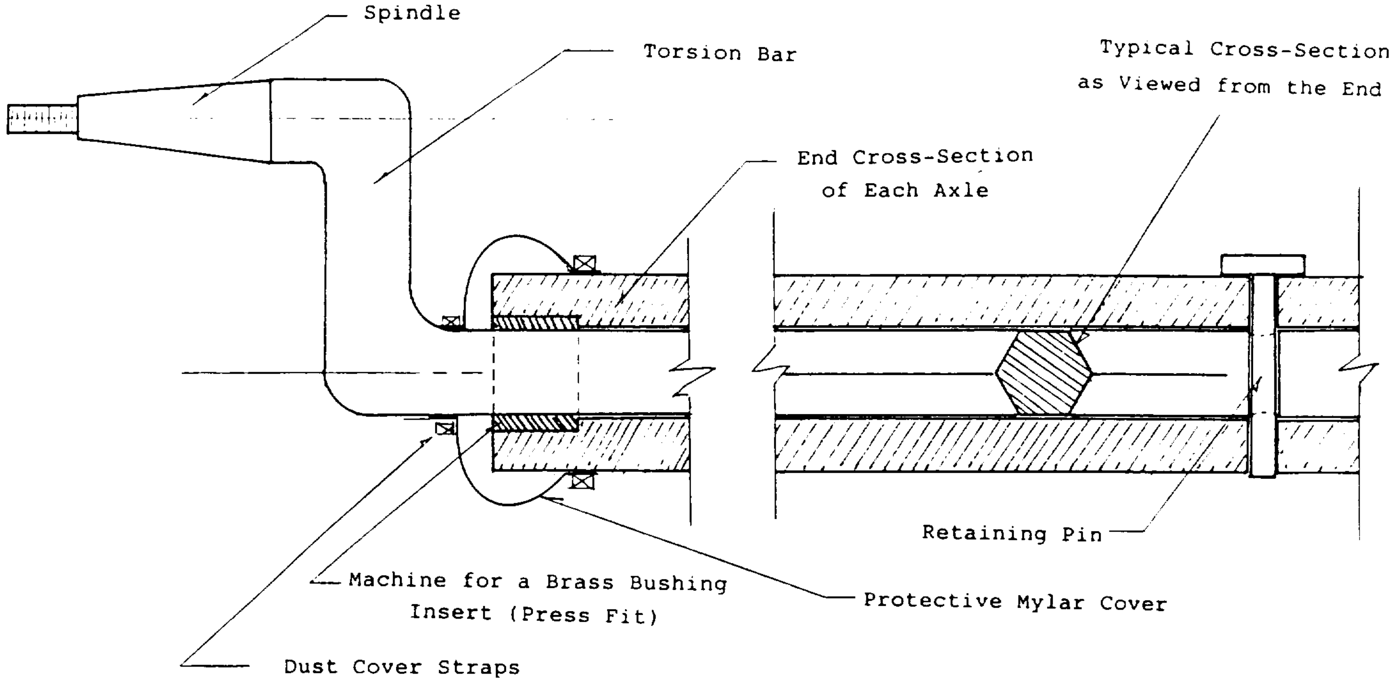
The suspension layout diagram shows the location of the four load bearing areas. The two shown on the fixed axle are rigid supports for the lunar shelter chassis. The two circular load bearing areas consist of four rigid plates; one mounted to each axle and one mounted to the lunar shelter chassis. each load bearing area must be sufficiently large to withstand the resulting moment induced



Suspension layout

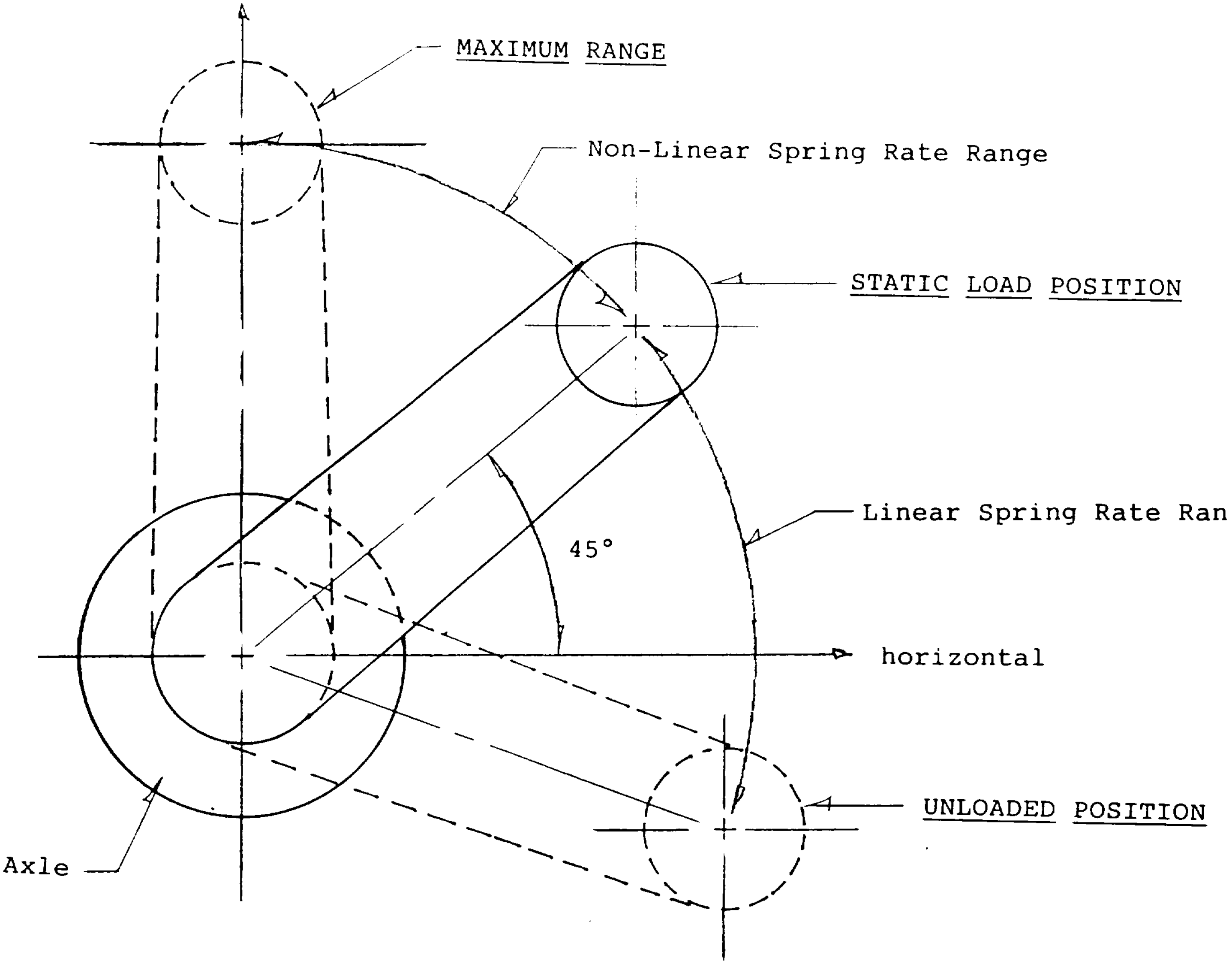
by the torsion bar suspension and/or inclined terrain. the moment induced by the torsion bar susension can be compensated for by translating the load to a position above the spindle. Steering attitude of the middle axle is accomplished by two sets of steering linkages attached to the front axle. The length and positioning of the steering linkage can be adjusted to provide the proper steering angles.

The torsion bars are designed to lock into position using a hexagonal configuration on one end (refer to the torsion bar diagram). A retaining pin is used to fix the torsion bar in place. A pliable protective dust cover is placed at the end of the axle to prevent the lunar dust from entering the brass bushing insert. The bushings are necessary to minimize frictional wear between the torsion bars and each axle. The appropriate wheel base dimension shoulkd be sufficiently large to avoid intereference between the wheels and chassis.



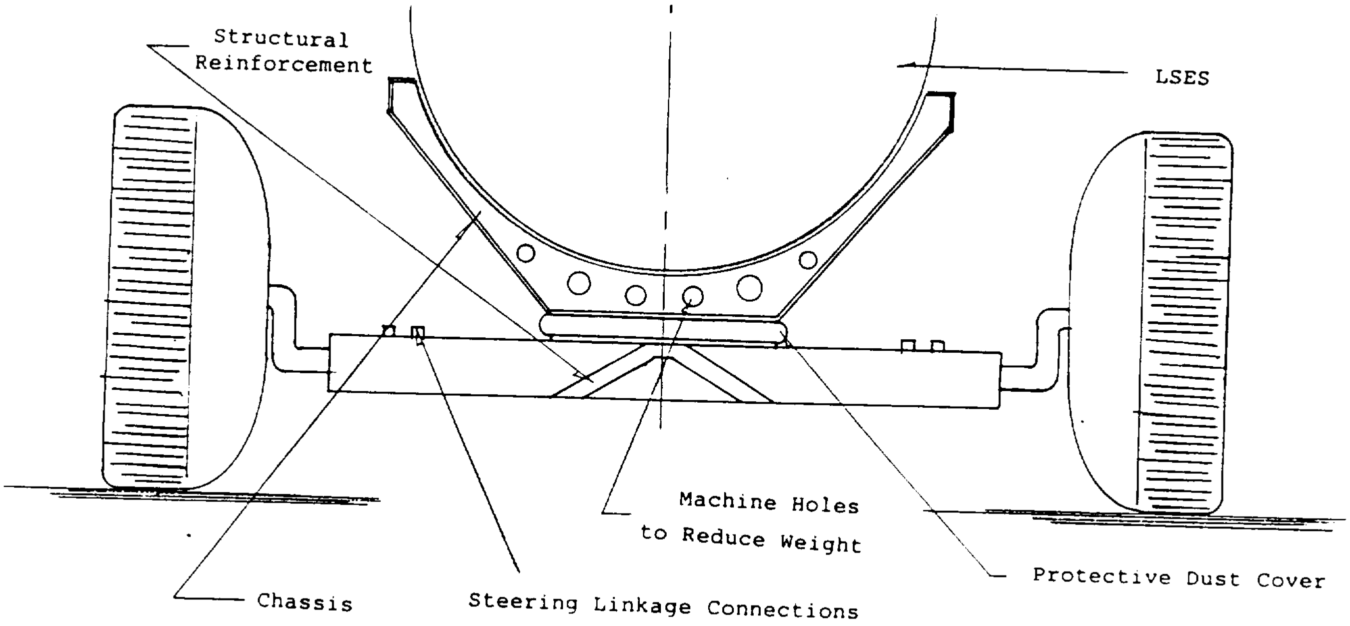
Torsion bar configuration

Under static load conditions, the torsion bar position will be approximately 45 degrees from the horizontal; see range of motion diagram. In this position, the spring rate or spring constant will not be linear for positions approaching 90 degrees. As long as the twing speed is below approximately 15 mph (24.1 kph), there should not be a need for dynamic damping devices. All wheels are specified to have sealed bearings with protective dust covers. The two front load bearing surfaces are to be teflon coated to minimize friction and wear. The pivot points will have large machined pins to transmit the towing forces. At these pivot locations, sealed roller bearings will again be used. Dust covers will be needed for the circular load bearing areas. Specifications for the dust covers will include having the capability to rotate with the motion of the towing bar.



Torsion bar range of motion

The chassis is in the form of a cradle onto which the cylindrical shelter is attached (see front profile). It consists of seven curved beams which follow the curvature of the cylinder plus three straight beams which run along the length of the chassis, connecting the curved pieces. The chassis is constructed of the same aluminium-titanium alloy as was used for the shelter walls. This material was selected for its high strength-to-weight ratio and weldability. By attaching the cradle in many locations, tensile and compressive loads can be well distributed throughout the entire structure.



Front Profile

TRANSPORT DESIGN

The transport system consists of a simple ball and socket hitch with slight modifications (curved edges) to allow some vertical pivoting. This mobility will allow the astronauts to leave the base for extended lunar excursions with the security of having full radiation shielding and life support systems within close proximity.

The hitch is made of the same aluminum as the chassis. Weight is minimized by this passive transport system, since the power and steering systems are located on the vehicle that will do the towing. There is a trade off in that less power is required by the LSES, but the towing vehicle will require more power.

HITCH DESIGN

The connecting hitch between the LSES and the towing vehicle must allow for pitching, yawing and rolling relative to the two vehicles. This is accomplished with a ball and socket joint. The following design allows for 30 degrees of yaw (turning in the horizontal plane), 30 degrees of pitch (vertical plane) and 360 degrees of roll. Under normal operating conditions, the hitch would never be subjected to angles greater than these.

The socket is mounted permanently on the towing vehicle, rigidly attached to the chassis. The shaft will, similarly, be rigidly attached to the cradle chassis of the LSES. All relative motion between the two will take place at the ball and socket joint, as in a conventional trailer.

The hitch will be constructed of the same material as the chassis since it possesses a high strength to weight ratio and has proven to be durable and reliable. To determine the thickness of the shaft, a worst case scenario was used where all of the shelter's weight was supported by it (see appendix D).

DESIGN SUMMARY

The tracking system for the LSES is a set of six flexible, hemispherical wheels, supported by an array of curved ribs. Kevlar 49 is the material used to ensure flexibility. The stainless steel wire mesh and the fiberglass reinforced cleat provide the traction over the loose lunar regolith. A Mylar cover is used to prevent the buildup of dust within the system.

The suspension design is a torsion bar system capable of supporting the vehicle and absorbing the dynamic load associated with the uneven terrain. Each wheel has independent suspension for maximum ground contact and a mylar dust cover.

The transport system for the LSES is a ball and socket hitch that will allow the shelter to be attached to another vehicle. This passive system minimizes the weight and power requirement of the shelter.

POWER

POWER
CONTENTS

Introduction

Power system requirements

Status of power system requirements

Predicted power system allocations

General description of power system alternatives

Guidelines for selection

Power system comparison

Power system selection

Start-up and shutdown procedures

Summary

INTRODUCTION

Power system selection is generally a function of mission duration and power required. Six power systems are in use or under development at the present time. They are the radioisotope thermoelectric generator, the photovoltaic solar array, the solar dynamic system, the nuclear reactor system, the battery and the fuel cell.

The purpose of this section of the report is to select the power supply for the emergency lunar shelter based on system mass, volume, availability of fuel and deployed area. Its specific features will be outlined at the conclusion of this section.

POWER SYSTEM REQUIREMENTS

The emergency lunar shelter power system should operate for a maximum of five day/night periods and supply continuous energy at a rate of 10.7kW. Only critical systems, such as life support, were considered. Power need and allocation were extrapolated from preliminary power requirements for NASA's lunar base and space station. [1,11,12].

Because the lunar shelter is portable, the power system must operate safely and at a close proximity.

The system's weight and volume should be minimized to provide portability and decrease earth to moon transportation costs.

Deployable area of subsystems external to the shelter must be minimized to prevent damage caused by solar flares, lunar dust, and meteorites.

STATUS OF POWER SYSTEM REQUIREMENTS

Requirement	Status
Supplies 10.7 kW nighttime power	Met: The present day primary fuel cell with cryostorage is capable of power levels less than 25kWe.
Provides continuous power (5 days)	Met: The present day PFC is recommended for short duration missions(less than 10 days).
Operates safely	Met: The PFC requires no radiation shielding but does require safety precautions that prevent hydrogen explosion.
Is in close proximity to shelter	Met: The PFC doesn't produce radiation and operates at a temperature of 355K. It may be insulated to operate within the shelter.

Minimizes volume	Met: For the given duration, the PFC posses the lowest volume of all systems compared (2 cubic meters)
Minimizes mass	Met: The PFC possesses the lowest mass of all systems compared. (1112kg)
Minimizes deployable area	Met: The PFC requires the smallest deployed area of all systems compared. (18 square meters)

PREDICTED POWER SYSTEM ALLOCATIONS

The allocation of power given in the table below is an extrapolation of power requirements of NASA's lunar base and space station [1,11,12]. They are ,therefore, only a prediction of the lunar shelter's power needs. Final power assessment is dependent on the final design of the shelter.

Table 1 Power System Allocations

System	Power Requirement
Communications	0.5 kWe
Life Support	8.0kWe
• Air production and Revitalization	
• Air handling	
• Heating/Cooling/Humidity control	
• Food Storage/Preparation	
• Housekeeping	
• Water production and maintenance	
• Waste Control	
Lighting	0.3kWe
Radiation Protection	0.5kWe
Airlock	0.8kWe
Work Stations	0.2kWe
Electrical Power Distribution	1.0kWe
• Conversion and Control	
• Power Storage	
Total	10.7kWe

GENERAL DESCRIPTION OF POWER SYSTEM ALTERNATIVES

Solar Power

Solar Dynamic

A solar dynamic (SD) system uses a solar concentrator to concentrate solar energy into a high temperature receiver. This energy is used to heat the working fluid of a dynamic energy conversion (DEC) cycle (Brayton, Rankine or Stirling cycle). For lunar night operation, a thermal energy storage (TES) material provides heat to the DEC.

SD systems are still in the development phase for space operation but promise power levels between 3 and 300 kWe. [13]

Advantages

Future SD systems offer potential for efficient, lightweight, relatively compact power.

Thermal storage provides a more energy dense medium than electrochemical batteries. Also, SD systems generally weigh less than power systems using photovoltaic (PV) arrays. In addition, TES requires less deployed array area.

Disadvantages

During the lunar night, power is only provided by TES. Therefore, if the emergency shelter was needed for the last five days of the fourteen day lunar night, fourteen days of thermal storage would be required.

The thermal energy fluid and power subsystems cool during a lunar night. An additional power source may be required to produce temperatures for normal DEC operation.

The production of heat is dependent on sun angle. At times, power consuming sun tracking devices may be needed.

Solar Photovoltaic

Solar photovoltaic arrays (PV arrays) are static conversion devices which directly convert solar radiant energy to electrical energy. Present state of the art PV systems use a nickel hydrogen batteries for night storage. Regenerative fuel cells are being considered as storage devices for future PV arrays.

PV power systems have been used extensively for satellites requiring power levels of 2kWe and below [14]. PV arrays using regenerative fuel cell storage are being considered for a future manned lunar outpost requiring 100kWe.

Advantages

During a lunar day, PV systems directly convert radiant energy into solar energy. Power conversion units and storage devices are not needed during daylight operation.

PV systems are a low risk technology because they are presently operational.

Solar energy is an abundant available energy source.

This system requires little or no moving parts.

Disadvantages

The present state of the art nickel-hydrogen battery possesses a low energy density (14W-h/kg). Massive systems would result from high power requirements or missions of long duration.

Regenerative fuel cells produce their own fuel supply (H_2 and O_2) through the electrolysis of water. Electricity from a PV solar array is needed to produce electrolysis[15]. During the fourteen day lunar night, this is not possible.

PV efficiency is dependent on sun angle.

PV systems require a larger array area than SD systems.

Nuclear Power

Radioisotope

Radioisotope Thermoelectric Generators (RTG's) produce heat through the radioactive decay of an isotope (usually Pu-238). The heat produced on the hot side of a thermoelectric device provides a temperature difference for a thermoelectric device. The temperature potential is converted directly into electricity by the thermoelectric device.

Previous RTG's have produced power no larger than 500We. Radioisotopes may be used to produce heat for dynamic energy conversion cycles to produce power ranging from 1 to 10kWe [16]. These systems are called Dynamic Isotope Power systems. (DIPS)

Advantages

RTG's have been used for planetary exploration missions and have operated for up to 12 years in space. They are an existing long-life space power source.

RTG and DIP systems are compact and require less radioactive shielding than nuclear reactors.

They don't require sunlight. RTGs and DIPs are autonomous systems whose operation is independent of sun orientation and position.

RTG systems have a small amount of moving parts.

Disadvantages

RTGs are only used for low power operations.

RTGs and DIPs are potentially dangerous systems which require shielding from radioactivity.

They are dependent on rare and costly radioactive isotopes. Plutonium 238, for example, costs approximately $20 million per kWe [17].

Nuclear Reactor

Nuclear reactors provide heat through the controlled fission of heavy nuclei (such as uranium-235). This heat is converted to electrical energy through the application of a dynamic energy conversion cycle.

Nuclear reactors remain in the development stage. They are predicted to supply from 10kWe to 100MWe of power for space applications [17].

Advantages

The nuclear reactor seems to be the only realistic power option in the megawatt regime.

Nuclear reactors are autonomous and independent of sun position and orientation.

With minimal shielding, nuclear reactors possess less mass/kWe than solar and chemical power sources. Therefore, by shielding them with regolith, transportation costs are less.

They have long operating lifetimes. The SP-100 nuclear reactor designed for a future lunar base is predicted to operate for seven years [18].

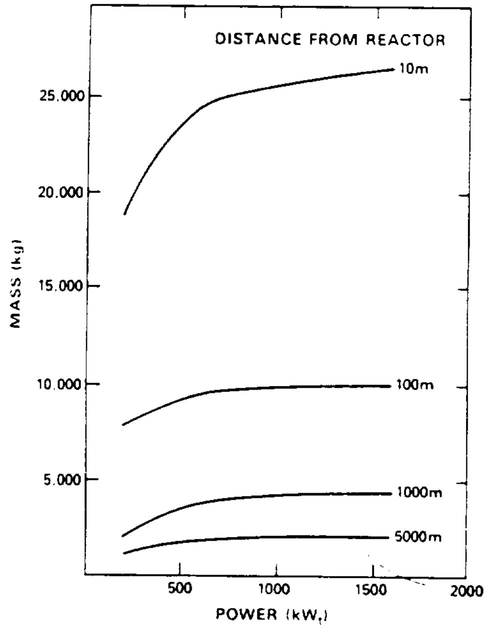
Disadvantages

Radioactive systems are potentially hazardous.

A delay is needed before power is supplied.

The portability of the system requires that the nuclear reactor be placed in close proximity to crew members. The mass required for shielding crew members located 10m from the reactor exceeds 15000kg [18].

MANNED SHIELD MASS



Typical 4 pi shield mass needed for a manned space mission.

Electrochemical Power

Batteries

A battery is an electrochemical cell arrangement of two electrodes and an electrolyte which produces current as a result of the chemical reaction within the cell.

Battery powered systems are generally reserved for short duration missions (less than one week) for a maximum power supply of 7kWe [19].

Advantages

Battery power is independent of sun position and orientation.

Batteries are compact and safe energy sources

Disadvantages

Batteries are limited to low power, short duration missions.

Batteries posses a low specific energy. The state of the art nickel-hydrogen battery has a specific energy of 14W-h/kg [19].

Fuel Cells

A primary fuel cell is a form of storage battery in which the chemical energy is stored in a reactant tank outside the cell. The reactants are fed to , or removed from the electrodes when required. A typical space power fuel cell is the hydrogen/oxygen fuel cell in which hydrogen reacts with oxygen to produce water. The release of electrons due to the reaction produces power.

A regenerative fuel cell differs from a primary fuel cell because of its use of an electrolysis unit (EU). The EU converts the product of a fuel cell (i.e. H_2O) into required fuel (i.e. H_2) and an oxidizer (O_2). In this manner, regenerative fuel cells last longer.

Since the successful testing of the space shuttle orbiter fuel cell unit (UTC PC-17C) [20] primary fuel cells are capable of powers beyond 25kWe. Regenerative fuel cells, which are still in development, are theoretically capable of providing power in the 100kWe range.

Advantages

Primary fuel cells are existing technology and have made significant advances. The Apollo fuel cell provided 115 kW-h of energy at a rate of 2kWe in 1968 [20]. The Space Shuttle Orbiter's fuel cell, in 1979 , produced 2600 of energy at a rate of 26kW.

The efficiency of fuel cells increase for low power levels

Fuel cells are not dependent on sun orientation or position.

Fuel cells posses little or no moving parts.

Disadvantages

Fuel cell systems are primarily used for short duration missions (less than 10 days).

Certain safety precaution must be followed to prevent the explosion of hydrogen.

A delay is needed before power is provided.

The following table gives a summary of the levels of power provided by each power system. Because of the massive shielding requirement of the nuclear reactor and the insubstantial power provided by the battery and RTG systems, they will not be considered as a power supply.

Power Level Summary

Power System	Power Range
Solar Dynamic	3 to 300 kWe
Solar Photovoltaic	<2kWe to >100kWe
RTG	< 500kWe
Dynamic Isotope	1 to 10 kWe
Nuclear Reactor	10kWe to 100MWe
Batteries	<7kWe
Primary Fuel Cells	< 25kWe
Regenerative Fuel Cells	<100kWe

GUIDELINES FOR SELECTION

Power system selection was determined by studies done by NASA on multi-kWe power source alternatives [21], and on recommendations provided by Los Alamos National Laboratory(see Figure 2 below) .

Portability was the main consideration when comparing power alternatives. A power system was chosen which minimized mass, stowed volume and deployed area.

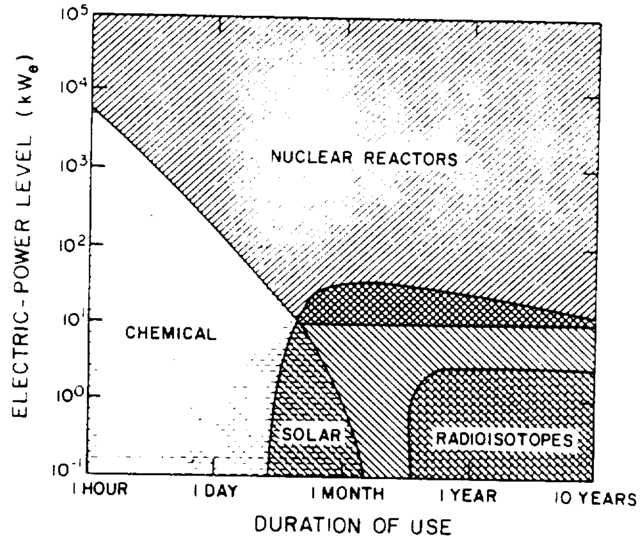


Figure 2. Regimes of possible space power applicability.

POWER SYSTEM COMPARISON

The values of mass, volume and deployed area are compared below for a nighttime power of 10.7kWe. The estimates given are based on a study done by NASA on multi-kWe power source alternatives [21].

Mass Comparison

Figure 3 illustrates the differences in mass for the various power systems. Lithium Fluoride is a storage medium for solar dynamic power systems. Based on a specific thermal energy of 302 W-hr/kg [22], the mass of this medium alone eliminates the SD system from further consideration.

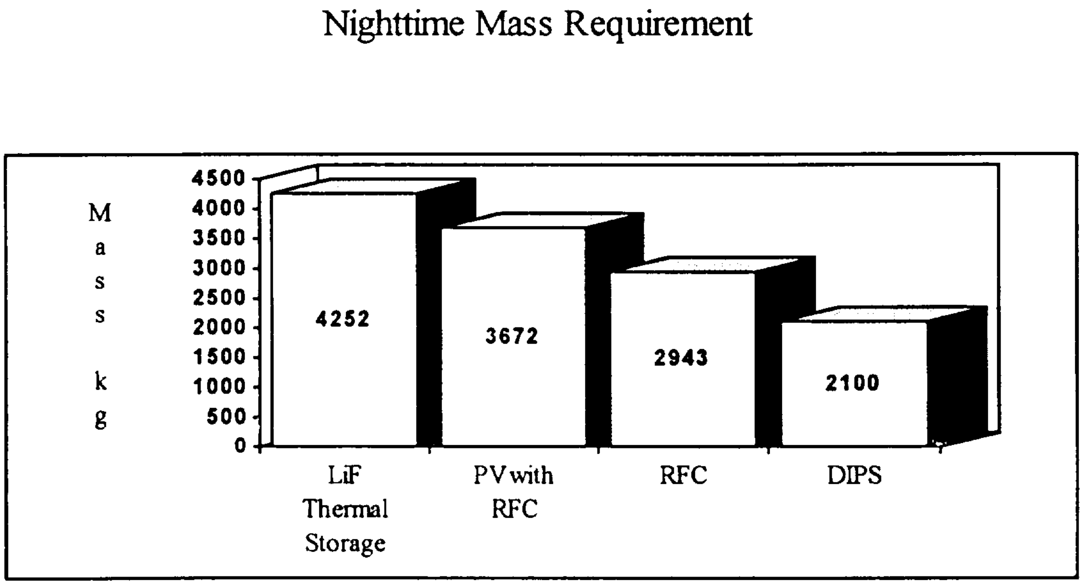


Figure 3. Mass of power systems

Of the four systems compared above, the least massive are the DIP and RFC. Figure 4 compares the mass of the DIP to the PV/RFC system and various fuel cell systems.

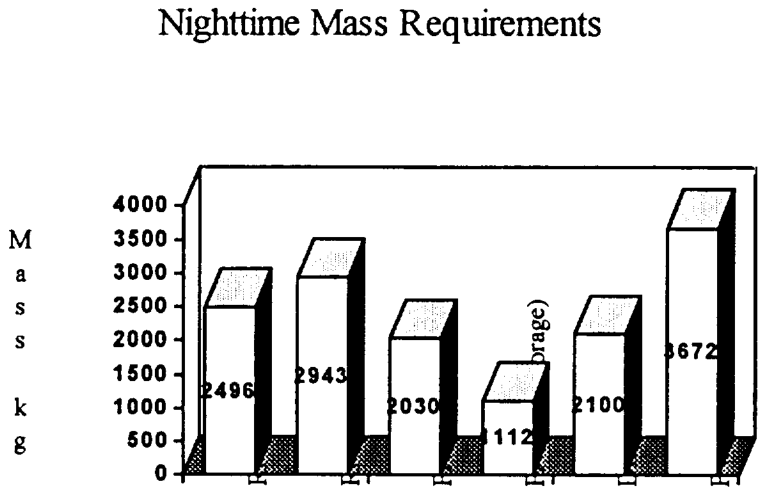


Figure 4 Mass of specific power systems

Volume Comparison

Figure 5 shows a comparison of the stowed volume of each power system. These estimates are based on the combined volume of major system components.

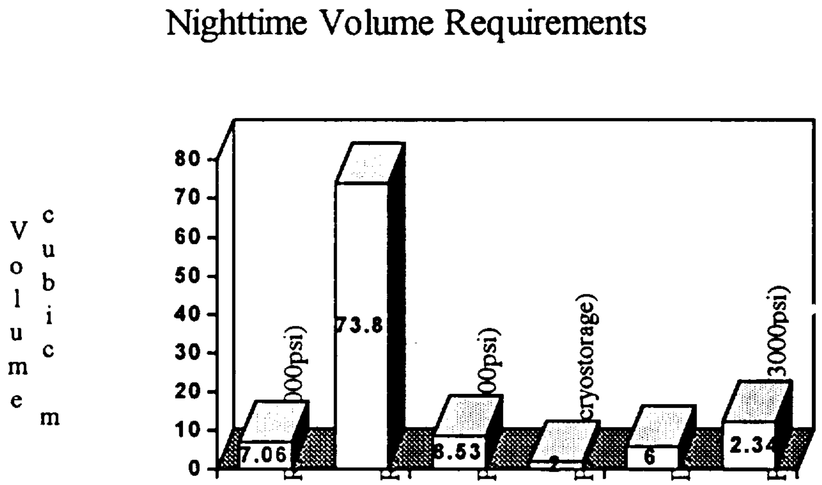


Figure 5 Stowed volume of specific power systems

Comparison of Deployed Area

Figure 6 illustrates the differences in deployed area of these systems. The deployed area is the area of components external to the shelter. For the fuel cells and the DIPS system, the deployed area is the area of the radiator needed. For the PV/RFC system, this area also includes the area of the array.

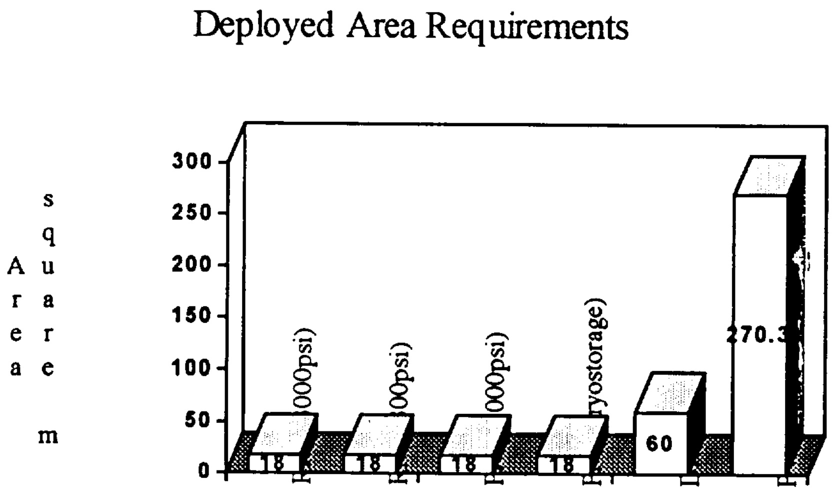

Deployed Area Requirements

Figure 6 Deployed area of specific power systems

POWER SYSTEM SELECTION

Of the power systems compared, the primary fuel cell with crystorage required the least mass, volume and deployed area for the 5 day/night duration at an energy rate of 10.7kWe. Specific attributes of the system are given below [22].

Power System Specifics

Hydrogen-oxygen alkaline fuel cell:	
Current density, mA/cm^2	215-1075
Cell active area, m^2	0.092
Operating pressure, MPa	0.4
Operating temperature, K	355
Conversion efficiency, percent	70
Electrical power management and distribution (PMAD)	
Specific mass, kg/kWe	10
Specific volume m^3/kg	0.00025
Efficiency, percent	90
Radiator	
Effective emmissivity	0.595
Specific mass kg/m^2	5
Rejection temperature, K	355
Sink temperature, K:	
Day	220
Night	20

Fuel cell reactant storage

Cryostorage, psi	15
Specific volume, m^3 per 1000kg reactants	2.6
Tankage mass, kg per m^2 enclosure	42

Totals

Mass, kg	1112
Volume, m^3	5
Radiator area, m^2	18

START-UP AND SHUTDOWN PROCEDURES

Because the PFC system will be used as needed, the astronauts using the system should know the necessary procedures in starting and stopping the system to prevent hydrogen explosion. This section will give a brief explanation of these procedures.

Unfortunately, starting a fuel cell is never a matter of opening the reactant feed valves and turning on a switch. Depending on the characteristics of the system, certain routines must be followed to ensure all cells are functioning according to design and that no mishaps, such as hydrogen explosions, take place.

A start-up procedure claimed to minimize explosions in hydrogen-oxygen fuel cells consists of the following steps [23]:

1) Hydrogen is supplied to the hydrogen compartments for 1 to 10 minutes.
2) After this period of time, an inert gas is blown into the hydrogen compartments.
3) Oxygen is then supplied to the oxygen gas compartments.
4) When the correct open circuit voltage is attained, more hydrogen is fed into the hydrogen chambers.
5) Stack operation is then begun.

Before system shutdown, the reliability and stability of low temperature hydrogen-oxygen fuel cell batteries may improve if the current load is lowered to about 30,A/cm^2.

Astronauts should possess knowledge of the particular start-up and shutdown procedures necessary to begin power production and to prevent disaster.

SUMMARY

Power system selection is generally a function of mission duration and power required. The following systems were compared to provide power for the lunar emergency shelter:

1) Solar Dynamic
2) Solar Photovoltaic
3) Radioisotope Thermoelectric Generator
4) Nuclear Reactor
5) Dynamic Isotope Power Source
6) Regenerative Fuel Cell
7) Nickel-hydrogen battery
8) Primary fuel cell

The power system selected was required to operate continuously and safely at a rate of 10.7kWe and for a maximum of five day/night periods. Because the shelter is portable, a system was selected which could operate in close proximity to the shelter and minimize volume, weight and deployable area.

Although it required safety precautions during its start-up and shutdown processes, the primary fuel cell with cryostorage was chosen because of its portability. The PFC required the least volume, mass and deployed area than any other system considered.

COMMUNICATIONS

COMMUNICATIONS
CONTENTS

ASSUMPTIONS

This section outlines the investigation and design of the Communications system for the LSES. Several alternative systems were studied utilizing the assumptions below and the guidelines presented later in this section.

It is assumed that a lunar base exists which includes the equipment necessary to provide bi-directional communication between the Earth and Moon. This equipment is fully operational, serviceable, and independent of LSES operations.

A maximum required range is set at 1000 km for the system. This allows full communication capabilities for the LSES at any point within the range of lunar vehicles.

Initial audio and telemetry data rate is set at 250 Kbps (Kilo Bits per Second). This rate is supported by all communication links comprising the system.[24]

Satellites and/or space stations exist for relay of communication signals. Linking with these platforms is readily available and fully adaptable.

ASSUMPTIONS

Lunar base with communication link between Earth and Moon.

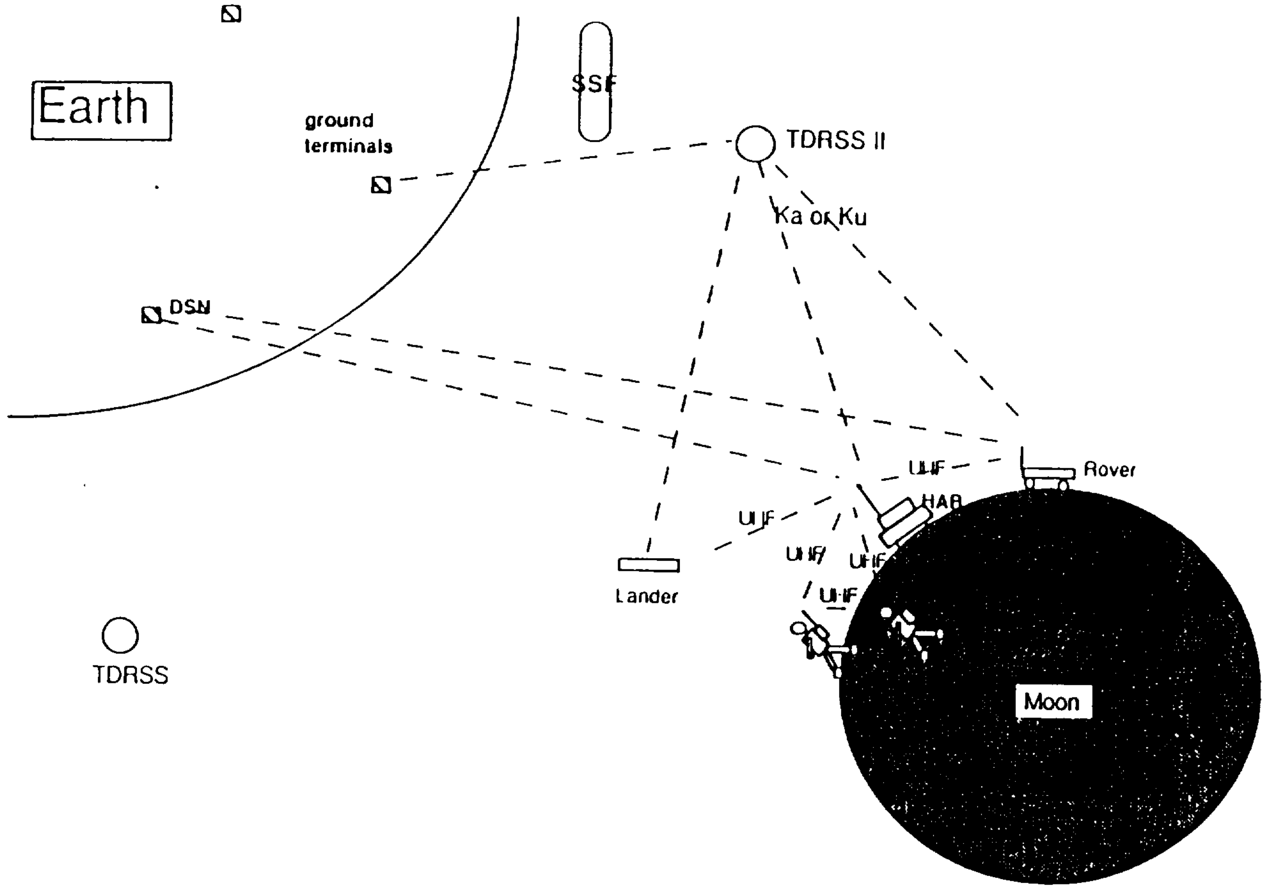
Maximum range of 1000 km. (621 miles).

Audio and telemetry data rate set at 250 Kbps.

Existing satellite and/or space station for communication signal relay.

LUNAR COMMUNICATIONS

The facing diagram depicts the various communication links required for the LSES. Space station, satellite, and lunar base positions are assumed for providing Earth communications. All system requirements and options are further discussed later in this section.



Lunar Communications

SYSTEM REQUIREMENTS

Established links to allow communication between the LSES and each of the following: Lunar base, EVA suits, Lunar vehicles, and Earth. Earth communication is via the lunar base.

Allow communication at any point within the maximum range of the lunar rover. This distance is set at 1000 km (621 miles).

Required to operate within the geophysical and environmental conditions that exist on the lunar surface. This includes terrain fluctuations (i.e. crater walls) as well as a relatively sharp lunar surface curvature. Environmental condition hazards are thermal variance, radiation, nearly non-existent atmosphere, and solar storm magnetic interference.

System power requirement must be low in order to satisfy the overall design of the LSES. Power level is set at less than 2.0 kW. However, the system must be able to handle the required data rate of 250 Kbps.

System reliability and probability of success must be high to ensure that communications are available and accurate at all times. At the same time, hardware parameters of volume, weight, and cost are requisitely minimized.

Human interaction with the system must be simple to allow ease of operation and maintenance. Redundant sub-systems will minimize maintenance requirements and location of equipment within the LSES for easier access.

COMMUNICATIONS REQUIREMENTS

Allow communication between LSES and:

- Lunar base	- Lunar vehicles
- EVA suits	- Earth (via lunar base)

Must allow communication over the entire range of lunar vehicles, set at 1000 Km.

Overcome geophysical barriers such as crater walls and lunar surface curvature.

Resist environmental conditions (radiation, thermal).

Overcome solar storm magnetic interference.

High reliability and probability of success.

Minimal volume, weight, and cost.

Low power requirement (less than 2 kW).

Handle required data rate and human interaction.

DESIGN GUIDELINES

The main design considerations are high reliability and probability of success. This ensures that communications will be available and accurate at all possible locations and in any conditions. Proper design and redundant sub-systems will allow this to be met.

Existing technology will be utilized whenever possible to minimize the need for technological innovation and the related expense. Adapting and upgrading existing equipment will meet design requirements while also satisfying cost requirements.

A modular design will be utilized whenever possible to allow for easier component replacement. This enhances the human interaction aspect by making maintenance easier and more accessible.

Optional equipment will not be included because this is an emergency shelter and space is extremely limited. This will minimize cost, complexity, and contribute to reliability. Additionally, this will minimize the cost of transporting the shelter to the Moon.

Emphasis is put on the system design being able to accept technical changes in the future. This takes into account the possibility of design requirement changes and technology upgrades.

DESIGN GUIDELINES - SUMMARY

High reliability and probability of success.

Use of existing technology whenever possible.

Use of a modular design for low cost and ease of maintenance.

Emergency shelter design without use of any optional equipment.

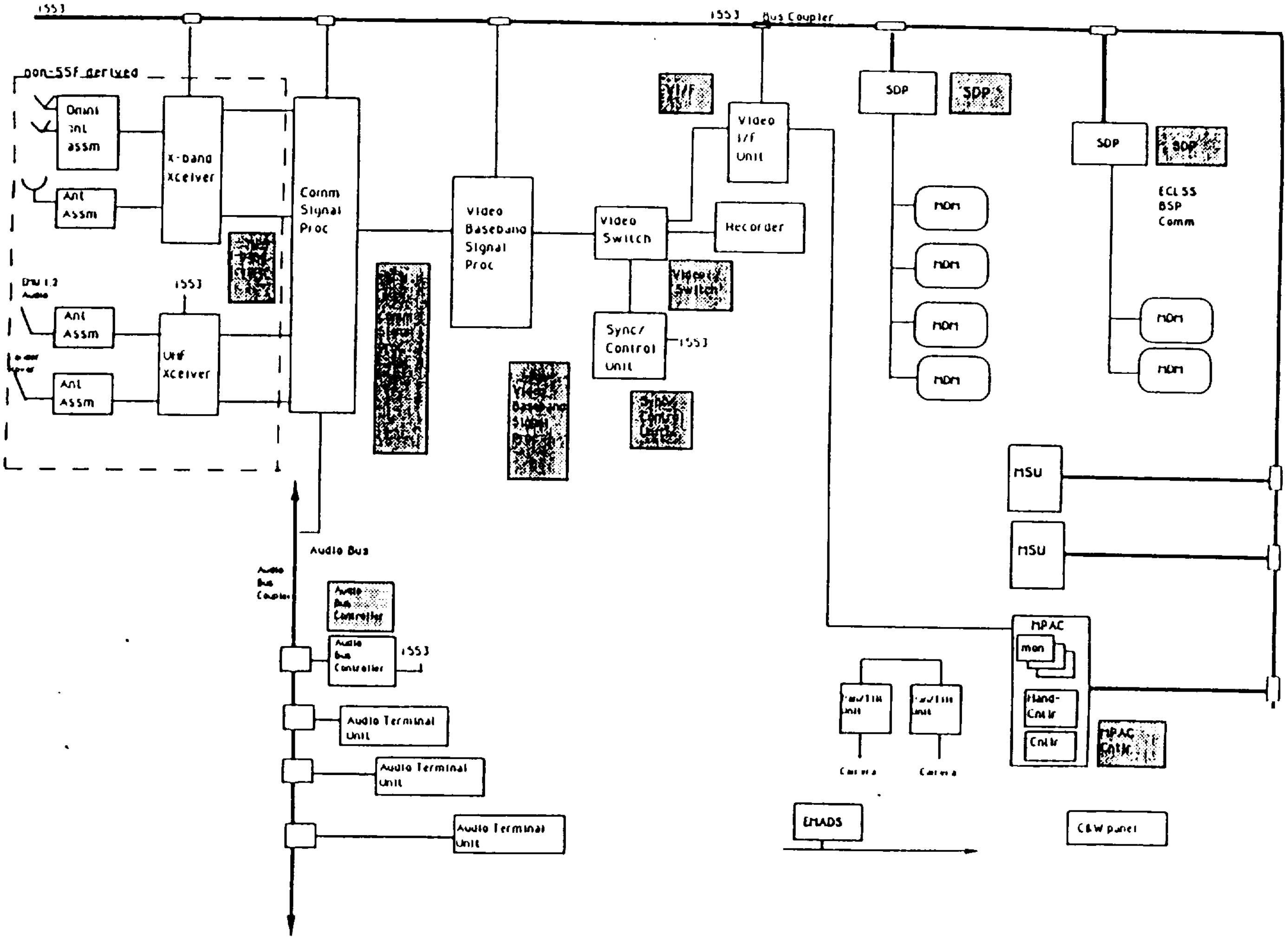
Allow for possible design requirement changes and technology upgrades.

COMMUNICATIONS DESIGN

The facing figure is a block diagram of the communications system for the LSES. The combined communication and data management equipment are distributed processing networks for long-term use on the lunar surface. The main components are the Overall Data Processor (ODP), Multipurpose Control Console (MCC), Multiplexer, Transceiver, and Antenna Assemblies. The ODP provides storage and power for data management and communication control functions. The MCC provides the shelter crew with a centralized workstation for command and control of all communications. The multiplexer allows use of multiple receivers and transmitters with multiple antenna assemblies.[25]

The system is dual redundant in several areas to ensure continued operation in the event of a single failure. Redundant subsystems include power supply, multiplexer, antenna assemblies, and transceiver. With the exception of the power supply, all redundant equipment is maintained in a "cold" ready condition. That is, the equipment is connected to the system but not supplied with power. This reduces the load on the shelter power supply. The communication system backup power supply is connected and powered up to ensure continuity of power at all times.[25]

Antenna assemblies consist of antennas, control equipment, and all required wiring and waveguides. Two omni-directional dipole antennas are used, as well as two paraboloidal aperture antennas.



Communications System block diagram

SHELTER COMMUNICATIONS WITH EARTH

There are several options for communicating between the LSES and Earth. The primary options are listed in the facing chart and discussed below. In selecting an option, consideration must be given to the cost of implementing the system within the shelter. In addition, the restraints of power, weight, volume, and complexity are considered.

The direct communication system involves communication with Earth ground stations without the use of intermediate relays or stations. The system would require high power output and complex control equipment. The benefit would be the lack of dependency on outside systems, such as satellites or space stations.

Communication via satellite involves the relaying of signals from the shelter to an intermediate satellite and then to an Earth ground station. This reduces the complexity and amount of ground equipment required, but still requires a large power output.

Communication via the lunar base utilizes the existing Earth communication equipment aboard the lunar base. Communication signals from the LSES are relayed through the lunar base equipment and then to an Earth ground station. This dramatically reduces the power output requirement, control equipment complexity, and antenna size. The signal from the shelter is relayed to the lunar base via an existing satellite.

Communication via the lunar base is selected due to the significantly lower cost. The lower cost is attributable to lower power output requirement, less control equipment, smaller antennas, and less overall complexity of the system. Another primary reason for this selection is the relative use of this part of the communication system. The shelter is emergency in nature and will be in use for a relatively short time. Therefore, a self contained and complex system is not warranted.

SHELTER COMMUNICATIONS WITH EARTH

SUMMARY OF OPTIONS

Direct communication with Earth

Communication with Earth via satellite

Communication with Earth via lunar base

SHELTER COMMUNICATIONS WITH EVA SUITS AND LUNAR VEHICLES

There are several options for communicating between the LSES and either EVA suits or lunar vehicles. The primary options are listed in the facing chart and discussed below. In selecting an option, consideration must be given to the cost of implementing the system within the shelter. In addition, the restraints of power, weight, volume, and complexity are considered.

Owing to the emergency nature of the lunar shelter, communications with personnel on the lunar surface will be minimal. Also, these communications will be short range.

Communication via satellite involves relaying signals through an in-place satellite to personnel on the lunar surface. Additional equipment will not be required because this system is utilized for other communications.

Lunar surface relay stations makeup a large array of fixed receiving and transmitting UHF stations covering the lunar surface. A single system aboard the shelter would then be capable of communication with all outlying areas. The cost and complexity of this system are both high, as a large number of stations is required for ample coverage.

An independent short range UHF system involves a fixed receiving and transmitting station aboard the shelter and portable sets for use by personnel when outside the shelter. A UHF system ensures accurate and reliable communications even under the effects of high levels of solar radiation.

The independent short range system is selected for its relatively low cost, effectiveness, and self containment. Reliance on outside equipment and power sources is eliminated at no reduction in service. As a backup, the existing satellite system utilized for Earth communications may also be used for lunar surface communications.

SHELTER COMMUNICATIONS WITH EVA SUITS AND LUNAR VEHICLES

SUMMARY OF OPTIONS

Communication via satellite

Communication via lunar surface relay stations

Independent short range UHF system

SHELTER COMMUNICATIONS WITH LUNAR BASE

There are several options for communicating between the LSES and the lunar base. The primary options are listed in the facing chart and discussed below. In selecting an option, consideration must be given to the cost of implementing the system within the shelter. In addition, the restraints of power, weight, volume, and complexity are considered.

Communication with the lunar base is highly probable during the short duration stay within the shelter. This part of the communication system must be highly reliable and include a backup means.

A direct link system involves 'hard wiring' between the shelter and lunar base or a single antenna large enough to allow communication at any distance (up to 1000 km) from the lunar base. The hard wiring is necessarily impractical due to the mobile nature of the shelter while the single antenna would need to be very tall to allow for the curvature of the Moon.

Communication via satellite involves relaying signals through an in-place satellite to the lunar base. Additional equipment will not be required because this system is utilized for other communications.

Lunar surface relay stations makeup a large array of fixed receiving and transmitting UHF stations covering the lunar surface. A single system aboard the shelter would then be capable of communication with the lunar base from any location on the lunar surface (within 1000 km). The cost and complexity of this system are both high, as a large number of stations is required for ample coverage.

Communication via satellite is selected primarily due to the lower cost and not requiring additional equipment aboard the shelter. The direct and relay station alternatives are effective, but both are cost prohibitive or too massive for the limited space availability aboard the LSES.

SHELTER COMMUNICATIONS WITH LUNAR BASE

SUMMARY OF OPTIONS

Direct link

Via satellite

Relay stations

LIFE SUPPORT SYSTEMS

Life support systems include all of the necessary systems to provide and maintain a habitable environment within the LSES. This includes any required equipment as well as integration of this equipment into the shelter. The following systems are discussed in detail:

Environmental Control system

Thermal Control system

Fire Detection and Suppression system

ENVIRONMENTAL CONTROL FOR LIFE SUPPORT SYSTEMS (ECLSS)

ENVIRONMENTAL CONTROL FOR LIFE SUPPORT
CONTENTS

INTRODUCTION

The following section discusses various alternatives for controlling the environment in the Lunar Surface Emergency Shelter. A major part of the ECLSS is the production of oxygen and nitrogen. The life support system will be required to deliver a total of 2,138,400 liters of an oxygen/nitrogen mixture. This total is based on the assumption that each person takes an average of 25 breaths/min. and consumes 3 liter/breath of regular air that is composed of 21% oxygen, 78% nitrogen, and 1% of trace elements. For the purpose of the life support system, the 1% of trace elements need not be reproduced because they are not vital for life support. Each alternative for oxygen/nitrogen production will be analyzed with respect to the following parameters:

mass
volume
power
reliability
efficiency
production of undesirable byproducts
safety

Since safety is such an important requirement, and man made equipment is never 100% fail-proof, a back-up safety system will be incorporated into the final design.

Other functions of the ECLSS involve:

monitoring and maintaining the quality of cabin atmosphere
utilization/removal of carbon dioxide
humidity control

Systems for these functions will be proposed and analyzed according to their efficiency and reliability. The systems that perform these functions will be able to successfully meet the requirements for mass, volume, and power, and none have been known to produce undesirable byproducts.

REQUIREMENTS FOR ECLSS

Requirement	Status
Produce oxygen/nitrogen	Met: by use of cryogenic storage
Mass	Met: by keeping system as simple as possible
Volume	Met: by keeping system as simple as possible
Power	Met: by keeping system as simple as possible
Reliability	High: based upon previous research
Efficiency	High: based upon previous research
Undesirable byproducts	Negligible: based upon previous research
Safety	Met: by incorporation of back-up system
Maintenance of cabin atmosphere	Met:by incorporating air monitors/filters
CO_2 removal	Met:by incorporating separate subsystem
Humidity control	Met:by incorporating separate subsystem

DESIGN GUIDELINES

Mass, volume,and power requirements will all be minimized by use of a simple system. However, the simpler system is not guaranteed to be the most efficient, therefore, efficiency will be determined from research previously performed on the various systems. Reliability and production of undesirable byproducts, such as various gases, will also be analyzed from the research and testing previously performed on each system. Safety of the final design will be met by incorporating a back-up system. Monitoring and maintaining the quality of the cabin atmosphere will be achieved by use of air monitors and filters. A separate system will also be incorporated for carbon dioxide and humidity control. This system will be created from already existing and researched technology.

ALTERNATIVE SOLUTION PRINCIPLES

OXYGEN/NITROGEN PRODUCTION

Automated Subsystem Control for Life Support System (ACLSS)

Use of lunar soil to produce oxygen

- -electrolysis
- -fluorination
- -carbo-chlorination
- -magma oxidation
- -vapor pyrolysis

Physicochemical methods

- -physical methods
- -chemical methods

Electrolysis
- -water vapor
- -carbon dioxide

Bioregenerative

- -plant use
- -animal use

Chemical O_2 generation

- -potassium superoxide
- -lithium peroxide
- -sodium superoxide
- -calcium superoxide

Cryogenic storage

MONITOR/MAINTAIN CABIN ATMOSPHERE QUALITY

Particle counter monitor (PCM)

Major constituent analyzer (MCA)

Trace contaminant monitor (TCM)

Air filters

CARBON DIOXIDE REMOVAL

Lithium hydroxide scrubbers

Four bed molecular sieve

Electrochemical depolarized cell

Air polarized concentrator

HUMIDITY CONTROL

Condensing heat exchangers

Desiccant

4BMS

DISCUSSION OF ALTERNATIVE SOLUTION PRINCIPLES

OXYGEN/NITROGEN PRODUCTION

Various alternative solutions will be discussed for the function of oxygen/nitrogen production. These alternatives will be analyzed as to the various requirements previously introduced.

Automated Subsystem Control for Life Support Systems (ACLSS):

This system requires the use of highly advanced computer networks to generate all the systems necessary for the function of life support. This has been researched by NASA upon the demand of a permanently manned Space Station. Due to the complexity of such a system, the requirements for mass, volume, and power are not feasible for the use in an emergency shelter, despite its ability to be reliable, efficient, and not to produce any undesirable byproducts.

Use of lunar regolith to produce oxygen:

This system is based on the knowledge that lunar regolith contains significant amounts of oxygen. Various methods for the removal of oxygen from regolith are:

-electrolysis
-fluorination
-carbo-chlorination
-magma oxidation
-vapor pyrolysis

This alternative has been only moderately researched for a permanently manned Space Station and, therefore, would require quite complex equipment for use in a temporary emergency shelter. This system would only produce oxygen, therefore, an alternative system would be required for the production of nitrogen. The equipment required for use of this alternative would exceed the mass, volume, and power requirements for a feasible emergency shelter. The reliability, efficiency, and tendency to produce undesirable byproducts is not yet certain since intensive research and experimentation on this system has not yet been completed.

Physicochemical methods:

This system uses physical or chemical methods to perform life support tasks. Physicochemical systems are well understood, despite the fact that they have never been utilized on Earth or in space. Therefore, this system would not be very reliable and not guaranteed to be efficient. This system would be able to perform acceptably with respect to mass, volume, and power requirements. Several components of physicochemical systems have been proven to create hazardous byproducts.

Electrolysis:

Electrolysis systems can be used to produce oxygen from either water vapor or carbon dioxide. Water vapor electrolysis (WVE) can be used to generate a quantity of oxygen for metabolic consumption and provide partial humidity control by removing water vapor from the atmosphere. Oxygen and H_2 are generated from the water vapor in an air stream flowing through an electrochemical module consisting of a series of individual water vapor electrolysis electrochemical cells. Carbon dioxide electrolysis is performed in much the same manner as WVE and produces potable water for crew consumption. These systems would require an alternative system for nitrogen production. The extra hardware required would exceed the mass, volume, and power requirements for the life support system. Electrolysis is reliable, efficient, and produces no known hazardous byproducts.

Bioregenerative systems:

Bioregenerative life support systems utilize plant growth for food, water, and atmospheric revitalization. The biggest stumbling block in the initial phases of developing a bioregenerative life support system is encountered in collecting and consolidating the data. Therefore, these systems have been poorly understood in the engineering community. Additionally, organisms do not have constant, predictable performance characteristics; rather, they operate within a range of performance characteristics that may differ between individuals, as well as between organisms. This fact contributes to this systems unreliability and inefficiency. Bioregenerative systems also utilize a great deal of volume and mass for successful plant growth. This system would not require a great deal of power to be successful. Bio-regenerative systems cannot produce nitrogen and do produce an undesirable byproduct, carbon dioxide.

Chemical O_2 generation:

This system involves the production of oxygen from reactions that take place between various compounds and carbon dioxide. A few of the compounds that have been tested include potassium superoxide, lithium peroxide, sodium superoxide, and calcium superoxide. Problems with efficiency occur during experiments with most of these compounds. Most of the problems that have occurred involve over or under production of oxygen relative to the amount of CO_2 utilized. This system also does not produce the nitrogen necessary for life support in the emergency shelter. This system would operate under acceptable mass, volume, and power requirements.

Cryogenic storage:

Oxygen and nitrogen can be termed cryogens and can be stored as a cryogenic fluid in pressurized tanks. A cryogen is transferred from its tank to the atmosphere by injecting a gaseous pressurant into the ullage of a cryogenic supply tank. This raises its pressure from some base level to a desired transfer level. Cryogenic storage is presently in use for space applications and is, therefore, considered to be efficient and reliable. This system would operate under the necessary mass, volume, and power specifications, and does not produce any undesirable byproducts.

MONITOR/MAINTAIN CABIN ATMOSPHERE QUALITY

Various solution alternatives will be discussed for the function of monitoring and maintaining the cabin atmosphere, monitoring for O_2 and CO_2 as well as for other major constituents and trace contaminants in the cabin atmosphere. If particulates are detected, the system should be able to readily remove them from the atmosphere. In order to satisfy the requirements for this function, all of the alternative solution principles introduced will be utilized in this system. A particle counter monitor (PCM) will be implemented to detect particles from .5 to 100 micrometers. A major constituent analyzer (MCA) will be implemented to detect such substances as N_2, O_2, H_2O, H_2, CH_2, and CO_2. A trace contaminant monitor (TCM) will be implemented to detect various undesirable byproducts that may be produced. Common, durable, and available air filters will be included in the cabin equipment to remove particulates that may build up in the cabin atmosphere.

CARBON DIOXIDE REMOVAL/UTILIZATION

Various alternatives will be discussed to perform the function of either utilizing or removing carbon dioxide that is detected in the cabin atmosphere by the MCA. Of the solution alternatives presented, the lithium hydroxide scrubbers and the 4BMS are the most efficient and reliable for CO_2 removal. The 4BMS could also be implemented for humidity control as well as for CO_2 control. Therefore, it would be more efficient to use the 4BMS for the function of carbon dioxide removal.

HUMIDITY CONTROL

Of the alternative solution principles introduced to perform the function of humidity control, the 4BMS, which utilizes a two-media desiccant bed for water removal, would be the most efficient alternative because of its adaptability for carbon dioxide removal.

DESIGN SUMMARY FOR ECLSS

The final design of the ECLSS utilizes cryogenic storage to perform the function of oxygen/nitrogen production. The oxygen and nitrogen are stored in separate cryogenic storage tanks as cryogens. The cryogens are released into the cabin through the use of a gaseous pressurant. This pressurant, stored in separate pressure vessels, is injected into the ullage, empty space in the cryogenic storage tanks, thereby raising the pressure of the cryogenic storage tank from some base level to the desired transfer level (ramp process). Once the desired transfer pressure is obtained, liquid cryogen is discharged from the tank via a connecting line to a receiver tank (expulsion process). A brief hold period between the ramp and expulsion periods is often utilized to allow stabilization of tank pressure and temperatures before expulsion is initiated. The amount of each cryogen that is released to the cabin atmosphere is determined by the amount of pressurant that is injected into its storage tank.

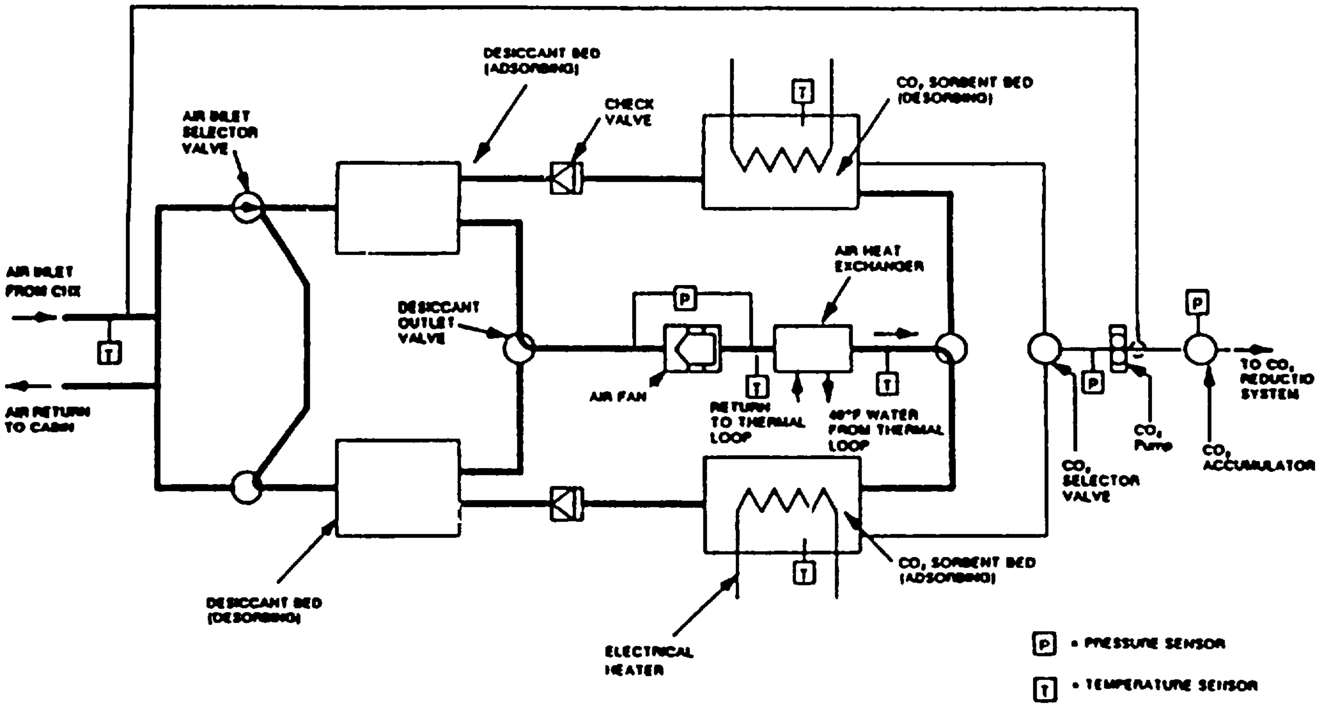
Particulates in the cabin atmosphere will be monitored using a PCM. This device uses an AlGaAs laser diode to produce a light beam at 780-nm wavelength which is scattered by particles in the air sample and detected by a photodetector. The light beam passes through several lenses and an aperture to produce a thin plane in the particle sensing zone. As each particle passes through the sensing zone and scatters light, the photodetector converts the scattered light energy into electrical pulses which have an amplitude corresponding to the particle size. Particles that are monitored are between .5 and 100 micrometers.

Oxygen, nitrogen, carbon dioxide, water vapor, methane, and hydrogen are all detected by a MCA. The MCA is a mass spectrometer which utilizes a single focusing magnetic sector with a Faraday cup detector. It has a capability of monitoring in the mass to charge range of 1 to 48. The instruments response time is less than 100 ms for all gases except water which has a response time of 500 to 800 ms. Vacuum is maintained to the instrument by an ion pump which operates by surface absorption and chemical reaction of gases with the active metals of titanium and tantalum. It has a sampling rate of one sample per minute and draws samples through long, thin tubing from several locations within the cabin.

Trace contaminants are monitored by a TCM. The TCM utilizes a gas chromatography/mass spectrometry principles to analyze both species and quality for mass to charge ratio of 24 to 250. The unit is capable of detecting trace contaminants at a resolution of 50% of the shelters maximum allowable concentration for each species monitored. The typical cycle time is 1 hour. The samples are drawn through tubing similar to that used for the MCA.

Heavy duty air filters will be utilized to filter the air for particulates and trace contaminants. Carbon dioxide removal will be accomplished by a 4BMS, as shown in the accompanying schematic. This uses a zeolite material which has been further modified by the supplier to produce a material which is extremely efficient in absorbing carbon dioxide. This material also has a high affinity for water vapor, therefore, the influent air must be dried, aiding the function by using a two-media desiccant bed. This bed is made of silica gel and a second zeolite material (Linde 13X) with a high water removal efficiency. The influent air, carbon dioxide, and water vapor mixture is first passed through the desiccant bed where the dew point is reduced to a range of -30 F to -90 F. The carbon dioxide is then absorbed in the second 5A zeolite bed until the absorbent material becomes saturated. The carbon dioxide molecular sieve material is then desorbed by a combination pressure and temperature swing process which requires first evacuating the bed, then heating it to 400 F. The desorbed carbon dioxide is then purged from the bed in a concentrated form. During this cycle, the remaining beds are absorbing so that a continuous carbon dioxide removal capability exists at all times utilizing this four-bed concept.

A back-up safety system must be incorporated into this design in case of equipment malfunction. This back-up safety system will utilize easily accessible safety masks that are attached directly to the cryogenic storage system. These masks will operate much in the same manner as S.C.U.B.A. regulators in case of malfunction of the cryogenic expulsion apparatus.



4BMS CO_2 removal subassembly schematic

THERMAL CONTROL SYSTEM FOR LIFE SUPPORT (TCS)

THERMAL CONTROL SYSTEM FOR LIFE SUPPORT
CONTENTS

Introduction

Design Guidelines

Status of Requirements for Thermal Control System (TCS)

Thermal Control System Design

Alternative Solution Principles

INTRODUCTION

It is necessary to provide a safe and comfortable temperature for the astronauts during their emergency stay in the shelter. This temperature will be maintained between 65 F and 75 F. The heat accumulation inside of the lunar shelter comes from multiple sources. These sources include: harmless radiation from the sun through the protective shielding, heat produced by the life support equipment, heat produces by the power system, and the heat produced by the astronauts themselves.

A summation of these heat sources renders a resultant heat accumulation. This amount of heat must be kept down to the specified comfortable temperature range. The alternatives for this thermal control system were examined on the following criteria:

Reliability
Ease of Implementation
Efficiency
Mass
Safety
Power

The thermal control system will be electronically monitored and controlled. However, in case of electrical malfunction, it will be easily convertible to manual operation.

DESIGN GUIDELINES

The design of the thermal control system should be simplistic in nature because of its limited emergency usage. Ease of implementation is crucial to the success of the thermal control system for the emergency lunar shelter. However, a simple system does not infer the most desirable efficiency. The efficiency will be tested. based on previous research of existing hardware, during the synthesis phase of the manufacturing process.

Mass and power considerations fluctuate depending on the final thermal control system chosen. Reliability of the system is a result of the mechanical quality of the device used. In the case of a mechanical malfunction, a back-up thermal control system will be incorporated in the design of the overall life support network.

STATUS OF REQUIREMENTS FOR THERMAL CONTROL SYSTEM (TCS)

Requirement	Status
Reliability	Met: By research and synthesis testing.
Ease of Implementation	Met: The TLS is installed on Earth.
Efficiency	Acceptable: A low maintenance system which is self contained.
Mass	Met: Basic design and light weight materials.
Safety	Met: A back-up, circulatory air turbine may be implemented.
Power Requirement	Acceptable: The system is kept as simple as possible.

THERMAL CONTROL SYSTEM DESIGN

The design utilized for the thermal control system is a tubing system. Tubing, located on the walls of the habitable section of the emergency shelter, extend in a helical formation down the length of the shelter. The working fluid follows a closed-loop path to a heat exchanger after it has circulated through the shelter. The heat exchanger cools the passing working fluid while heat is provided by the power system. Components of this coolant system are as follows:

Working fluid
Tubing
Pumping System
Heat Exchanger
Radiator
Cryogenic Storage

Modeled after the astronaut's EVA suits, this temperature controlling system utilizes cooling tubes [30]. The walls of the emergency shelter will be lined with tubing that houses a working fluid that extracts the excess heat in the shelter.

The variables to consider for this heat transfer system are the working fluid, the material of the tubes, the diameter of the tubes, the length of the tube, and the velocity of the working fluid through the tube.

The working fluid implemented is oxygen. Oxygen will be cryogenically stored in the shelter for the power and oxygen supply systems; therefore, it will not be inconvenient to store additional oxygen for the thermal control system. As a cryogenic fluid, oxygen is relatively inexpensive and readily available. However, it should not be used in systems involving hydrogen or where oil-sealed vacuum pumps have to be used to lower the vapor pressure [26]. Since neither of these limiting criteria are involved with the coolant system, oxygen is an ideal choice.

The dimensions of the habitable shelter are 6 feet in diameter and 8.11 feet in length. The tube will be wound in a helical formation inside of the shelter; therefore, the number of coils will depend on the working fluid and mass flow rate.

Material of the tubing must have excellent thermal conductive properties and be capable of achieving the helical formation desired. Aluminum was chosen for this task. Even though there are better thermal conductive materials, such as copper, aluminum will best weld to the aluminum protective shell of the shelter. This welding may be done on Earth to minimize labor for installation of the TCS on the MOON. Also, aluminum is inexpensive, lightweight, and has acceptable thermal conductive properties. The inner walls of the aluminum tubing will be anodized such that no oxidation may occur between the tubing and liquid oxygen [29].

With the given length and critical temperatures, the last variables, diameter and velocity, can be mathematically manipulated. A successful combination is obtained, such that the diameter of the tubing will adequately support fluctuating fluid velocities necessary to maintain the desired heat transfer from the shelter during the critical temperature phases.

Obviously, the manufacturers choice of the pumping system to be used should be one that is capable of a fluctuating flow rate and can be electrically and manually tractable by the astronauts during their emergency stay. A hydraulic pump is an excellent means of driving the flow through the thermal control system including the heat exchanger [27]. Also, the pump should be of low maintenance and capable of sustaining the force, known as the acceleration head, required to accelerate the fluid in the suction line.

A heat exchanger is necessary to control the temperature of the working fluid through the shelter. A compact heat exchanger, such as a shell and tube or a plate-fin arrangement, is an good method of extracting or inserting heat from or to the working fluid [28].

As the working fluid completes a cycle, it is necessary to recompress the fluid and recirculate it through the process. The heat generated by the compression process must be removed from the shelter. A good solution for this heat rejection is a radiator. The difficult lunar environment requires that the radiator be positioned in such a way so as to avoid direct solar radiation and to be out of view of the hot surface of the Moon. Oversized radiators, radiator shading devices, or raising the radiator temperature by using a heat pump, are several solutions which may be implemented to achieve safe solar radiation shielding [26].

The design of the TCS is protected from many environmental problems inside the shelter. However, the radiator system will have to take into account its reduced efficiency due to any possible lunar dust contaminants.

APPENDICES

Appendix A: Radiation shielding pressure vessel calculations

Appendix B: Radiation shield thickness calculations

Appendix C: Wheel calculations

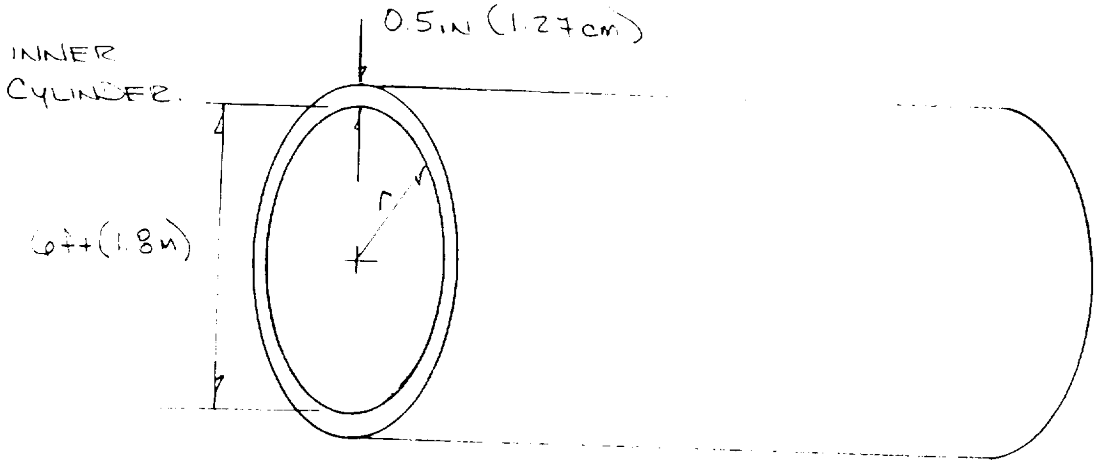
Appendix D: Calculation of towing hitch shaft thickness

Appendix E: Airlock hatch calculations

Appendix F: Internal layout calculations

APPENDIX A: Radiation shielding pressure vessel calculations

FOR THIS DESIGN SAFETY IS THE MOST CRITICAL FACTOR
DIMENSIONS ARE AS FOLLOWS:



FOR ALUMINUM 3003-H12, THE APPROPRIATE PROPERTIES ARE:

ALUMINUM ASSOCIATION NUMBER	TEMPER	YIELD, S, MPa (KPS.)	BRINELL HARDNESS
3003	H12	117 (17)	55

HOOP STRESS: $\sigma = \frac{Pr}{t}$

WHERE r IS THE RADIUS
P IS THE INTERNAL PRESSURE
t IS THE VESSEL THICKNESS

$r = \frac{1.8m}{2} = 0.9m$, $P = 14.7\ psi = 101352.9\ Pa$

$t = 0.5\ in = 0.0127m$

APPENDIX A: Radiation shielding pressure vessel calculations

$$\sigma_{HOOP} = \frac{(101352.9\ Pa)(0.0127\ m)}{(0.9\ m)} = 1430.2\ Pa$$

HE CORRESPONDING FACTOR OF SAFETY BASED ON
YIELDING STRESS IS:

$$F.S. = \frac{\sigma_{ALLOW}}{\sigma_{ACTUAL}} = \frac{1.17 \times 10^{8}\ Pa}{1430.2\ Pa} = 81.8 \times 10^{3}$$

ORIGINAL PAGE IS
OF POOR QUALITY

APPENDIX B: Radiation shield thickness calculations

REQUIRED THICKNESS OF ALUMINUM AND REGOLITH GUARDING AGAINST RADIATION EXPOSURE GREATER THAN 25 REM/MONTH:

10.4 cm OF ALUMINUM

50 CM OF REGOLITH

AMOUNT OF REGOLITH/ALUMINUM SHIELDING NEEDED TO GUARD AGAINST EXPOSURE GREATER THAN 25 REM/MONTH:

2.54 CM ALUMINUM FOR THE TWO AL. CYLINDERS

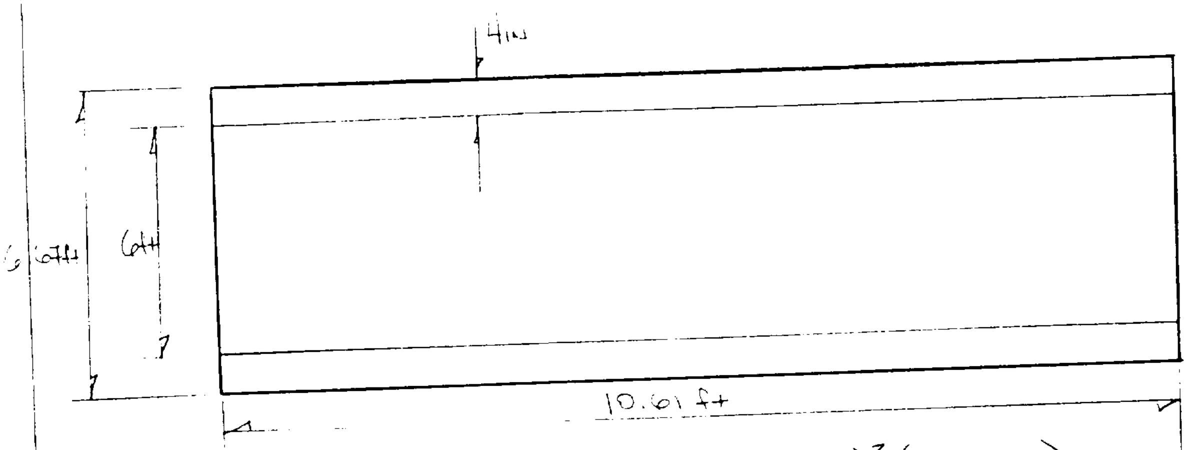
$$\frac{2.54\ \text{cm}}{10.4} = 0.244 \rightarrow 24.4\%$$ REDUCTION IN RADIATION

∴ 50 cm (0.244) = 2.2 cm REDUCTION IN REGOLITH CAN BE MADE.

THICKNESS OF REGOLITH 37.8 cm (14.9 in)

APPENDIX B: Radiation shield thickness calculations

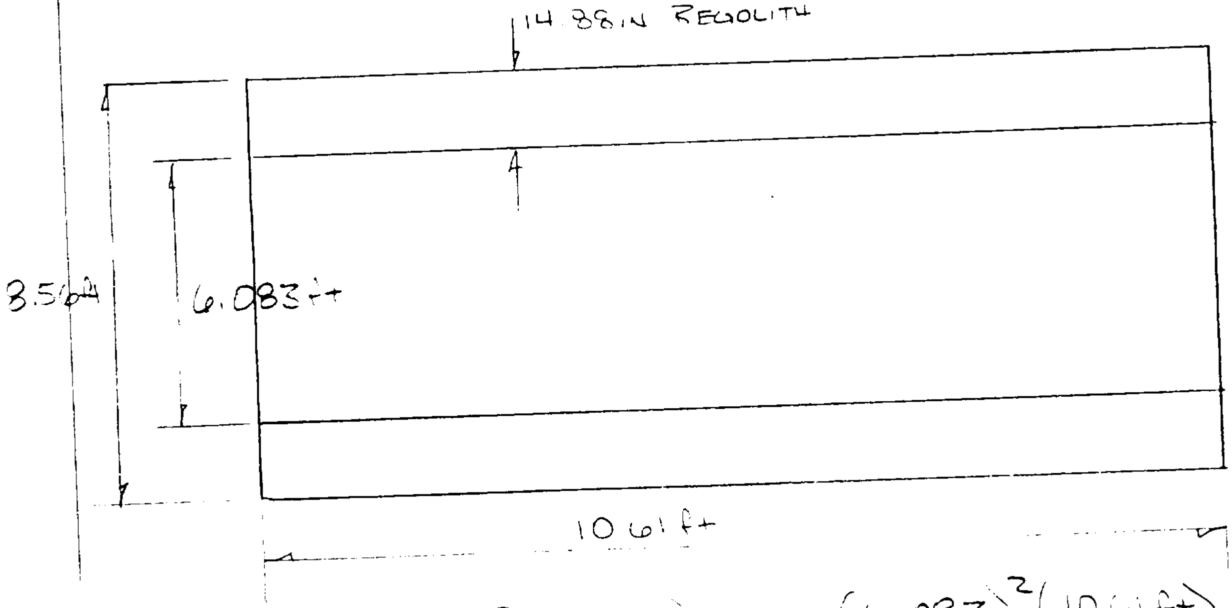
MASS COMPARISON BETWEEN PURE ALUMINUM AND ALUMINUM/REGOLITH COMPOSITE SHIELD.



$$V_{AL} = \frac{1}{4}\pi(6.67ft)^2(10.61f) - \frac{1}{4}\pi(6ft)^2(10.61ft)$$

$$= 70.7\,ft^3 = 2.00\,m^3$$

$$M_{AL} = (2.00\,m^3)\left(\frac{2702\,kg}{m^3}\right) = \underline{\underline{5404\,kg}}$$



$$V_{REG} = \frac{1}{4}\pi(8.56)^2(10.61ft) - \frac{1}{4}\pi(6.083)^2(10.61ft)$$

$$V_{REG} = 302.24\,ft^3 = 8.56\,m^3$$

$$M_{REG} = (8.56\,m^3)\left(\frac{800\,kg}{m^3}\right) = 6846.94\,kg$$

APPENDIX B: Radiation shield thickness calculations

OUTER ALUMINUM SHELL MASS:

$$V = \frac{1}{4}\pi(8.643\ ft)^2(10.61\ ft) - \frac{1}{4}\pi(8.56\ ft)^2(10.61\ ft)$$

$$= 11.95\ ft^3 = 0.34\ m^3$$

$$M_{OUTER} = (0.34\ m^3)\left(2702\ \frac{m^3}{kg}\right) = 914.04\ kg$$

INNER CYLINDER MASS:

$$V = \frac{1}{4}\pi(6.083)^2(10.61\ ft) - \frac{1}{4}\pi(6.0\ ft)^2(10.61\ ft)$$

$$V = 8.39\ ft^3 = 0.24\ m^3$$

$$M_{INNER} = (0.24\ m^3)\left(2702\ \frac{kg}{m^3}\right) = 642.01\ kg$$

TOTAL ESTIMATED MASS:

$$M_{TOTAL} = 6846.94\ kg + 914.04\ kg + 642.01\ kg$$

$$\boxed{= 8402.99\ kg}$$

NOTE: THIS CALCULATION DOES NOT INCLUDE WEIGHT CONSIDERATIONS FOR THE POLYETHALENE HONEYCOMB END SECTIONS, SUSPENSION, FURNISHINGS, EQUIPMENT, OR SUPPLIES.

APPENDIX C: Wheel calculations

$M_{shelter} \approx 2500$ kg

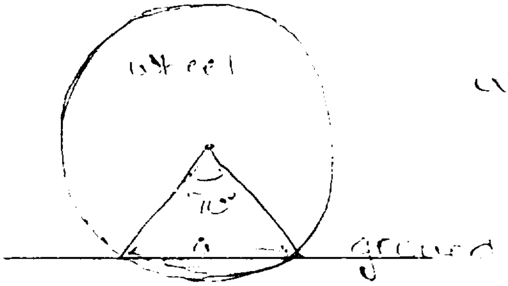
$W_{shelter} = 24.3$ kN

W (per wheel) = 6.1 kN (4 wheels)

W (per wheel) 4.05 kN (6 wheels)

$(A_s)_{min} = \frac{6.1\ kN}{10\ kPa} = .61\ m^2$ (4 wheels)

$(A_s)_{min} = \frac{4.05\ kN}{10\ kPa} = .405\ m^2$ (6 wheels)



assume: 70° flattening angle

$d = 2.5$ m $r = 1.25$ m

Law of Cosines: $a^2 = (1.25)^2 + (1.25)^2 - 2(1.25)^2 \cos 70°$

$a = 1.43$ m

If width = 0.3 m

⇒ contact area: (1.43m)(0.3m) = 0.43 m^2

ORIGINAL PAGE IS
OF POOR QUALITY

APPENDIX D: Towing hitch calculations

Calculation of Towing Hitch Shaft Thickness

Approximate mass of Shelter:	10,000 kg
Weight on Lunar Surface:	16350 N
Ultimate Strength of Alloy:	351.59 Mpa

Area = Weight/Ultimate Strength

$A = W/S_y$

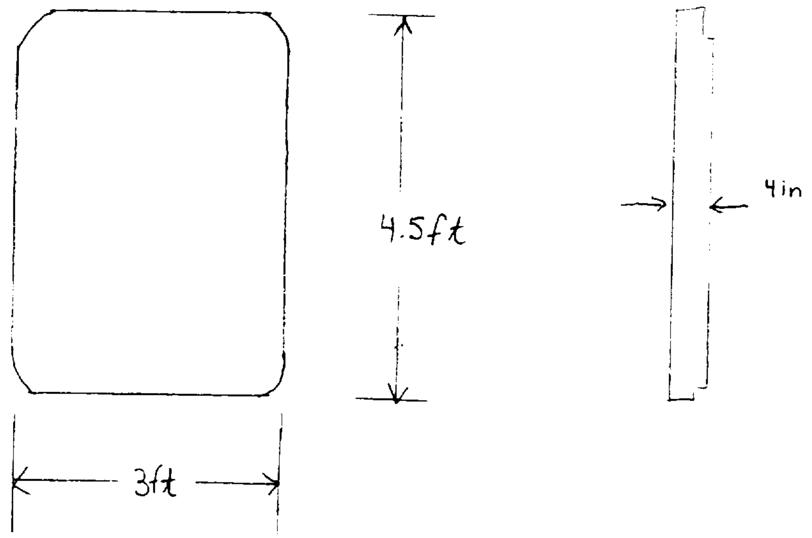
$= 46.5 \text{ mm}^2$

Factor of Safety = 4: Area = 186 mm^2

This corresponds to a circular rod of diameter 1.54cm

APPENDIX E: Airlock hatch calculations

Mass Calculation for Aluminum Door:

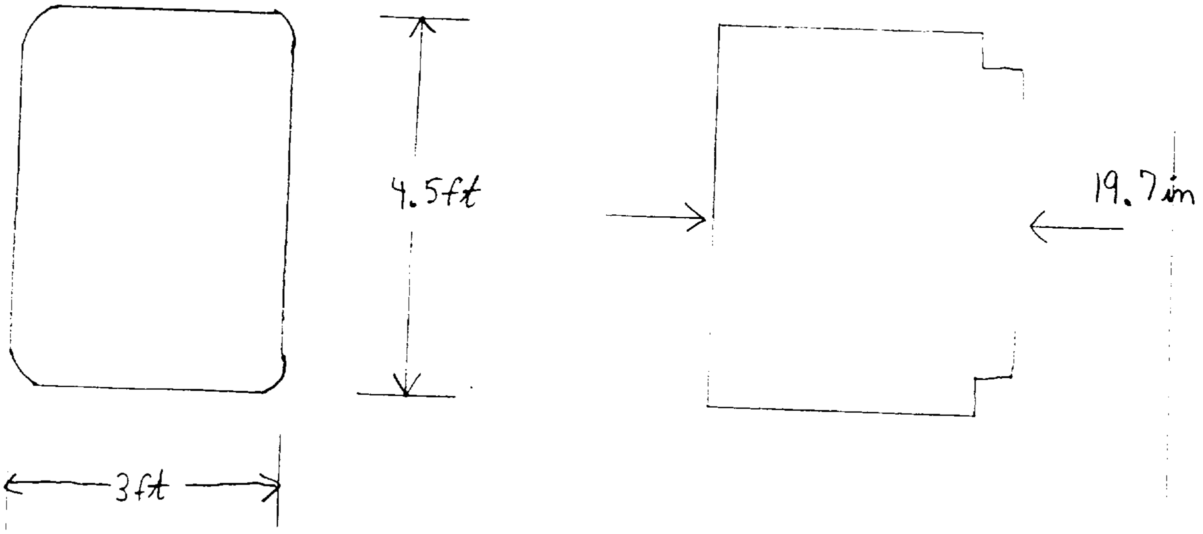


$$3\,\mathrm{ft} \times 4.5\,\mathrm{ft} \times \frac{4}{12}\,\mathrm{ft} = 4.5\,\mathrm{ft}^3 = .12744\,\mathrm{m}^3$$

$$.12744\,\mathrm{m}^3 \times \frac{2702\,\mathrm{Kg}}{\mathrm{m}^3} = 345\,\mathrm{Kg}.$$

APPENDIX E: Airlock hatch calculations

Mass Calculation of Regolith filled door:



$$3\text{ft} \times 4.5\text{ft} \times \frac{19.7}{12}\text{ ft} = 22.1625\text{ ft}^3 = .627642\text{ m}^3$$

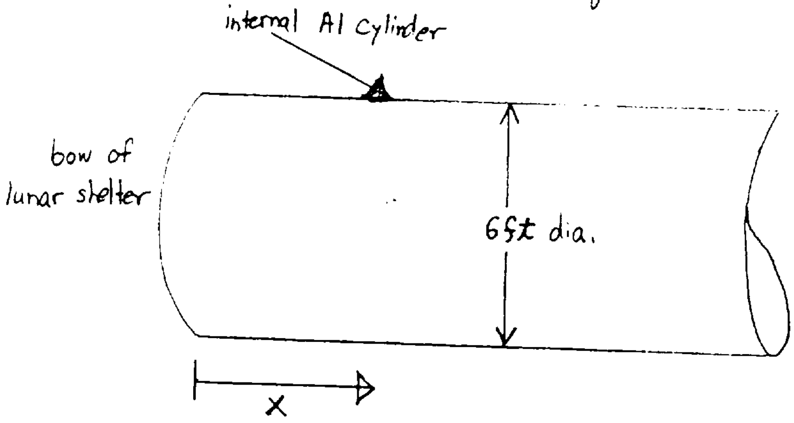
$$.627642\text{ m}^3 \times \frac{800\text{ Kg}}{\text{m}^3} = 502\text{ Kg}$$

APPENDIX F: Internal layout calculations

Space required for the Power System.

Required volume for Power Supply is approximately $2\ m^3 = 70.6 ft$

Placing the Power Supply at the front of the lunar shelter will require x ft of room.

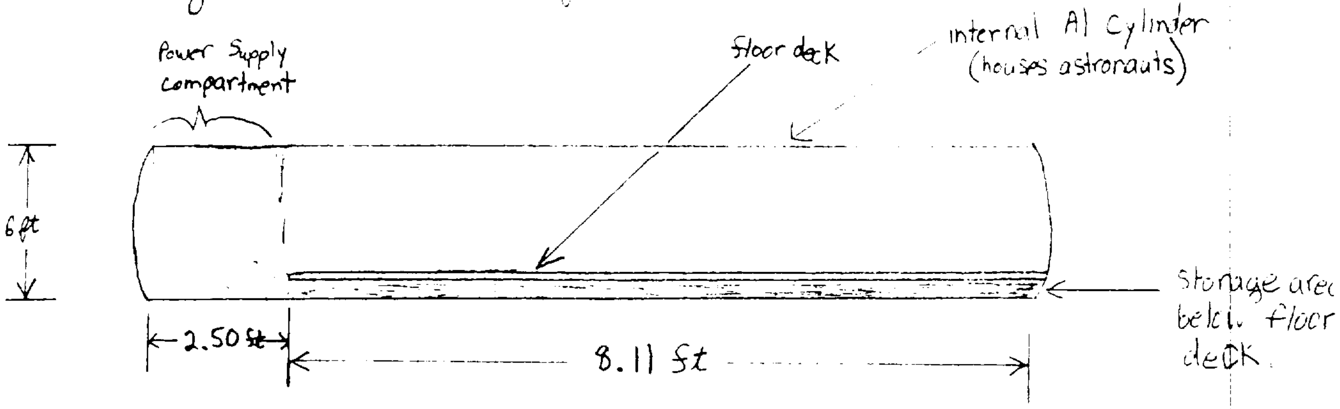


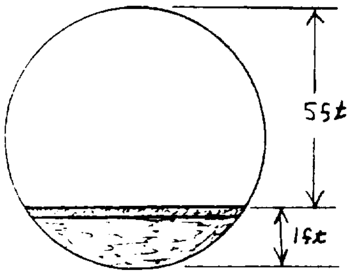
$$V = 70.6\ ft^3 = \frac{1}{4}\pi\left(6ft\right)^2 * x$$

$$2.50\ ft = x$$

APPENDIX F: Internal layout calculations

Storage Volume below floor deck:





$$V_{storage} = \frac{1}{6}\left[\frac{1}{4}\pi d^2 * \ell\right]$$

$$V_{storage} = \frac{1}{6}\left[\frac{1}{4}\pi (6\,ft)^2 * 8.11\,ft\right]$$

$$V_{storage} = 38.2\ ft^3$$

INTEGRATION OF INTERNAL SUBSYSTEMS

Power Source

It was determined that an electrochemical power system utilizing fuel cells would require 2 cubic meters of space to provide the necessary power of 10.7 kW. Thus, a cylindrical section 6 feet in diameter and 2.50 ft long is required to house the power system (see appendix F). Because the power source is quite massive, 1100 kg, it must be positioned so that it does not hinder the daily routine of the astronauts. Therefore, it was decided to place the power system at the anterior portion of the LSES. The accompanying diagram shows the major areas and equipment within the LSES. The power supply is positioned directly over the front suspension system such that the weight is transferred straight to the wheels and then to the lunar surface. This minimizes the bending moment that would normally be induced if the power system were cantilevered.

The normal operating temperature of the power source is 355 K. In order to shield the astronauts from the heat, a two part urethane mixture is used to form an insulative barrier between a 1/8 inch aluminum divider and the power source's control panel, as shown in the diagram.

In order to cool the power source, the liquid oxygen used to control the cabin temperature (see Thermal Control System for Life Support) will be routed to the power system exterior.

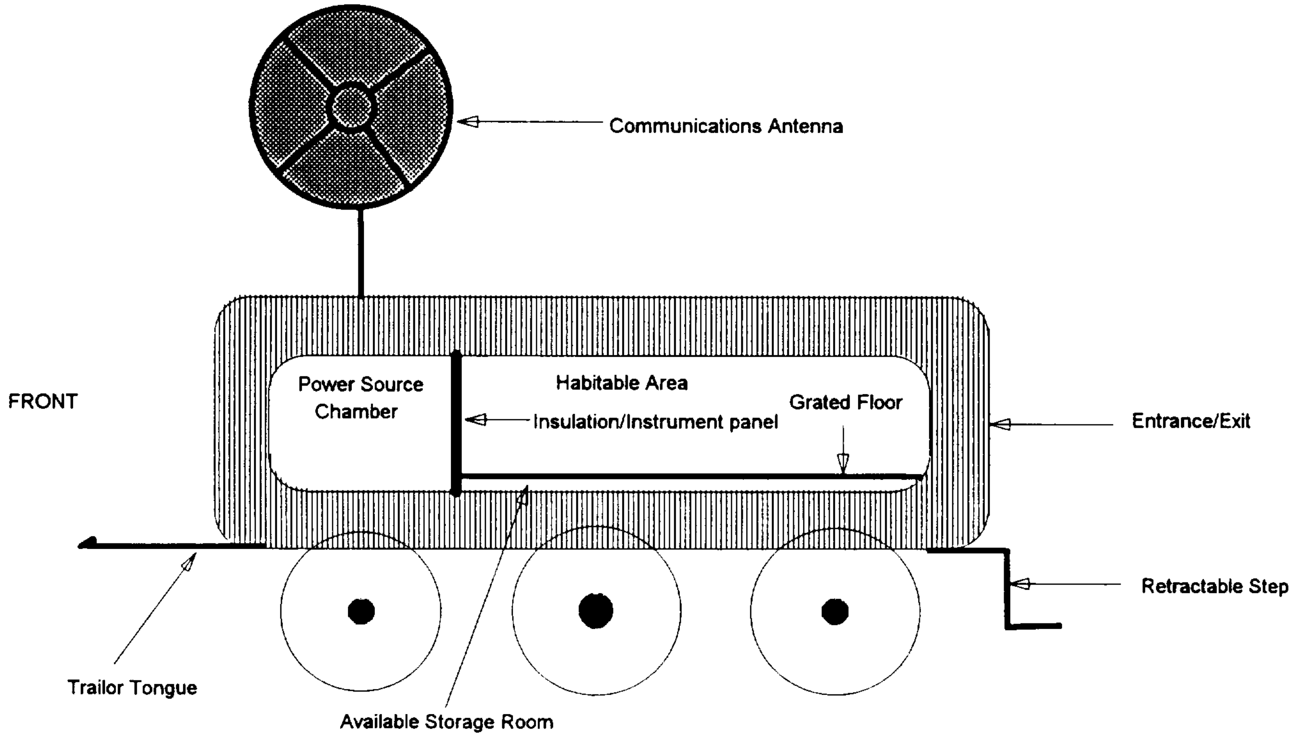
Floor Deck

Because the living compartment is made from a cylinder, the floor would have a steep curvature which would hinder movement about the shelter. Therefore, it has been proposed to attach channels to the side walls of the internal cylinder to hold an insertable floor grating. Beneath the grating, 38.2 ft^3 of useable space [see appendix E] will be available to store equipment or perishable items such as food and water. The floor will consist of several trap doors which will permit access into this storage area.

An aluminum floor has been selected for use due to its weight -to-strength ratio of 0.5. The floor will be grated in order to save weight.

Retractable Step

The design of the shelter resulted in the bottom of the airlock door being about three feet above the lunar surface. Thus, an astronaut donning a space suit would have a difficult time climbing into the shelter. To overcome this problem, a retractable step, similar to those found on recreational vehicles, has been incorporated into the design. When the vehicle is in transit, the step can be raised to avoid it from becoming snagged on an impediment.



General shelter layout

CONFIGURATION DESCRIPTION

CONFIGURATION DESCRIPTION

The major elements comprising the shelter are a radiation protection shield, pressure shell, power generation system and thermal control system. The habitat will house the crew and provide equipment for crew safety and comfort.

The entire mobile lunar shelter will be cylindrical in shape, measuring 12.2ft. in length and 8.65 ft. in diameter. On a flat surface the suspension will allow a ground clearance of 4.9ft. The shelter will provide 188ft^3 of habitable space and 38.2ft^3 of storage space below the floor deck.

The radiation shield will consist of aluminum, regolith and a honeycomb polymer. The honeycomb polymer and regolith also provides some protection from micro-meteorite bombardment. A total of 1in thickness of aluminum will be used with the regolith and honeycomb structure measuring 14.9in thick. The shield has been designed to guard against the largest solar flare activity that has been recorded in the last half century.

The anterior portion of the shelter houses the electrochemical power system which utilizes fuel cells. The power system occupies 70.6ft^3 of cabin space and has a mass of 1112kg. It is capable of supplying 10.7kW of power.

To provide a safe and comfortable ambient temperature for the personnel inside the shelter, a thermal control system is used. This automatic system electronically monitors and controls the heating and cooling of the LSES. Heating of the shelter is accomplished through the heat transfer from onboard equipment. Cooling is performed by tubular cooling ducts within the shelter walls.

Control of the atmosphere within the LSES is the function of the ECLSS. Full time monitoring and maintaining of the livable environment is the sole function of this system. This includes production of nitrogen and oxygen, carbon dioxide removal, humidity control, and air filtering. Cryogenic storage is used for providing oxygen and nitrogen while high capacity air filters remove particulates and contaminants. Carbon dioxide is removed by a 4BMS system. A back-up safety system provides oxygen to personnel in the event of failure of primary equipment. This is provided through safety masks available throughout the shelter.

The onboard communication system consists of all necessary equipment to allow communication with Earth, the lunar base, and personnel on the lunar surface in EVA suits or lunar vehicles. The system utilizes existing satellites to relay signals to the approprate locations, as well as an independent, short range UHF system for surface communication.

Mobility of the LSES is accomplished through the use of six hemispherical wheels in conjunction with a torsion bar suspension. The shelter does not provide its own mode of movement, but rather is towed by a lunar vehicle using a ball and socket hitch.

In order to provide a safe and reliable means of accessing the shelter, an airlock hatch is utilized. The hatch creates an airtight sealing surface as well as providing required radiation protection. Many afety features are built in to ensure that pressurization of the shelter is maintained when personnel are aboard.

The habitat is configured to fit well within the 10m diameter internal payload envelope of the proposed heavy lift launch vehicle (HLLV).

REFERENCES

[1] NASA, George C. Marshall Space Flight Center, Alabama, First Lunar Outpost Lunar Habitat Documentation, May 1992.

[2] Recommendations of the International Commission on Radiological Protection. ICRP Publ. 26., Pergamon Press, January 17, 1977.

[3] Nealy, John E., Wilson, John W., Townsend, Lawrence W., Solar Flare Shielding at a Lunar Base Site, NASA Technical Paper 2869, December 1988.

[4] Townsend, W. Lawrence, Estimate of Galactic Cosmic Ray Shielding Requirements During Solar Minimum, NASA Technical Memorandum 4167, 1990.

[5] Volkman, Douglas E., Radiation Shielding for the 21st Century; Journal of Testing and Evaluation , v.20 (American Society for Testing and Materials 1992).

[6] Lunar Construction Utility Vehicle, NASA/USRA Rummer Report, NAS1.26:186231, July 1989, p.9.

[7] Lunar Surface Transportation System Conceptual Design, Lunar Base Systems Study Task, NAS1.26:172077, July 7, 1988, p.55.

[8] Boom, R.W., et al, Repulsive Force Support System Feasibility Study, NAS1.26:178400 Hampton, VA, 1987, p.iii.

[9] Lunar Surface Transportation System Conceptual Design, p.52.

[10] LARTS 1992 Senior Design Project, FAMU/FSU

ECLSS BIBLIOGRAPHY

1. Block, Roger F., Automated Subsystem Control for Life Support System (ASCLSS) Florida, 1987.

2. Colson, Russell O., Larry Haskin, and R. Keller, In Arizona Univ., Resources of Near-Earth Space: Abstracts, 1991.

3. Goldman, Michelle, Shawn Gomez, and Mike Voorhees, Methods for the Development

of a Bioregenerative Life Support System, Proceedings of the 6th Annual Summer Conference: NASA/USRA, University Advances Design Program, 1990.

4. Gould, Marston J., Method for optimal configuration of an ECLSS on the Space Station Freedom, In NASA, VA, 1991.

5. Heppner, D.B., Advancements in oxygen generation and humidity control by water vapor electrolysis, Life Systems, Inc. Ohio, 1988.

6. Keller, Rudolf, In NASA, Lewis Research Center, Space Electrochemical Research and Technology, 1991.

7. Perry, J.L., Space Station Freedom environmental control and life support system phase III simplified integrated test trace contaminant control subsystem performance, In NASA, VA, 1990.

8. Technology 2000, Report no: NASA cp-3109, Vol. 1, NASA Technology Utilization Division, 1991.

9. Van Dressar, Neil T., and Robert J. Stochl, Pressurization and Expulsion of Cryogenic Liquids: Generic Requirements for a Low Gravity Experiment, In NASA, Lewis Research Center, Ohio, 1991.

10. Wood, Peter C., Improved oxygen sources for breathing apparatus: final report, 1983.

TCS BIBLIOGRAPHY

1. Bailey, C. A., Advanced Cryogenics, London-New York, Plenum Press,1971

2. Kays, W. M., Compact Heat Exchangers, New York: McGraw-Hill, 1964

3. Matley, Jay, Fluid Movers, New York: McGraw-Hill, 1979

4. McDonnell-Douglas Astronautics Co., Advanced EVA System Design, 1981

5. Lockheed Missiles & Space Company,Inc., Fluid Flow

Analysis of the SSME High Pressure Fuel and Oxidizer Turbine Coolant Systems, National Aeronautics and Space Administration, July 1989

1. Heiken, G., Vaniman, D., French, B., Lunar Sourcebook, New York, Cambridge University Press., 1991

2. Niedz, F. J., Survey of the Physical and Environmental Parameters of the Moon, Daytona Beach, Florida, Apollo Support Department General Electric Company, 1963

Townsend, Lawrence W., Preliminary Estimates of Radiation Exposure for Manned Interplanetary Missions From Anomalously Large Solar Flare Events, NASA Technical Memorandum 100620, 1988.

Rust, David M., "Solar Flares, Proton Showers, and the Space Shuttle", SCIENCE, Vol.216, AAAS, New York, 1982, pp.939-945.

Dirch, Thomas W., Automotive Suspension and Steering Systems, Harcourt Brace Jovanovich, Inc., Orlando, Florida, 1987, p.224.

ALTERNATIVE SOLUTION PRINCIPLES

Alternative solutions considered in the design for the TCS are a circulatory air turbine and a conglomeration system combining the oxygen supply and thermal control systems. Major subsystems of each alternative are listed below, with detailed discussions following.

CIRCULATORY AIR TURBINE

Radiator
Pumping System
Monitoring System

OXYGEN SUPPLY/ THERMAL CONTROL SYSTEM

Heat Exchanger
Pumping System
Radiator

CIRCULATORY AIR TURBINE

This design consists of a circulatory air turbine pump which draws the existing air in and passes it through a heat exchanger. The magnitude of the temperature difference will be a function of the fluctuating heat accumulation in the cabin air with respect to time. The monitoring system will be electronically controlled as will be the pumping system which it regulates. This system leaves little room for manual tractability in case of malfunction [27].

This system adds to the power requirements and does not compare favorably in the areas of reliability and efficiency [30]. Therefore, this system should be rejected as a viable coolant system solution. However, it is not to be completely ignored as it's features are basic and make for an excellent backup possibility.

OXYGEN/ THERMAL CONTROL SYSTEM

A conglomeration of the oxygen supply system and the thermal control system will complete two tasks at once, and reduce the mass and complexity associated with redundant systems. This system will consist of a heat exchanger placed after the filtering system, modifying the temperature of the incoming air prior to it being pumped into the habitable area.

As a major modification, this conglomerate alternative adds to the complexity of the oxygen supply system. By retaining simplicity for the oxygen supply system, the quality of efficiency and other specified goals are enhanced. The implementation of the conglomeration does not allow for desirable reliability, safety and efficiency and is therefore rejected as a viable alternative.

FIRE CONTROL

A safety, as well as an ergonomic feature, is to have panels covering the tubing in the shelter. A thin sheet of material that is durable and insulative may safely protect the astronauts from the cold tubing in the shelter, but not hinder the heat transfer characteristics of the TCS.

This coolant design satisfactorily meets the specified requirements for the coolant system. Therefore, it is a acceptable solution.

FIRE CONTROL
CONTENTS

ALTERNATIVE SOLUTIONS

Detection

Heat detectors operate when a certain temperature is reached or the temperature rises abnormally quickly due to the heat from the fire.

Fusible Links are made of a soft metal alloy that melts at high temperatures to activate a detection circuit.

Glass bulbs are filled with a liquid or solid material that expands readily when the temperature rises, breaking the bulb.

Photoelectric cells detect the presence of smoke in the surrounding air.

Infrared beams waver due to variations in air temperature. These changes can be detected by a receiving grid.

Suppression

Water extinguishers operate by squeezing two levers together, which releases the water. The water may be continually pressurized by dry air or nitrogen (maintained pressure type) or by carbon dioxide stored in a small pressure cylinder within the extinguisher shell.

Foam extinguishers use a stabilized protein or synthetic foam liquid mixed with water to be discharged as a solution to an aspirating nozzle where air is introduced to form a foam.

Dry chemical extinguishers discharge a variety of special, easy flow powders as high velocity streams to inhibit flame chain reaction.

Carbon dioxide extinguishers consist of a high pressure gas container filled with liquid CO_2 which is discharged via a tapered horn to form a vaporized cloud of inert gas.

Halon extinguishers generally use bromochlorodifluoromethane (BCF). This is stored as a liquid and is usually pressurized to 145 psi (10 bar) to be discharged as a long-reach jet before expanding into a heavy flame-inhibiting vapor.

Sprinkler systems consist of pipes placed near the ceiling, with sprinkler heads placed at intervals along them. The heads are sealed off with fusible links, or small glass bulbs. When the links melt or bulbs break, the heads are opened releasing water, foam or inert gas.

SELECTION

Detection

	QUESTIONS				
Y indicates Yes N indicates No	Sensitive	Dependable	Easy Operation	Heat dependant	Smoke Dependant
Heat detectors	Y	Y	Y	Y	N
Fusible links	N	Y	Y	Y	N
Glass bulbs	N	Y	Y	Y	N
Photoelectric cells	Y	Y	Y	N	Y
Infrared beams	Y	Y	N	Y	N

The best choice as a detection device is photoelectric cells. The only 'no' answer received for the photoelectric cell is due to its capacity to detect smoke rather than heat. For the purposes of the LSES, this is warranted.

Suppression:

	QUESTIONS						
Y indicates Yes N indicates No	Paper or wood fire	Liquid Fire	Electrical fire	Metal fire	Air contamination	Easy Maintenance	Easy cleanup
Water	Y	N	N	N	N	Y	N
Foam	Y	Y	N	N	N	Y	N
Dry chemical	Y	Y	Y	Y	Y	Y	N
Carbon Dioxide	Y	Y	Y	N	Y	Y	Y
Halon	N	Y	Y	N	Y	Y	Y
Sprinkler	Y	N	N	N	N	N	N

The best choice as a suppression device is a carbon dioxide extinguisher. The only 'No' answer received for the carbon dioxide extinguisher is due to its inability to extinguish metal fires. For the purposes of the LSES, this is acceptable.

FIRE CONTROL DESIGN

An important safety concern in the design of the LSES is the control of fire hazards. The fire detection and suppression system consists of photoelectric cells mounted within the ventilation system. These cells can be used in conjunction with the filtering system to detect the presence of smoke in the circulated air. The ability of the photoelectric cells to detect smoke rather than temperature variation is important. The temperature of the cabin may not be extremely stable due to the lunar environment, and abnormal increases in temperature which might inadvertently trigger an alarm if the detection device was heat dependant.

The greatest fire hazard stems from the electronic circuitry aboard the shelter. Therefore, separate photoelectric cells are strategically positioned within the circuit panels of the electronic equipment to immediately detect an electrical fire. All of the photoelectric cells throughout the shelter are linked to the automatic fire detection unit which operates on its own circuitry. If smoke is detected, the fire detection panel indicates which photoelectric cell has been triggered.

The cryogenic expulsion operation is shutdown when a fire is detected, and the back-up safety system is utilized. A carbon dioxide extinguisher is utilized to eliminate the fire. When the contaminated air is evacuated, operation of the cryogenic expulsion system is resumed.

AIRLOCK HATCH

AIRLOCK HATCH
CONTENTS

REQUIREMENTS FOR AIRLOCK HATCH

The airlock door should provide adequate radiation protection for the astronauts inside. In order to achieve this, the door must be made a specific thickness depending upon the type of material used.

The airlock door should minimize weight, but at the same time maximize entry area. Thus, a lighter door that must be made two feet thick may not be the most advantageous choice.

The airlock door should be reliable. The hatch should therefore have a simple overall design and a fail-safe locking mechanism.

In order to provide adequate radiation protection, the door will inevitably be quite massive. Therefore, the door should be designed so that it can be opened and closed using minimal force.

The airlock door must be hinged to a foundation capable of supporting the weight of the door.

The pressure hatch must be capable of withstanding the pressure differential of vacuum and normal Earth atmosphere (14.7 psi).

The pressure hatch opening must accommodate an astronaut wearing a full space suit.

No protrusions should exist that may damage an astronauts space suit.

The size of the hatch should be designed so that a visual safety check can be made to ensure it is secured properly.

The airlock door should provide a lock/unlock lever on the inside and outside of the shelter in order to allow the door to be opened from either side.

The airlock door should utilize a proven sealing material to create an airtight fit between the door and the frame.

A safety release pressure valve should exist that will allow the cabin to be depressurized. Such a valve is important in case the primary system malfunctions and the astronauts cannot depressurize the shelter.

In order to see inside or outside the shelter, a window should be used. Such a window would help minimize claustrophobia and allow rescuers to see inside the shelter in order to determine the condition of the astronauts in the event they are incapacitated.

The shelter's aft section should permit a rescue vehicle to dock with it thereby allowing direct access to the shelter. Once docked, a zero pressure differential would exist between the inside and outside of the shelter's door allowing the shelter's hatch to be easily opened.

In case the airlock door's latching mechanism fails, the shelter should be outfitted with an alternate means of escape.

STATUS OF REQUIREMENTS FOR AIRLOCK HATCH

Requirement	Status
Adequate radiation protection	Met: The door will be made out of 4 inch thick aluminum. Its mass will be 345 kg [see appendix E].
Hatch maximizes entry area and minimizes weight	Met: The door made from will only be 4 inches thick compared to 15.7 inches thick for an aluminum and regolith door. The mass is also minimized using a solid aluminum door rather than an aluminum and regolith door; 345 kg versus 502 kg [see appendix E].
Reliable	Met: The hatch is made of solid aluminum providing adequate radiation protection at all times. The door utilizes a simple locking mechanism that does not depend on a motor to open or close it. See hatchway specification drawing.
Minimal force to open and close	Met: The door is mounted on three hinges hatch which allows the hatch to swing horizontally. Due to the size of the door, sufficient torque can be applied that will allow the door to move freely.
Strong foundation onto which the used to hatch door is hinged	Met: A four inch aluminum wall is support the 345 kg door. At the same time, the aft aluminum wall protects the astronauts from the radiation from large solar flares.

Specifications for Hatchway

all dimensions in feet

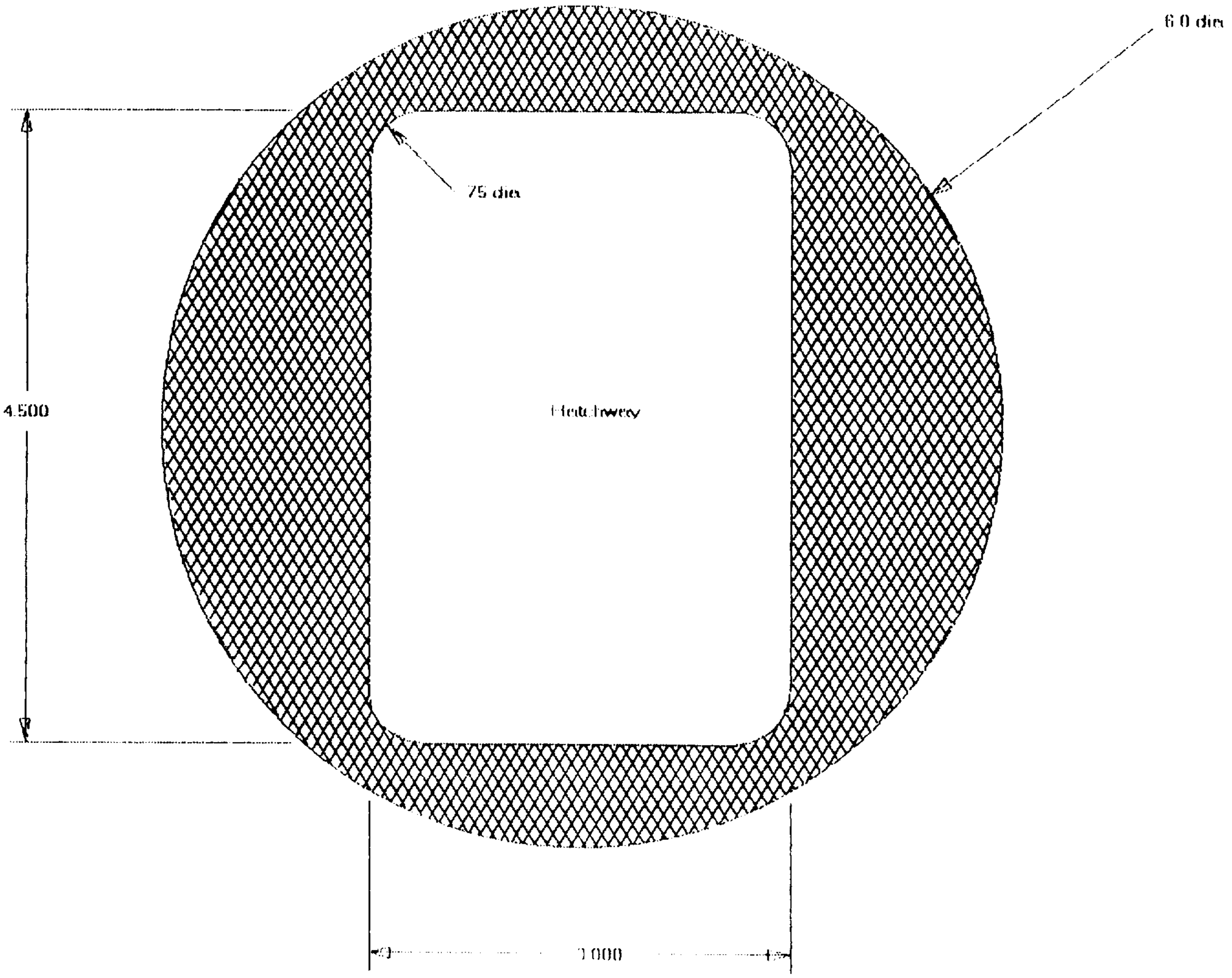


Figure 1

Interior Cross Sectional View of Shelter Depicting Entrance/Exit Hatch

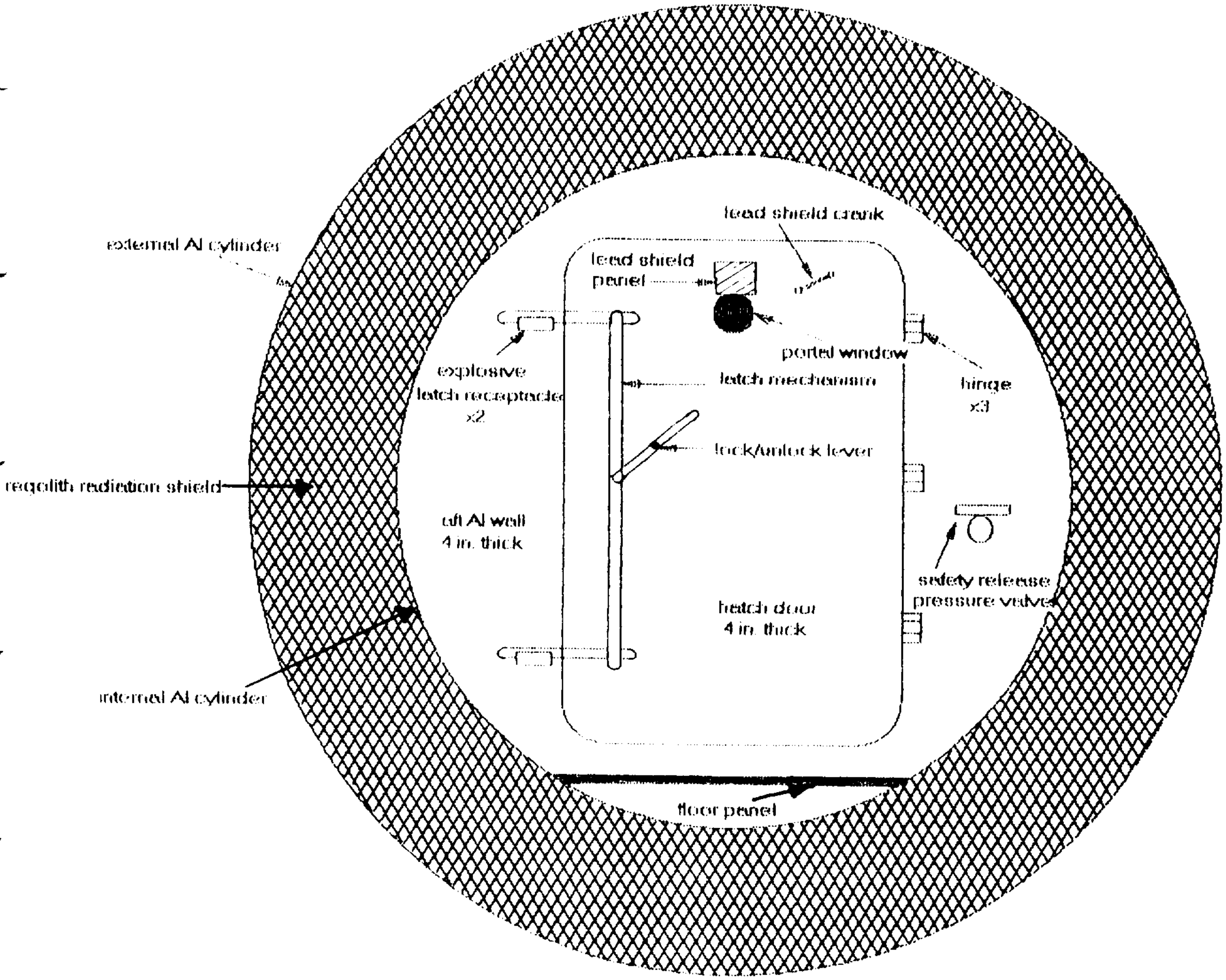


figure 2

External Aft View of Shelter Depicting Entrance/Exit Hatch

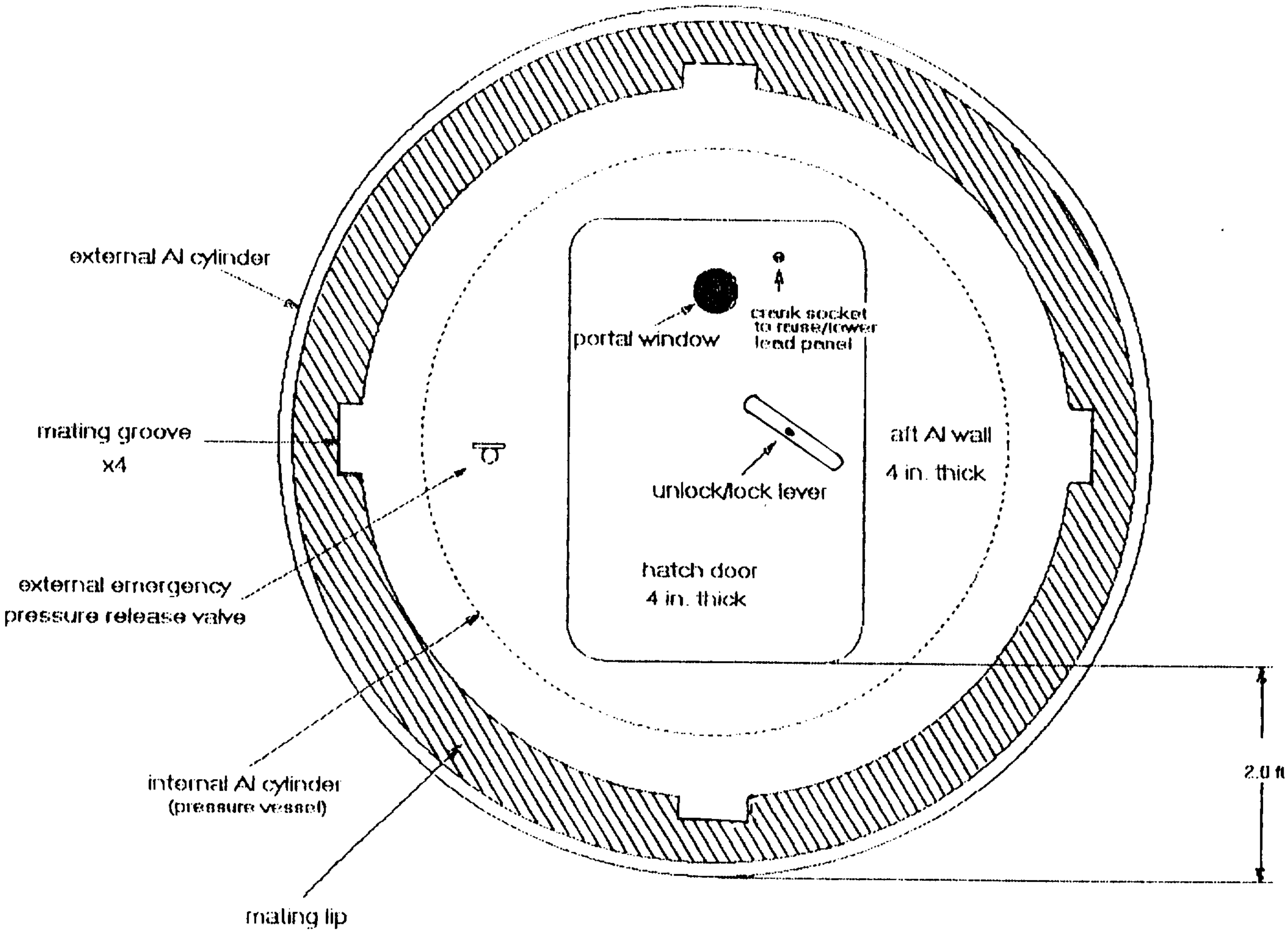


Figure 3

Cross-Sectional View of Hatchway and Aft section of Shelter

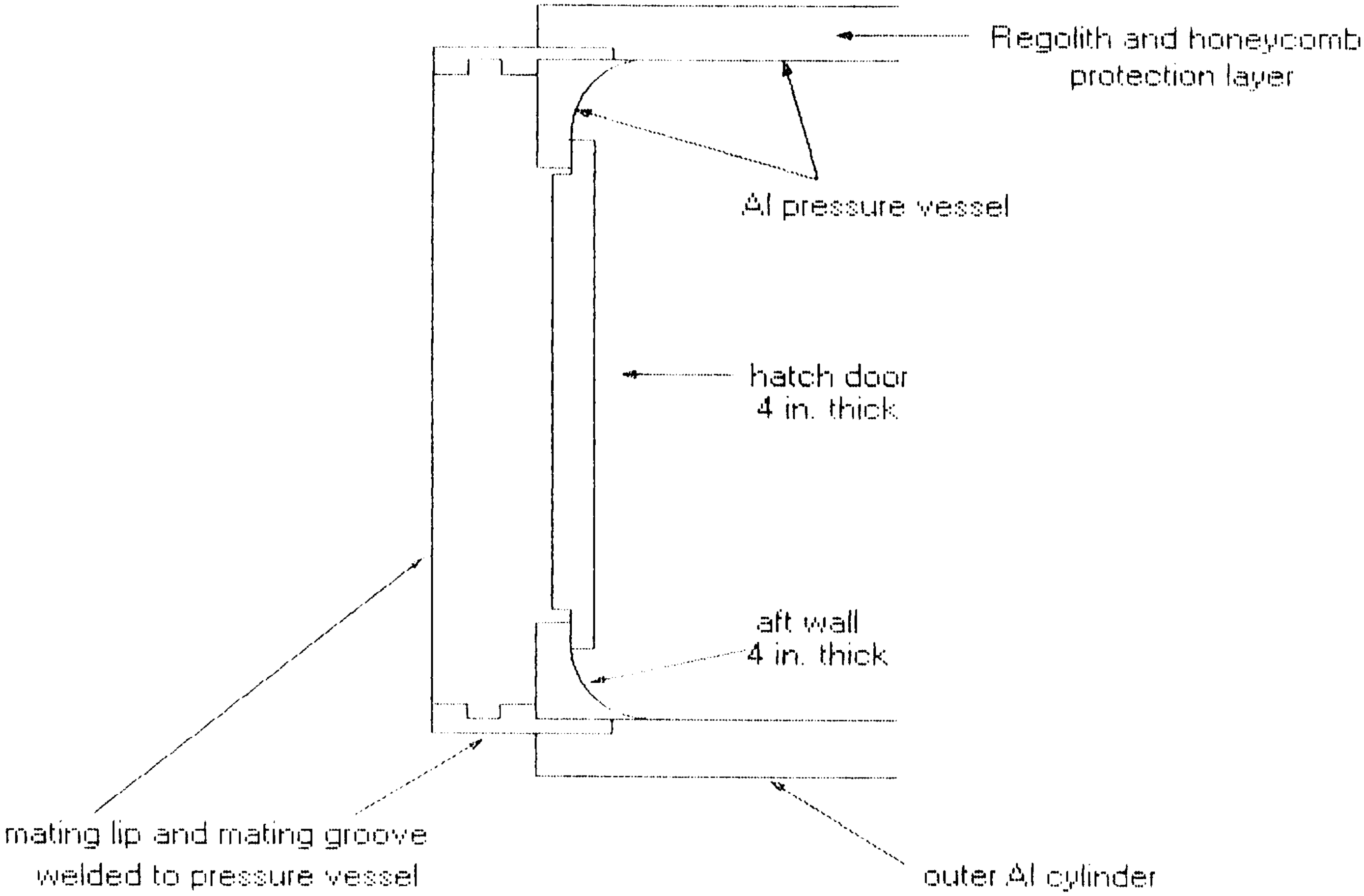


Figure 4

INTERNAL LAYOUT

Requirement	Status
Hatch must withstand a 14.7 psi pressure differential	Met: The material and dimensions used to construct the hatch can withstand a 14.7 psi pressure differential. In addition, the hatch has been designed to swing inward into the shelter so that sealing is assisted by cabin pressure.
Pressure hatch opening large enough to accommodate astronaut with space suit	Met: Refer to hatchway specs. for the dimensions of hatchway.
Design of hatch and hatchway should minimize the number of protrusions that may snag astronauts spacesuit	Met: All sharp edges have been rounded. The hatchway has been made large enough to accommodate astronauts wearing spacesuits.
Allow enough room at the airlock door for a safety check	Met
Lock/unlock lever on the inside and outside of the shelter	Met: Referring to interior and exterior drawings, a lock/unlock lever is used on both sides of the airlock door.
Use of a proven sealing material to create an airtight fit	Met: Around the entire door, a polymer is used to create an airtight seal.
Use of a safety release pressure valve	Met: In the exterior and interior drawings, a safety release pressure valve is depicted. The needle valve allows the astronauts to vary the rate at which cabin pressure reduced.

Requirement	Status
Use of a window	Met: The window is made of glass and integrated into the design of the door, as can be seen in the exterior drawing. A crank-down lead shield is used for additional radiation protection. The lead shield can be raised and lowered from the outside by rescue personnel by turning an external hexagonal socket with a crank (see interior drawing).
Design of a docking mechanism for a rescue vehicle	Met: A circular lip that extends slightly outward is used about the aft section of the shelter, see interior drawing and cross section of hatchway. The lip contains mating grooves which allow a compatible airlock on an emergency vehicle to attach onto the shelter. As a result, pressurized passageway exists between the shelter and the emergency vehicle.
Alternate means of escape	Met: Explosive latches are used to allow the crew an alternate means of escape if the latching mechanism fails.