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LUNAR MISSION SAFETY AND RESCUE

PREPARED FOR
NATIONAL AERONAUTICS & SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER HOUSTON, TEXAS
CONTRACT NAS 9-10969

SSD
SPACE SYSTEMS DIVISION

TECHNICAL SUMMARY

LOCKHEED MISSILES & SPACE COMPANY
A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION
SPACE SYSTEMS DIVISION · SUNNYVALE, CALIFORNIA

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TECHNICAL SUMMARY

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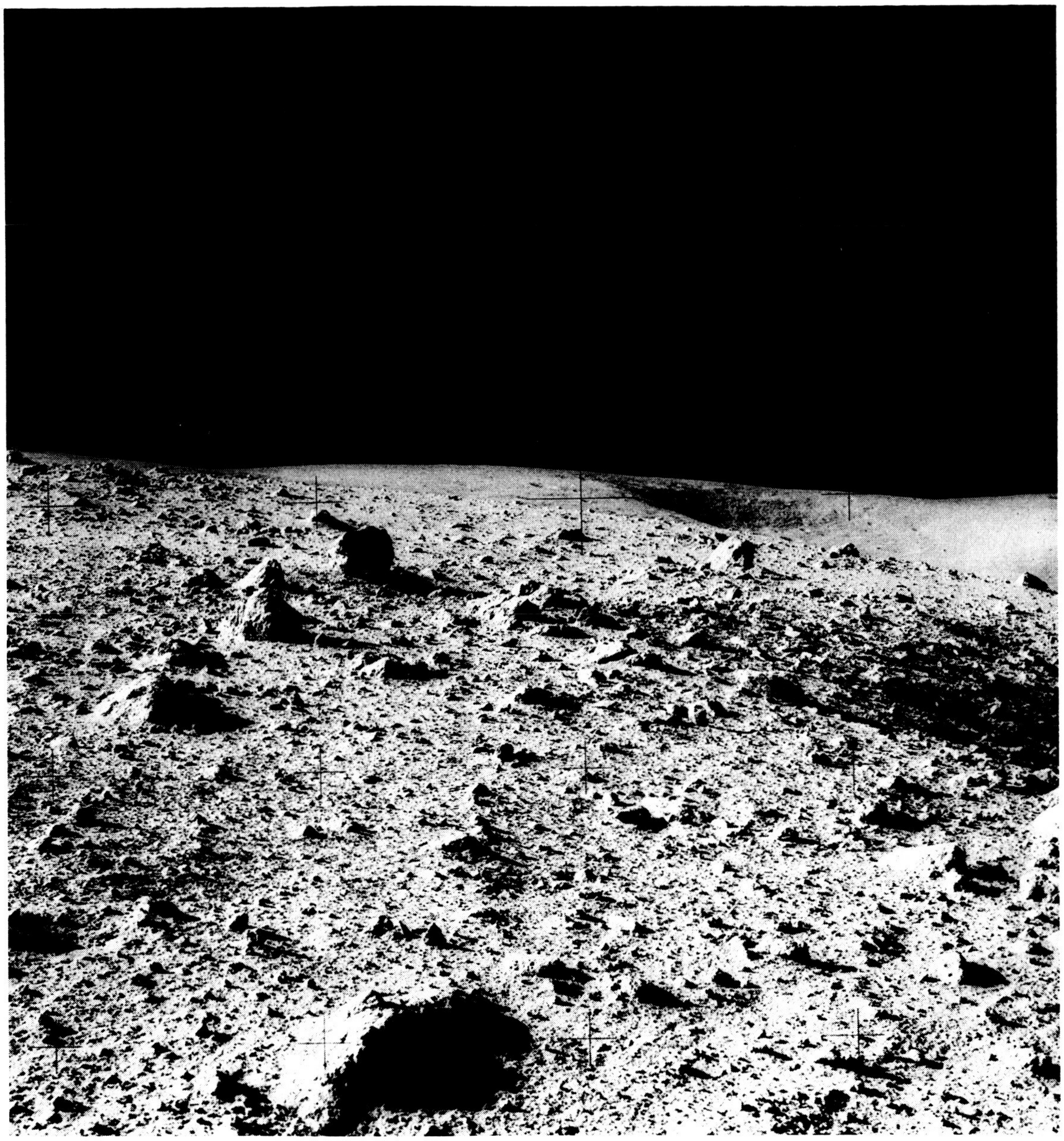

Lunar Surface Features - Apollo 14 Mission

FOREWORD

This report was prepared by the Lockheed Missiles & Space Company, Sunnyvale, California, and presents a technical summary of results of the Lunar Mission Safety and Rescue Study performed for the National Aeronautics and Space Administration, Manned Spacecraft Center, under Contract NAS 9-10969. This is one of the following four reports documenting the contract findings:

MSC-03975, LMSC-A984262A,	Lunar Mission Safety and Rescue Executive Summary
MSC-03976, LMSC-A984262B,	Lunar Mission Safety and Rescue Technical Summary
MSC-03977, LMSC-A984262C,	Lunar Mission Safety and Rescue Hazards Analysis and Safety Requirements
MSC-03978, LMSC-A984262D,	Lunar Mission Safety and Rescue Escape/Rescue Analysis and Plan

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P. J. Van Zytveld	Rescue Flight Mechanics
E. D. Webb	Rescue Flight Mechanics

CONTENTS

Section		Page

Glossary

SYMBOLS, ABBREVIATIONS, AND DEFINITIONS

AMU	Astronaut Maneuvering Unit (generic term)
Activation Time	The time required to ready the rescue vehicle and crew for a rescue operation following receipt of the alert signal
Backpack	Portable Life Support System (PLSS) carried on the back of an astronaut (generic term)
Base	Lunar Surface Base (generic term)
Buddy System	Two or more men working together in the same location and environment
CC	Crew Compartment used to house and transport men on the PTV and tug (generic term)
Communications Lag	The time required for the distressed crew to communicate a request to the rescue crew
C-PTV	Chemically Powered Prime Transport Vehicle (generic term)
Delta V or Delta Velocity	Change in vehicle velocity in inertial space
Earth Vicinity	A general, unspecified location in Earth orbit or on Surface
EC/LSS	Environmental Control/Life Support System (generic term)
ECS	Environmental Control System (generic term)
EMV	Extravehicular Maneuvering Unit (generic term)
Escape	Utilization of on-hand equipment and resources, without outside assistance, to effect immediate removal from the proximity of danger
ESS	Emplaced Scientific Station (generic term)
FD	Propellant Depot (generic term)
Flyer	Generic term for any flying vehicle designed for limited travel over the lunar surface (LFV)
G&N	Guidance and Navigation
Hazard	Presence of a potential risk situation caused by an unsafe condition, environment, or act

IPP	Integrated Program Plan
IVA	IntraVehicular Activity
LCG	Liquid Cooled Garment
Lander	See Lunar Lander Tug (LLT)
LEAP	Lunar Escape Ambulance Pack
LESS	Lunar Emergency Escape System (See Ref. Page 5-4)
LFV	Lunar Flying Vehicle (Flyer)
L_2 Libration Point	Point of stable equilibrium in orbit on the far side of the Moon
LLT	Lunar Lander Tug (generic term); space tug with landing gear
LM	Lunar Module
LMP	Lunar Module Pilot
LOD	Lunar Orbit Departure
LOI	Lunar Orbit Insertion
LRV	Lunar Roving Vehicle (Rover)
LSB	Lunar Surface Base
LSSM	Lunar Scientific Survey Module
Maneuvering Work Platform	Platform designed for use in working on the exterior of an Orbiting Lunar Station
Mev	Million Electron Volts
MOLAB	Mobile Laboratory
MPL	Manned Payload
N-PTV	Nuclear-Powered Prime Transport Vehicle (generic term)
OLS	Orbiting Lunar Station (generic term)
OPS	Oxygen Purge System (generic term)
PDD	Project Description Document (produced by NASA-MSC)
PDI	Powered Descent Initiation
PGA	Pressure Garment Assembly

PLSS	Portable Life Support System or Backpack (generic term)
PTV	Prime Transport Vehicle used to transport personnel and cargo between Earth orbit and lunar orbit (generic term)
RCS	Reaction Control System
Rescue	Utilization of outside assistance to effect a return to a safe haven
rem	Roentgens equivalent man
Response Time	The span of time between the occurrence of an emergency and the placement of the stranded crew into a temporary or permanent safe haven
RNS	Reusable Nuclear Shuttle (N-PTV) (generic term)
Rover	Generic term for any lunar surface transport vehicle moving on tracks, wheels, etc. (LRV)
Safety	Freedom from chance of injury/loss
SLSS	Secondary Life Support System (generic term)
Survival	Refers to the utilization of resources immediately at hand to extend the lives of crewmen to permit escape or rescue
Survival Time	Refers to the maximum length of time that a crew can live following an emergency, using resources immediately at hand
Space Tug	Multipurpose vehicle used to transport men and cargo in lunar orbit and to the lunar surface (generic term)
Tug	Space Tug
TEI	Transearth Injection
Tumbling	Random angular motion about any axis
ΔV	Delta velocity
Pogo	A minimal weight, cabinless, rocket propelled vehicle for horizontal flights in which the crew manually stabilizes and flys the vehicle from a standing position

Section 1

INTRODUCTION

This report presents a technical summary of the hazards and escape/rescue requirements identified, and the safety guidelines, escape/rescue guidelines and concepts, and rescue plan developed, during performance of the Lunar Mission Safety and Rescue Study.

1.1 OBJECTIVES

The primary objective of the study was, within the limitations of current concepts and planning, to establish the essential guidelines for the enhancement of safety in advanced lunar missions. This was accomplished by (1) identifying and analyzing hazardous conditions and situations and their effects, and establishing effective countermeasures; (2) identifying conditions and situations which can require a rescue mission; (3) developing escape, survival, and rescue mission requirements, techniques, and concepts, and a rescue plan. It is expected that the study results will provide major inputs to current and planned advanced lunar mission design and operations studies related to the proposed Integrated Program Plan.

1.2 CONSTRAINTS AND ASSUMPTIONS

The study was performed under rather specific constraints and assumptions imposed to limit the effort to available information and resources. The more important constraints and assumptions are:

Analyses are constrained to the lunar sphere of influence, and missions and operations in the 1980 time frame.

Operations and interfaces of major Integrated Program Plan (IPP) elements are analyzed.

It is assumed that design and routine internal operations of major IPP elements are optimized and no hazards analyses are required.

Terms and abbreviations such as Orbiting Lunar Station (OLS) and Lunar Lander Tug (LLT) are general, and imply a function or broad concept rather than a specific configuration, size, mass, or capability.

No classical reliability or probability analyses are performed. If a hazard could occur, it was assumed to be a threat, and analyzed accordingly.

Previous and current study efforts are not duplicated, but these and the results of Apollo missions (in particular, Missions 11, 12, and 14) are used where appropriate.

Planned IPP elements are used for rescue where feasible. Study results are intentionally kept general enough that the safety guidelines and rescue plan will be valid though IPP elements and operations change.

No significant effort is directed toward hardware design.

Lunar surface activities are defined to commence with the final flight phase immediately preceding spacecraft touchdown on the lunar surface, and to conclude once the crew has returned to a lunar ascent vehicle and ascent has begun.

Lunar orbital activities are defined to commence at lunar orbit insertion, and to conclude either during spacecraft contact with the lunar surface, or upon completion of the transEarth injection maneuver.

The study is concerned with hazards to man, and not with hazards to equipment, program schedule, or program objectives.

1.3 SCOPE AND APPROACH

The Lunar Mission Safety and Rescue Study covered the full range of hazards and escape/rescue situations that might occur in the missions presented in the high-level-budget Integrated Program Plan (IPP) of Ref. 1.

The study was divided into two major tasks. These were:

Hazards analyses leading to safety guidelines and recommendations, rescue mission need identification, and safety technology development recommendations.

Escape/rescue analyses leading to escape/rescue requirements and concepts and a lunar mission rescue plan.

A summary of the study approach is illustrated in Fig. 1.

1.3.1 Mission Model

The mission model and equipment elements assumed for the study were defined from the study Statement of Work, from Appendix A to the Statement of Work titled, "Description of Lunar Program Portion of Manned Spacecraft Integrated Plan", from the definitions of Integrated Program Plan elements and objectives, from the Project Description Documents, and from a melding of all these with the results of past and current lunar exploration studies.

Examples of lunar exploration equipment elements are illustrated in Fig. 2. The major items and their usage are:

- Transportation between Earth Orbit and Lunar Orbit
  - Nuclear Shuttle
  - Chemical Shuttle (alternate)
  - Lunar Lander Tug (emergency return)
- Operations in Lunar Orbit
  - Orbiting Lunar Station
  - Lunar Lander Tug (normal and rescue)
  - Propellant Depot
  - Consumables Capsules
  - Unmanned Satellite (scientific, communications, etc.)
- Transportation between Lunar Orbit and Lunar Surface
  - Lunar Lander Tug (normal and rescue)
- Operations on the Lunar Surface
  - Lunar Lander Tug (normal and rescue)
  - Lunar Surface Base
  - Roving Vehicles (normal and rescue)
  - Flying Vehicles (normal and rescue)
  - Science Equipment (emplaced stations, drills, telescopes, etc.)
  - Support Equipment (elec. power, trailers, supply canisters, etc.)

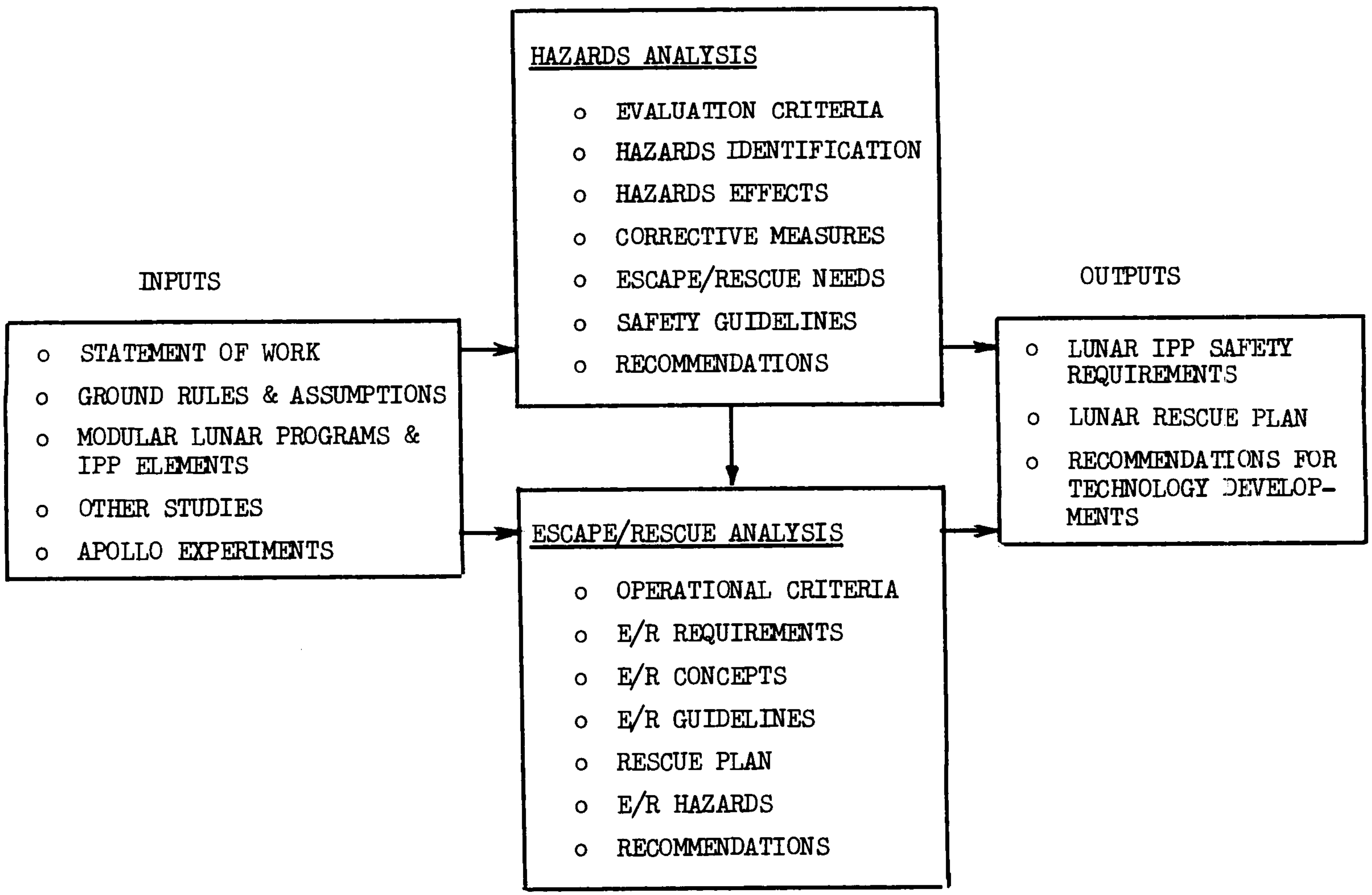

Fig. 1 Summary of Study Approach

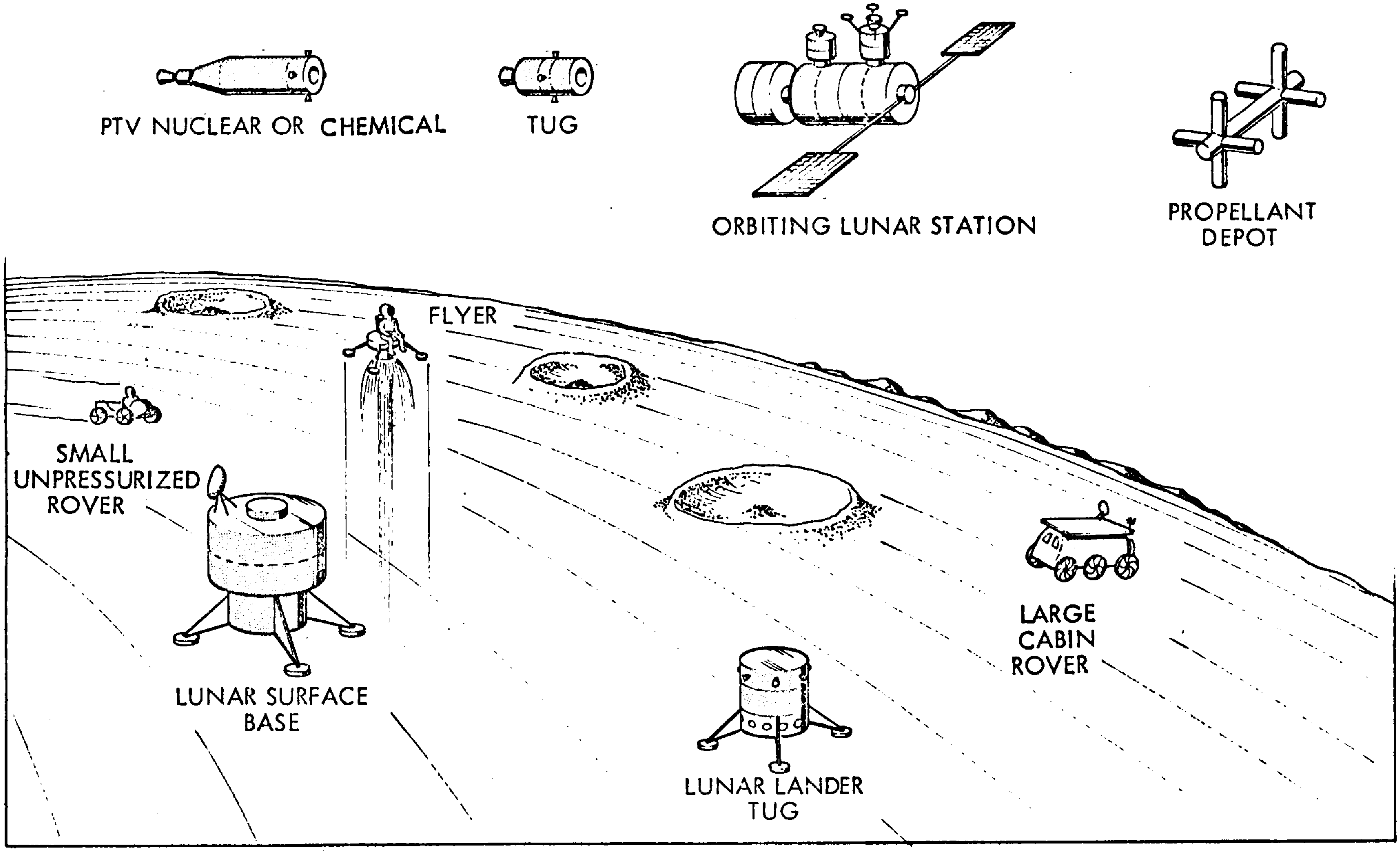

Fig. 2 Exploration Equipment Elements

Lunar mission operations, as well as equipment elements, were examined in the study. The primary operations considered are:

Earth-Moon Shuttle Operations	Orbital Operations	Surface Operations
Transport Payload	Rendezvous & Docking	Deployment
Lunar Orbit Insertion	Operations Base	Exploration
Transearth Injection	Orbit Keeping & Transfer	Technology & Engineering
Rendezvous & Docking	Resupply	Science
Station Keeping	Maintenance	Resupply
Contingency Operations	Tug Refueling	Maintenance
	Technology & Engineering	Walking
	Science	Driving (roving)
	Extravehicular Activity	Flying
	Satellite Place & Service	Escape/Rescue
	Escape/Rescue	Contingency Operations
	Contingency Operations	

Variations of the basic mission model, containing a set of equipment elements and mission operations, were considered during the analyses in the search for the resulting effects on safety and in recognition of the fluid state of future mission planning. Some examples of alternate operations and elements considered are:

Nuclear vs chemical shuttle
Space tugs, varying in size and number of stages
Non-cabin vs cabin-type roving vehicles
Orbiting Lunar Station (OLS) vs no OLS
Alternate propellant depot basing schemes, and no propellant depot

1.3.2 Hazards Analysis

The hazards analysis approach used was to work from the mission model and defined task objectives to:

a. Develop a top level functional flow and equipment operations diagram.

b. Develop a first level flow chart for each series of mission events to identify hazard generators, hazards, hazard groups, and range of hazard levels.

c. Identify events, situations, operations, and conditions requiring detailed hazards analyses.

d. Perform individual hazard studies of each item identified in (c) above to describe hazards, hazards effects, preventive and remedial measures and safety guidelines candidates, and to identify situations requiring rescue.

e. Analyze the results of individual hazard studies to arrive at recommended safety guidelines and requirements, and to identify areas requiring safety technology development.

The hazards analysis methodology is illustrated in Fig. 3.

1.3.3 Escape/Rescue Analysis

The escape/rescue analysis approach was to first examine the deployment and operational characteristics of the various exploration equipment elements, such as those illustrated in Fig. 2. The analysis was then separated into three parts to study operations during lunar arrival and departure, in lunar orbit, and on the lunar surface. Escape/rescue situations were developed from analysis of operations with the various hardware elements and from inputs from the hazards analysis task.

An escape/rescue requirements envelope, expressed in terms of operational and performance limits and constraints, was established. Critical requirements are: communications, crew survival time following an emergency; escape or rescue response time; and delta velocity (ΔV) needs. Candidate escape/rescue concepts were then defined and escape/rescue guidelines proposed, based on operations analyses and tradeoff evaluations. Recommended concepts and guidelines were then re-evaluated from the standpoint of safety, and an escape/rescue plan formulated.

The escape/rescue analysis approach is illustrated in Fig. 4.

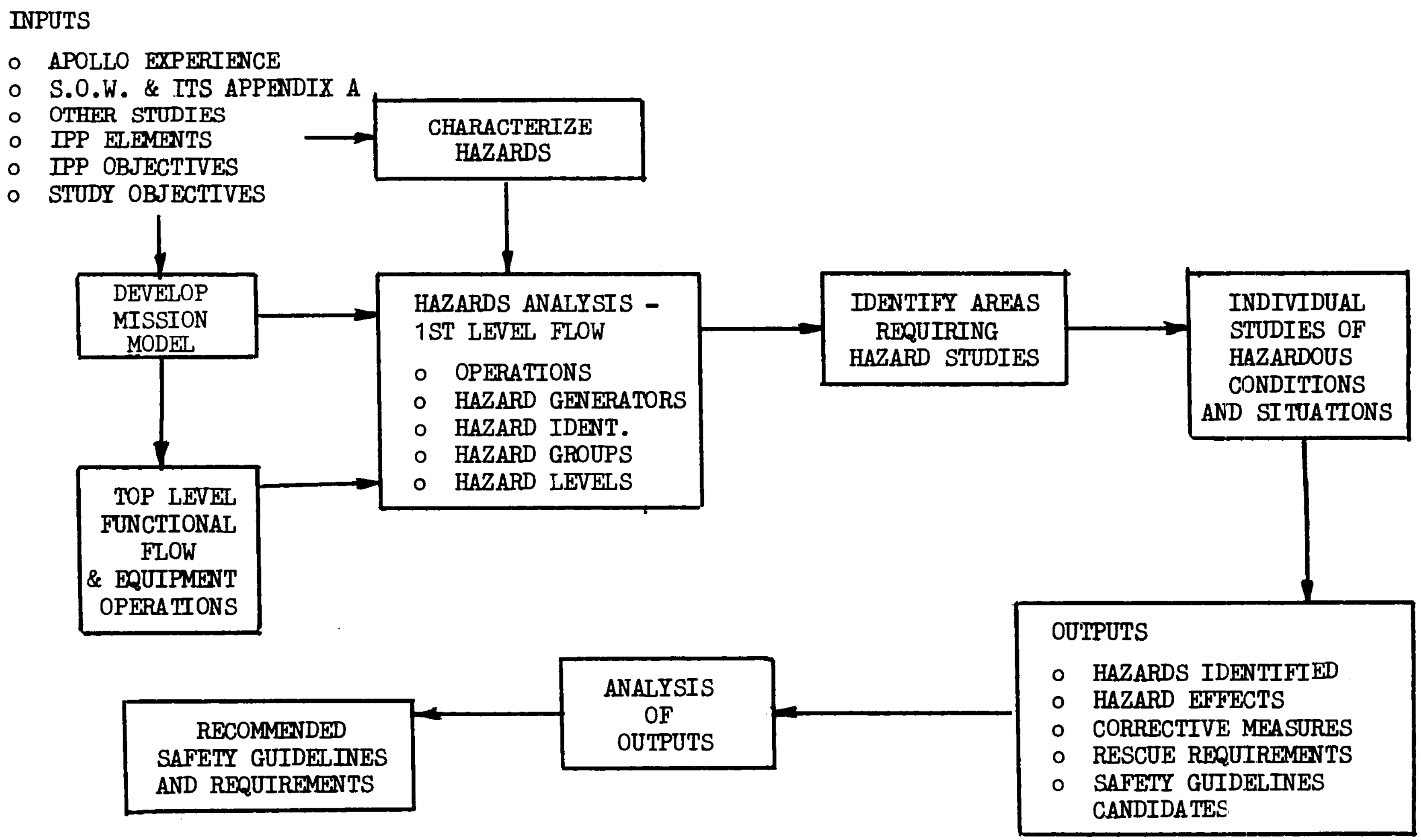

Fig. 3 Hazards Analysis Approach

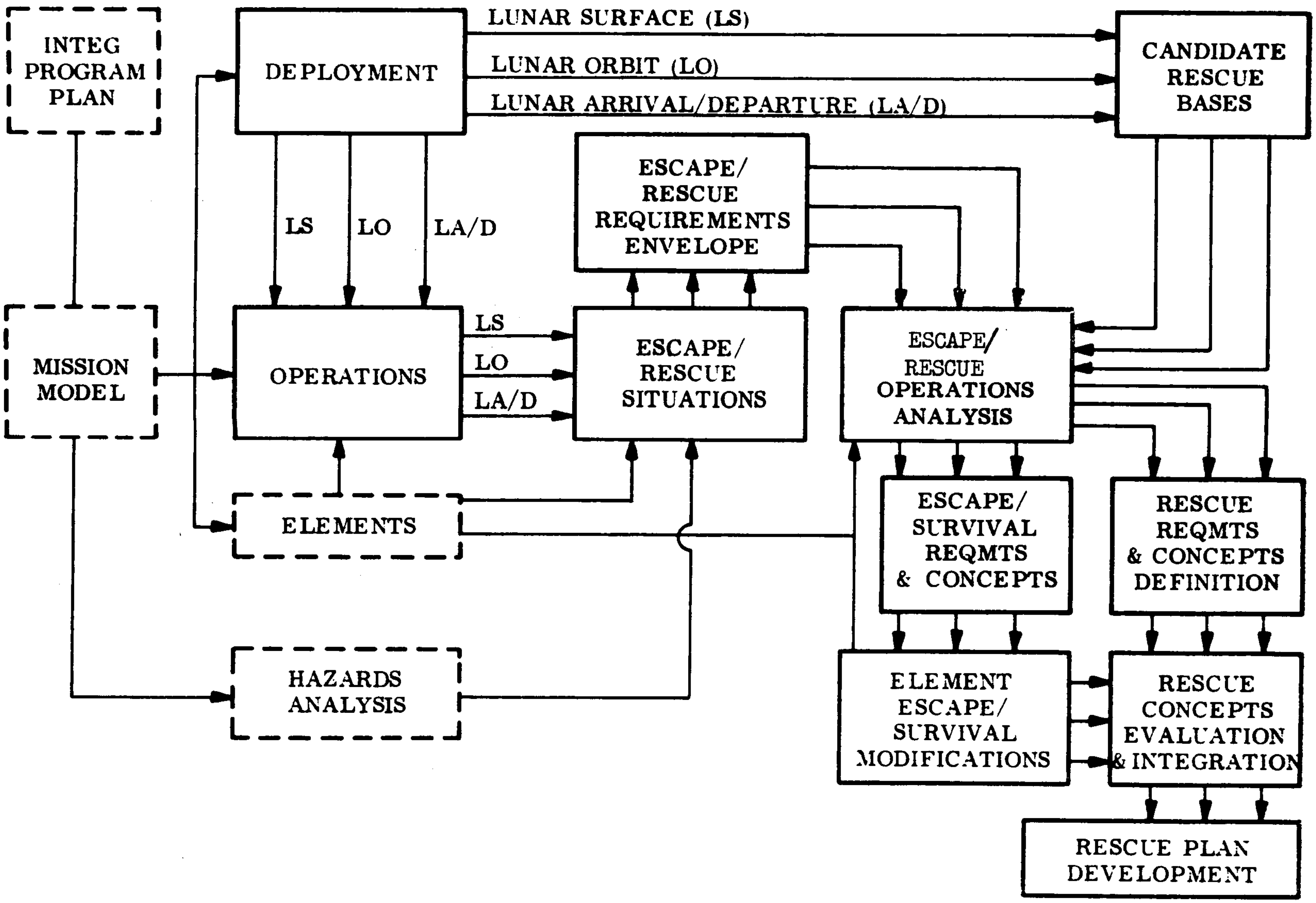

Figure 4 - Escape/Rescue Analysis Approach

1.4 HAZARD AND RESCUE INTERRELATIONSHIP

Report MSC-03977, Lunar Hazards Analysis and Safety Requirements, presents the results of the Hazards Analysis subtask and identifies the potential need for rescue associated with each hazard.

Report MSC-03978, Escape/Rescue Analysis and Lunar Mission Rescue Plan, accepts the potential rescue need identified in MSC-03977 and expands it to describe the escape/rescue situation in detail. Escape/rescue concepts and a rescue plan are developed to meet the needs identified. The results of the individual Hazards Studies presented in Section 2 of MSC-03977 were used as appropriate in developing the escape/rescue concepts and guidelines.

Section 2
ESCAPE/RESCUE ANALYSIS RESULTS

Future manned exploration of the Moon will involve more complex environmental and operational factors than have been encountered on the Apollo program. The advanced programs may involve orbital space vehicles and a multi-manned station, extensive surface exploration, and regular logistics and crew rotation flights between the Earth and the Moon. The hazards and risks associated with the use of future flight and crew equipment and the operational usage of this equipment in the lunar environment calls for new approaches to escape/rescue plans.

One portion of the study involved the identification of escape/rescue situations and associated requirements, the development of escape/rescue concepts, the definition of escape/rescue guidelines, and the formulation of an escape/rescue plan. The analysis was separated into three parts to study operations during lunar arrival and departure, in lunar orbit, and on the lunar surface.

This section summarizes the lunar escape/rescue situations and concepts that were analyzed, the escape/rescue plan developed, and the recommended escape/rescue guidelines and safety requirements. In some situations, possible design solutions have been indicated.

2.1 Escape/Rescue Situations and Concepts

This subsection describes operations in the lunar area and situations requiring escape or rescue. Alternate escape/rescue concepts to cope with the situation are also presented. The discussion is divided into three parts: Arrival/Departure operations, Lunar Orbital operations, and Lunar Surface operations.

2.1.1 Arrival/Departure Operations

Both nuclear powered and chemically powered prime transport vehicles are considered in arrival/departure situations. From the standpoint of escape/rescue the primary difference between the two is the radiation environment associated with the nuclear powered vehicle.

The initial manned flight to activate the orbiting lunar station is unique from the standpoint of escape/rescue because:

a. The only available permanent safe haven for escape purposes is in the Earth vicinity

b. If rescue is required it must originate from the Earth vicinity

The initial orbiting station manning operation is expected to be made by either a nuclear or chemical powered prime transport vehicle (PTV) with a payload consisting of the initial crew and either one or two tugs. One tug may be off-loaded in propellants. Rescue operations for this initial manning flight will not have the benefit of personnel and equipment in the lunar vicinity. Consequently, if rescue capability is required, rescue vehicles must be based in the Earth vicinity and the response time will be measured in days. A more attractive alternative to rescue is to provide self-contained escape capability, through use of the tug, for autonomous Earth return.

Routine PTV flights after lunar orbital station activation may be made with a crew compartment without a tug. The absence of the tug makes escape unlikely without augmentation of the crew compartment capabilities.

All practical lunar trajectories approach periselene at velocities exceeding the lunar escape velocity. A retro velocity impulse is therefore required to insert a vehicle into the desired lunar orbit. In the event of PTV failure, the addition of approximately 1,000 ft/sec of Δ V capability to the crew compartment would enable separation from the PTV and insertion into lunar elliptical orbit and subsequent rescue by a tug from the station.

A guidance or propulsion system malfunction during the lunar orbit insertion maneuver could result in a surface impact trajectory condition. Once this is detected, the crew could separate their crew compartment from the PTV and utilize the 1,000 feet/sec Δ V capability to enter an elliptical orbit with a perilune higher than 50,000 feet.

The use of nuclear propulsion would primarily affect the radiation danger to an escape or rescue effort. Either escape or rescue within 24 hours after nuclear engine shutdown would be radiation-limited to the PTV forward, safe-radiation shield cone.

Routine arrival and departure operations may have the advantage of orbiting lunar station personnel for rescue. The arrival and departure of manned PTV flights should be backed up by both vehicles and crews capable of rescue until the insertion or injection is achieved.

2.1.2 Lunar Orbital Operations

The base for lunar orbital operations is the orbiting lunar station. The basic mission model calls for this station to be placed into lunar orbit unmanned. A flight to man and activate the station takes place a month or two later. Following activation the station receives regular logistics flights from the Earth, and routine station internal activities and EVA sorties for routine station inspection and maintenance and repair are initiated.

A propellant depot may be added to the station at some future date. This would introduce related activities such as depot maintenance and repair, replenishment of depot expendables, and servicing and refueling vehicles.

A space tug will be a key vehicle in the spectrum of orbital station activities to ferry crewmen and cargo between the station and the prime transport vehicle, to perform station maintenance and repair missions, and as a general utility vehicle. The tug will also serve as the key vehicle for the orbital placement of scientific or communications satellites in various orbital positions, for logistics flights to the lunar surface base, and to carry out lander tug lunar surface sortie missions. Because of these capabilities the tug is a prime candidate for use as a rescue vehicle.

2.1.2.1 Orbiting Lunar Station - Initial Manning

The failure of a critical station subsystem, including any backup and emergency capability during the initial manning and activation operation results in two available options:

a. Remain at the station and await a flight from Earth with either repair or replacement capability

b. Abandon the station and return to Earth in the tug

If necessary, the docked tug could support the station in an emergency by means of a tug/station umbilical, in areas such as communication, station-keeping, attitude control, and data management. Such support could enable the crew to continue station activation while awaiting a repair flight from Earth.

A failure of the station primary life support/environmental control subsystem including all backup capability could be managed by having the crew retreat to the docked tug. They could operate from the tug while repairs were made or until a repair crew and parts could arrive.

In a critical failure situation the station may sustain severe physical damage. Emergency portable oxygen masks and supply bottles, and pressure garments with a built-in oxygen supply would provide sufficient protection from smoke or gases and the effects of depressurization to enable crewmen to evacuate the affected area or to traverse to the docked tug.

If the rate of oxygen depletion or production of smoke or toxic gases was so rapid that the crewmen could not traverse to the location of stored emergency gear or could not don and activate an emergency garment rapidly enough (perhaps due to an injury) the crewmen could enter an alternate compartment which provides a temporary safe haven. The crewmen would then have sufficient time to don and activate emergency gear. A crewman could either await rescue or could don the emergency pressure garment, depressurize the compartment to the station ambient pressure level and translate to the tug. If injuries prevented this procedure, the crewmen would have to retain a shirtsleeve environment in the compartment and await rescue. The rescue crew would require access into the alternate compartment through an airlock. If the compartment airlock was inoperative, or if no airlock was available, a portable airlock would be required.

After entering the pressurized compartment the rescue crew would be able to either assist injured crewmen in donning pressure garments and in traversing to the tug or could place the crewmen in a pressurized stretcher for transporting to the tug.

In order to ensure the availability of a rescue crew and immediate access to pressure garments and emergency equipment, two crewmen should remain in the docked tug at all times during the station activation period.

A critical failure could result in major damage to both the station and all docked tugs. No rescue crew would be available except from the Earth vicinity. The station crew would have to survive in an emergency compartment until a rescue crew arrived. A minimum of 114 hours is required, even under the best of trajectory conditions, for a rescue crew based in the vicinity of Earth to arrive at the station. A more realistic time for a rescue mission from Earth orbit is 14 days. This allows a wait of up to 10 days for alignment of the transfer orbit plane, a 60 hour transfer time, a 24 hour 90° plane change at lunar orbit insertion, and 12 hours for rendezvous, docking and rescue crew activities after arrival at the station. It follows that any station alternate compartments must have the capability for communicating to Earth vicinity and must have life support capability for a minimum of 14 days.

2.1.2.2 Orbiting Lunar Station - Routine Operations

During routine orbital operations the presence of a large orbiting lunar station, plus two space tugs in lunar orbit - one operational and one on rescue standby - should make the likelihood of need for outside assistance rather remote. Outside assistance might be required in the following situations:

a. Critical damage that involved the station and both tugs

b. Immediate need for medical aid that was not available at a damaged station

In the first situation, assistance could come from the lunar surface, from Earth orbit, or from both locations. A fully fueled lunar lander tug with the capability for performing an orbital rescue operation will be located at the lunar surface base. Also, a lunar lander tug used for a solo surface sortie mission could, by aborting its mission, be used as an orbital rescue vehicle, again with limited capability. The limiting feature for solo surface sortie tugs is that they will generally not have the capability to perform a plane change on the return to orbit, and thus must wait for up to 14 days to proceed to the orbiting lunar station. This is not a satisfactory rescue response time for situation (a). The same response time limit of 14 days is present for a practical rescue capability with a prime transport vehicle from Earth orbit. Thus it is concluded that an acceptable rescue mode for situation (a) is not available until refueling capabilities are available on the lunar surface.

In the second situation, the standby rescue tug in lunar orbit has the capability to perform up to a 90° plane change, descend to the lunar surface base, and land, if provided with a ΔV capability of 15,000 ft/sec. The tug used for the descent would require refueling before it could return to orbit.

2.1.2.3 Extra Vehicular Activities in Orbit

Orbital extra vehicular activity (EVA) escape/rescue situations in orbit can be divided into two general categories: (1) the crewman on EVA is attached to the orbiting lunar station (or some other spacecraft) by means of a tether, or umbilical, or both, or (2) the crewman is in an astronaut maneuvering unit (AMU).

Escape from an EVA situation implies that the crewman has the capability to return and enter the station without outside assistance. Rescue implies that the crewman on EVA cannot reach a safe haven unless outside assistance is supplied. Typically, a crewman on EVA performing a planned station maintenance function could be on a life support back pack or a short umbilical connection into the station life support, communications, environment control, and power. If the crewman could not wear a backpack because of operational considerations, he should have a minimum 90 minute duration emergency life support system. This required duration is a function of the probable rescue response time plus a contingency factor.

The EVA crewman needs a separate, self-contained voice communications link operating on a carrier frequency that is reserved for escape/rescue emergency use. In addition, since the crewman may be injured, ill, or otherwise incapacitated and unable to talk, a self-contained RF locator beacon and flashing light should be designed into the crewman's helmet. This emergency equipment should be capable of being activated manually by the crewman and should also be automatically activated in the event of such conditions as:

a. Suit power loss
b. Umbilical failure
c. Activation of emergency oxygen system
d. Suit static pressure decaying below a minimum level
e. Communications failure

It is recommended that an EVA crewman be assigned as a potential rescue crewman to back up the EVA crewman on work status. The rescue crewman should be suited, with a backpack, but attached to the station by an umbilical connection with a quick disconnect. The quick disconnect is needed to provide the rescue crewman with maximum maneuverability in the event of an emergency. By remaining on umbilical until an emergency occurs the full backpack metabolic capability is available.

It is also possible, though not recommended, for an EVA crewman to use an AMU to translate around the station while not attached by either tether or umbilical. The AMU would require redundancy and fail/safe design philosophy similar to that of the station. The crewman would need the 90 minute capability emergency O_2 system and emergency communications capability. The rescue crewman would also require an AMU with at least the propulsion, Δ V, and other capability of the AMU assigned to the EVA crewman. The rescue-assigned crewman would require line-of-sight, direct observation of the EVA crewman and therefore might have to maneuver his AMU to successive positions around the station.

A critical rescue situation could occur if the EVA crewman were drifting uncontrolled away from the station. He could be in an AMU or could be free-floating. If his velocity relative to the station is low, the rescue crewman and AMU should be able to reach the drifting crewman and return him to the station. If the relative velocity is high the drifting crewman might reach a range beyond the safe operating limit of the rescue AMU.

The recommended approach is to provide the rescue AMU with the capability to achieve at least a velocity of 150 ft/sec with respect to the station to catch the runaway AMU and then still be able to return to the station. The AMU used for normal EVA mode activities should be velocity-limited to a value of approximately 100 ft/sec. Thus, the rescue AMU with a total Δ V capability of 400 ft/sec would be able to chase, catch and return the EVA AMU even if its total velocity capability were expended in a runaway propulsion failure.

A guidance system failure, loss of attitude control, or a runaway reaction control thruster could result in a tumbling situation with the AMU. The crewman would have available the lunar surface, the station, and the stars and the Earth for use as a visual reference in determining his relative orientation and tumbling direction. Once the tumbling direction was determined, an emergency corrective reaction thruster could be used to stop or at least to reduce the tumbling rate to a manageable level. This emergency thruster could consist of clusters of manually activated solid motors oriented along the AMU 3 principle axes. By firing one corrective thruster at a time the magnitude and duration of the corrective velocity vector could be controlled. If the crewman were separated from the AMU, a hand-held thruster (perhaps using cold gas) could be used to arrest any tumbling motion.

The tumbling-arrest thrusters could also be used (by selective firing) to prevent a collision with the station and to roughly control the velocity vector until the rescue crewman arrived.

A pressure suit tear during EVA poses a difficult survival problem. Even if an EVA crewman were attached to the station by an umbilical, a suit tear could cause a critical or even fatal suit static pressure drop. If the tear could be located quickly and repaired or sealed off, survival could probably be extended. A self-sealing capability seems an attractive possibility. A pressure garment that could be unfolded and quickly deployed around the crewman and sealed also appears promising. The escaping gas would fill the garment and provide a satisfactory static pressure level. An exhaust pressure relief valve could provide sufficient cooling flow and still maintain proper static pressure.

2.1.2.4 Orbiting Lunar Station Deactivation

The same options available during station activation are also available during deactivation.

2.1.2.5 Space Tug Orbital Operations

The failure of tug equipment such as the docking mechanism, docking sensors, attitude control system, etc., could result in a rescue situation in which survival would not be a problem since the tug life support system would not be affected. The docked rescue tug could separate from the station and transfer to the near vicinity of the stranded tug to tow it back to the station. If the docking mechanism had failed, external attach points would be needed to provide a positive and rigid attachment between the stranded and rescue tug.

The loss of electrical power, including emergency power, will result in the loss of all tug functions including communication, life support and attitude control. Refer to Fig. 5 for a typical sequence of events related to life support. If a shirtsleeve environment existed in the crew compartment, the crew could use oxygen masks and await rescue. If the rescue could not be accomplished before cabin temperature went out of limits, or if the ambient pressure decayed, the crew would be forced to don pressure suits or emergency pressure garments. The tug environmental control system would stop functioning and the compartment would immediately start to cool down. If pressure suits and back packs were not available, the crew would need thermally insulated garments.

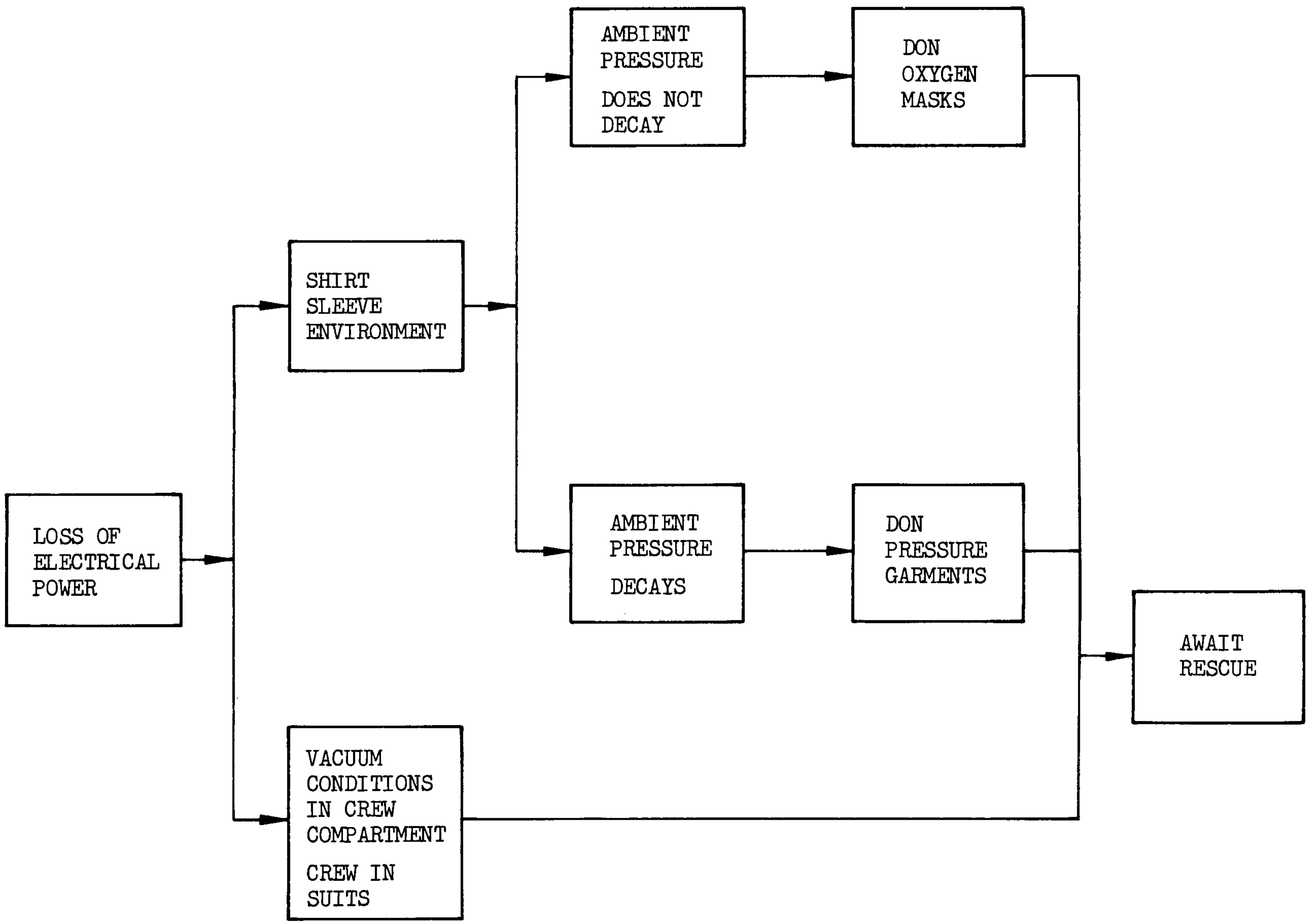

Fig. 5 Typical Sequence of Events Related to Life Support

In a critical failure situation the tug would probably sustain severe physical damage and a sudden loss or deterioration of a critical capability. Contamination of the ambient atmosphere could be counteracted by donning oxygen masks or emergency pressure garments. Crew compartment depressurization would require the immediate donning of pressure suits or emergency pressure garments. An umbilical connection into the tug life support system could provide indefinite life support and environmental control capability.

A critical failure in the tug during cargo transfer operations could result in the tug's operational capability being compromised by the on-board presence of cargo. Tug and cargo container design must be amenable to rapid and selective jettisoning or separation from the tug. If necessary, separation springs could be installed in the cargo attachment mechanisms to provide a separation ΔV of 5 to 10 ft/sec. Cargo module design should include corner reflectors or repeaters for laser or RF radar detection to aid in eventual recovery of jettisoned modules.

Because of the possibility of collision with the station, or structural damage to the tug while performing close proximity station maneuvers during maintenance and repair operations, it is recommended that the crewmen wear pressure suits at all times during such operations.

The failure of a critical tug subsystem while operating near the station could result in a collision or in tumbling. It is strongly recommended that the tug design provide for manual control, through mechanical linkages or cables, of emergency attitude control and emergency propulsion subsystems.

The emergency propulsion subsystem could be either liquid or solid propellant and would be used to prevent collision or undesired contact with the station or other spacecraft. The attitude control subsystem should be capable of low translational thrust, velocity vector control, and tumble-arrest, as well as attitude control.

The possible necessity to effect forced entry into a disabled tug or other spacecraft must be taken into account in the design phase. Emergency linkage or attachment mechanisms with attachment points designated on the vehicle exterior are needed. Manipulator arms with hooks or heavy duty pincer claws could be used to tie into these emergency attachment points or even to break through the skin to grasp a primary structural member. In addition, rescue crewmen should be familiar with the general structural characteristics of all manned spacecraft.

The tug vehicle may be used to transfer scientific statellites from the PTV or station to various orbital positions. For this type mission, up to approximately 5310 ft/sec of ΔV and 35 hours mission time are required. These requirements leave ample margins for crew survival regardless of when an emergency occurs during such a mission, assuming the life support subsystem remains functional.

A failure in the life support system (or a power failure) does not necessarily require immediate switchover to pressure suits or emergency garments. A breathable crew compartment atmosphere would exist at the time of failure and for perhaps as long as an hour or more. If cabin pressure remained above 2.5 psi the crew could don oxygen masks and a thermally insulated garment and survive for at least 36 hours and perhaps 48 hours even without food or water. If cabin pressure decays below a safe minimum, a pressure garment and backpack would be required. The available pressure garments and backpacks must permit a minimum of 20 hours of survival time to make rescue feasible.

2.1.2.6 Lunar Lander Tug Surface Sortie Operations

Lunar lander tug (LLT) surface sortie flights will probably be planned for descent and ascent in the orbit plane of the lunar station. Landing sites on the Earthside of the Moon will always have potential communication capability with the Earth. A critical LLT subsystem failure prior to powered descent initiation (PDI) would permit a mission abort and would leave the LLT in a slightly elliptical orbit with apolune at the station orbit altitude and perilune at PDI altitude. Rescue from the station would require only 330 minutes to accomplish versus a potential survival time of 12 hours for the worst case situation of either a total power or life support subsystem failure. The ΔV required for rescue is well under the recommended tug capability of 15,000 ft/sec.

The possibility of rescue after PDI depends on the nature of the failure and its side effects. A propulsion failure would result in impact unless a second stage or adequate auxiliary propulsion subsystem was available. To increase the chances and duration of survival following a crash landing, the crew should be in pressurized suits with freshly charged backpacks during powered descent. This would provide 12 hours of life support even though unconscious or injured which is more than enough time for a rescue tug to come from the orbiting lunar station. If the rescue tug were manned and activated during the powered descent phase of the lunar lander, it could get down to the site in 2 hours (one orbital period) because the orbiting lunar station would be in line-of-sight and coincident with the lunar lander. Because essentially no plane change would be involved, the rescue tug (with a total 15,000 ft/sec ΔV capability) could immediately return the distressed crewmen to the orbiting lunar station for medical treatment.

Loss of the guidance system, or even electrical power, could be counteracted by resorting to full manual control of vehicle propulsion and attitude control. The recommended procedure, however, for non-propulsive failures would be to switch to an ascent mode and return to an altitude above 8 nm and inject with an orbital velocity sufficient to provide a perilune minimum of 8 nm. An orbital rescue operation from the orbiting lunar station could then be accomplished, if required.

2.1.2.7 Orbiting Propellant Depot Operations

An orbiting propellant depot may be used to supply cryogenic propellants and other expendable liquids and gases for the tug propulsion, intelligence, and crew modules. Vehicle servicing requires that the manned vehicle rendezvous and dock with the depot, followed by the connection of liquid and gas transfer lines, the transfer of consummables into the tug, and then disconnecting and separating the tug from the depot. Depending on depot design and operations requirements, it could be required that one or more tug crewmen go on EVA in order to service the vehicle. It is recommended that use of EVA for this operation be avoided.

Crew survival, following a critical fuel depot failure while the tug is docked to the depot and being serviced, will primarily depend on the capability to disconnect fueling and servicing connections and to undock under emergency conditions. The use of pyrotechnic devices to cut lines, pull latching pins, or cut bolts might be appropriate and necessary even if open-and-still-flowing lines remained on the depot side of the interface. Control and power should come from the tug side of the interface.

One worst case survival situation occurs if the crew were solely dependent on pressure suits and back pack units or emergency pressure garments for survival and were unable to undock the tug from the propellant depot. The response time for rescue by a tug docked at the station is of primary concern. Table 2 presents a tabulation of the rescue tug sequence of events and time spans.

A critical situation with one or more crewmen on EVA on the depot could result in a situation in which the docked tug would be forced to undock and leave the EVA crewmen behind. These crewmen would be stranded and in extreme jeopardy unless some means of escape were provided. An astronaut maneuvering unit (AMU) located on the depot could provide a means of escape from the depot and possible return to the orbiting station. A cold gas propelled, manually operated unit could provide the approximate 100 ft/sec of ΔV needed to return to the station or provide one to two hours of survival time away from the station. An emergency flashing light, homing beacon, corner reflectors, and a short range voice communications system would be required.

2.1.3 Lunar Surface Operations

Surface operations can be divided into two phases: lunar lander tug (LLT) sortie operations and lunar surface base operations. Present planning indicates that surface sortie flights may be initiated about six months after activation of the orbiting lunar station, with the lunar surface base activated about $2\frac{1}{2}$ years later.

The lunar lander tug sortie operations will include surface exploration and scientific experiments. Potential landing sites include Earthside, farside, and lunar pole locations. Each mission duration will probably be no longer than 28 days. A typical mission sequence consists of:

a. touchdown of a lander tug at a predetermined site

b. deployment of support equipment and any local site experiments

c. the carrying out of traverse operations using equipment such as EVA rover, flyer, and ground-effect-machines. Short distance traverses could be made on foot, particularly if higher mobility suits are developed, though Apollo 14 traverse experience tends to cast doubt on the practicality of on-foot traverse operations with current equipment.

2.1.3.1 Lunar Lander Tug Surface Operations

A typical lunar lander tug sortie will probably be characterized by the touchdown of a single tug having a total crew of 4 men. The nominal mission duration will be 14 to 28 days. The site lurain may be somewhat rougher than that of the lunar surface base (LSB), and landing aids will be minimal.

In general, there are two emergency operations of interest:

a. Escape, in which the crew returns to the orbiting station in the tug

b. Rescue, in which a tug comes down from the orbiting station, lands at the sortie site, and returns to the orbiting station.

One of the first tasks after the tug has touched down on the surface is to deploy landing and location aids so that a rescue tug could land regardless of sun elevation angle and in either sunlight or darkness. In order to maximize tug payload capability, it is preferred that descent and ascent maneuvers be made in (or close to) the orbit plane of the orbiting station. Therefore, an emergency occurring during arrival or departure of the tug would not require a rescue tug to make a large plane change.

A rescue operation at some point in time midway through the LLT sortie mission could require the rescue tug to make a 90-degree plane change during the descent phase. A second 90-degree plane change would then be required during ascent, if immediate return to the orbiting station were required. Two 90-degree plane changes, plus the ascent and descent ΔV needs, would far exceed the anticipated impulse capability of the tug. A rescue tug with a ΔV capability of 15,000 ft/sec could descend and provide a temporary safe haven, but would have to remain on the surface for up to 14 days while awaiting further assistance from a second rescue tug.

A worst-case situation would occur if the LLT crew compartment pressure integrity was destroyed. In this case, the rescue response time must be less than the crew survival time using pressure suits and back packs. The rescue tug could have to make a 90-degree plane change for descent without delay.

2.1.3.2 Traverse Operations

Traverse operations take place in the vicinity of, or between, the permanent and temporary lunar surface bases. The traverse may be made by the crews on foot with or without an Apollo 14 type handcart, in an EVA mode mobility vehicle, or in a pressurized-cabin mobility vehicle.

EVA mode vehicles operate relatively close to a parked tug and/or lunar base. The pressurized cabin vehicle may travel between two widely separated points on the surface. The LLT from which it originates may return to orbit after the rover vehicle reaches a point of no return, and the pick-up LLT may not land until the rover vehicle nears its destination.

A critical factor in traverse operations is the condition of the pressure suits and backpacks. In the event of damage to the suit or backpack, the capability to walk back or drive back would be nullified or severely impaired.

2.1.3.3 EVA Mode Traverses

Walkback from the scene of an emergency is practical if the personnel are not injured, if the remaining backpack metabolic capability is adequate, and if the physiological suit limit is not exceeded.

In the case of a foot traverse, a handcart (similar to the one used on Apollo 14) could be used to carry an extra backpack or secondary life support unit. A survival bag (similar to an emergency pressure garment kit without the mobility feature) may be carried to encase a crewman with a substantial suit leak.

A rover vehicle can be used to make a surface rescue of men on foot, in another rover vehicle, or with a flyer whose location is accessible. However, the range of the EVA mode rover vehicle would probably be less than that of an uprated flyer or a ground effects machine.

The following conclusions were made relative to rescue of crewmen on EVA mode traverses:

a. The pressurized cabin rover vehicle is an acceptable rescue vehicle except in the case of an uprated flyer.

b. For two-man crews, the buddy system, plus an emergency oxygen supply of 5 lb total - or better - is required to enable rescue by a rover vehicle.

c. In the case of a damaged suit, some type of pressure garment must be provided which can utilize the residual backpack capability.

d. The rover vehicles should be capable of carrying a minimum of two men plus the rescue crew.

e. The rover vehicle must be capable of carrying and furnishing life support to a man in a pressure garment.

f. The activation of a rescue mission should not require more than two hours.

The LLT in lunar orbit offers a possible approach to the rescue of crewmen on EVA traverse. There are two general difficulties:

a. The LLT cannot land in rough lurain which might be acceptable for a flyer.

b. The LLT would have difficulty in searching for a disabled vehicle if the latter is without location devices.

In either of these cases it would be necessary to perform the rescue in two steps. The first step would be to land the tug from orbit. The second would involve a search for the disabled vehicle. Use of the LLT from orbit appears to have no advantages over rescue by rover or flyer dispatched from the nearby surface base, and has disadvantages of increased response time and unnecessary commitment of the primary rescue vehicle.

2.1.3.4 Cabin Rover Mode Traverses

The rescue of personnel in a cabin rover on a long traverse would be accomplished by a rescue tug from orbit. The problems discussed above for EVA traverse rescue apply, but no reasonable alternative is available except for the possibility of dispatch of a second cabin rover from the original surface site. In either case the response time could range from hours to days. It appears advisable to carry out long traverses using buddy cabin rovers.

2.1.3.5 Lunar Surface Base Operations

The lunar surface base will probably consist of the following elements:

a. Base structure including living quarters, laboratory, working areas, and supporting equipment.

b. Mobility vehicles for lunar traverses.

c. Propellant depot.

d. Landing site and lunar lander tug.

The separation between the lunar surface base and the normal tug landing site could be about 1-1/4 nm. This distance limits the possibility of damage to the surface base because of tug explosion and lunar soil ejata stirred up by the tug engines. This separation distance influences the escape and rescue response times.

Lunar surface base activities will probably be similar to those of the lander tug sortie missions except that more complex and heavier equipment with increased capacities will probably be used. Traverse operations will probably be virtually unlimited in range and may also take place during the lunar night. On the longer traverses cabin-type rovers will probably be used. Emergency situations may vary from injury or isolation of a single individual to incapacitation or isolation of the entire crew. Escape/rescue situations for individuals on traverses have been presented in preceding sections. Cases involving the lunar surface base crew in total are now considered.

Emergency Shelter Concepts

In the event of a critical accident rendering the lunar surface base uninhabitable, immediate survival is the first consideration. Temporary shelters are concepts which extend the survival time of the surface base crew. A minimum survival time of at least 12 hours should be provided so that rescue from lunar orbit is possible. The idea of providing a shelter for 14 days to allow for a zero plane change rescue seems to be an unrealistic requirement. This is because the injured men, if any, should be evacuated as soon as possible.

A second pressure compartment within the base with provisions for access by a rescue crew could provide the necessary support providing its integrity survived the accident.

An external life support compartment for the lunar surface base has been proposed as a preventive measure against the loss of cabin habitability. This compartment could be set apart from the main base, but connected by a pressurized tunnel. This concept may have an advantage if the base sustains an explosion. The external shelter, which should be at surface level, could also serve as a port through which the EVA crews could come and go during routine operations. The external shelter could be separated from the base, or it might be erectable only in case of an emergency. The problem with the detached shelter is that the base crew must resort to EVA to gain access. This requires some kind of pressure suit, but does not require a denitrogenization period if the shelter is easily accessible. The shelter pressurization should be greater than 6.8 psia so that the men can pre-oxygenate readily after they gain sanctuary in the shelter in case EVA activity is required.

Escape to a Standby Tug

The use of a standby lunar lander tug for escape from the lunar surface base is best suited for the case where no crewmen are injured or incapacitated. The standby rug should be fully fueled; that is, contain enough propellant to be capable of a total ΔV of 15,000 ft/sec. This will allow immediate ascent to the orbiting lunar station including a 90 degree plan change if necessary. If the tug is not refueled after landing, a waiting time of up to 14 days may be required for alignment with the orbiting lunar station.

The use of a standby tug for escape depends on the capability of at least two members of the crew to effect the transfer of personnel from the base to the escape tug, and to pilot it to rendezvous with the orbiting lunar station. The transfer of personnel may be accomplished in an EVA mode (either walking or riding) or by using a pressurized cabin rover compatible with airlocks on the base and the standby tug.

For the EVA mode, the rover vehicle should be capable of carrying at least two men in pressure suits and one pressurized stretcher. Instead of a rover vehicle, a hand cart similar to the Apollo 14 type could be used for transporting a pressurized stretcher, but the minimum separation distance of 1-1/4 nm between the base and the standby tug makes the traverse time about an hour versus 20 minutes using an EVA rover. Without the use of an EVA rover, the evacuation of four incapacitated crewmen by two able crewmen using a hand cart would require the capacity of two 6000 BTU backpacks for each of the two crewman. Use of an EVA rover would allow the transfer within the capacity of one backpack each.

The use of a pressurized cabin rover and compatible docking ports eases the problem of handling incapacitated men in the EVA mode and avoids dependency of the escape upon portable life support systems. These docking ports could be surface-mounted. If elevated, the cabin rover could climb a ramp to mate with the docking ports, or may dock with a pressurized elevator compartment. If the docking ports on the base and tug do not include airlocks, the rover vehicle airlock must be capable of pressurizing itself to the base and tug pressures. Response time is not critical, as the men are fully protected.

Lunar Escape System (LESS)

The use of a two-man EVA flyer vehicle was examined in the study. The feasibility of the concept depends on at least one crewman per vehicle being capable of piloting the escape flyer. The problems of ascending and rendezvousing with the lunar orbiting station within the time provided by a backpack do not make this approach attractive compared to escaping in a standby tug or awaiting rescue on the surface.

Rescue from Lunar Orbit

In the category of rescue, the most general approach is that of surface rescue from lunar orbit. This concept requires that a lander tug always be on-orbit at the station and on standby alert. A rescue crew must also be readily available. A second tug, as a minimum, must also be at the LSB during those periods of time that the base is manned. A third tug is then needed to perform routine orbital missions and as a backup for surface rescue. Thus, a minimum of three tugs are required in the lunar area during the operational use of the base and station, and for other manned missions in orbit.

The nominal response time for removing the distressed crew to the rescue tug is 10.75 hours including 2 hours for phasing and 2.6 hours for descent and landing including any plane changes. As a minimum the distressed crew could await rescue in pressure garments and 6000 Btu backpacks which can provide 12 hours survival time for crewmen at rest.

A fast-response rescue is possible in the case of the rescue of the crew of a tug which fails at a routine lift-off or landing. In this case, the space station orbit plane is approximately coincident with the base; the orbiting tug is in a dedicated, standby status; the space station orbital plane includes the base site at the time of surface lift-off or touchdown from orbit; and an investigation of conditions at the emergency site is not required.

The penalty, in terms of Δ velocity imposed by a rescue mission can be severe. The primary contribution to this penalty is derived from plane change requirements. (It should be recognized that the ascent/descent requirement is relatively fixed, and will probably be similar to the 13,900 ft/sec experienced on the Apollo program.) In general, rescue vehicle plane change velocity can be expressed as a function of two operating modes.

a. Plane change accomplished at orbital altitude

b. Plane change accomplished at apogee altitude of an elliptical orbit.

The rescue tug will, for a given configuration, have a specific velocity potential. The descent and ascent-to-orbit velocity requirements are relatively fixed. The remaining tug capability, if any, is available for accomplishing an orbit plane change during either descent or ascent, or both. After an orbital rescue tug has accomplished a landing at an emergency site, it is probable that the tug will have a limited ΔV capability available for a plane change.

The minimum remaining capability must be equal to, or greater than, that required for an in-plane ascent and rendezvous with the station. If the required ascent plane change and ascent ΔV requirements exceed the tug capability, it must remain on the surface until the Moon's orbital rotation reduces the required plane change to a level within the rescue tug's capability.

Table 2-1 presents typical ΔV rescue vehicle requirements for the two plane change modes. The choice between the two depends on the tradeoff advantage between ΔV needs and response time. For a descent and ascent 90 degree plane change, the table shows total ΔV savings of approximately 5500 ft/sec, if the plane change is made at apolune of a 24-hour-period elliptical orbit. On the other hand the elliptical orbit period represents the consequent cost in terms of increased response time.

Table 2-1

VELOCITY REQUIREMENTS FOR RESCUE ORBITAL MANEUVERS, 60 NM POLAR ORBIT

Event	Plane Change at Orbital Altitude		Plane Change at Elliptical Orbit Apogee	
	ΔV (ft/sec)	Cum. ΔV (ft/sec)	ΔV (ft/sec)	Cum. ΔV (ft/sec)
90 deg Plane Change	7,550	7,550	4,800	4,800
Descent & Landing	7,300	14,850	7,300	12,100
Ascent and Rendezvous	6,690	21,540	6,690	18,790
90 deg Plane Change	7,550	29,090	4,800	23,570
Total	29,090		23,590	

Another alternative to minimize ascent rescue vehicle ΔV requirements would call for the rescue vehicle, after recovering and loading the stranded crew, to ascend and inject into a circular orbit on a trajectory that minimizes the orbit plane angle with respect to the station orbit. An orbital vehicle, such as the prime transport vehicle, another orbital tug, or even the orbital station itself, would then make the required plane change and recover the crew and perhaps the rescue tug. If necessary, the rescue tug could be recovered on a later flight.

Conclusions for Lunar Surface Base Escape/Rescue

1. It is concluded that rescue capability from orbit is required at all times. Therefore, one rescue tug should always be stationed in orbit. During tug landing and takeoff from the surface, the tug in orbit should be placed in a standby condition. A standby tug stationed at the base at all time is also required.

2. A second stage on the lunar lander tug is not required for evacuating personnel in the event of landing or takeoff failures on the surface.

3. The penalties of providing for the IVA transfer of personnel between base and lander tug are sufficient to reject this plan for escape purposes.

4. An EVA rover vehicle must be carried by the rescue tug. The EVA rover vehicle must be able to carry at least two men in suits, plus a pressurized stretcher. The rover must be operable night and day.

5. The rescue tug must be capable of landing within 1/2 nm of the base under all day and night conditions.

6. A ΔV capability of 11,490 ft/sec in addition to the 14,850 ft/sec for 90 degree plane change, descent, and landing would give the rescue tug an immediate turnaround capability for ascent and rendezvous with the orbiting lunar station including a 90 degree 24-hour elliptical orbit plane change.

7. A ΔV capability of 7550 ft/sec in addition to the basic descent and ascent budget should be provided the logistics tug and the standby tug to permit escape without waiting on the lunar surface.

8. Rescue and evacuation aids should include the following:

   - o Portable airlock
   - o Hand cart which can carry a pressurized stretcher, or serve as a wheel chair
   - o Floodlights on the rover vehicle for lighting night operations during travel and ingress to the base
   - o Tools to gain ingress to the base
   - o Emergency power supply on rover vehicle to operate tools and elevators
   - o Emergency communications equipment
   - o Internal shelter in the base with 12-hour survival resources
   - o A 6000 Btu backpack with a battery life in excess of 12 hours for escape/rescue and survival

2.2 ESCAPE/RESCUE PLAN

The escape/rescue plan is presented in two major parts; first, a description of the vehicles and equipment recommended, followed by a description of the escape/rescue operations using that equipment. The equipment recommendations include a description of use of proposed Integrated Program Plan elements as rescue vehicles and the modifications and additions required to adapt these elements to use on escape/rescue missions. Special support equipment recommended for escape/survival/rescue use is also described.

The escape/rescue operations are divided into three general operational areas including lunar orbit arrival and departure, lunar orbit, and the lunar surface.

2.2.1 Escape/Rescue Vehicle and Equipment Requirements

2.2.1.1 Prime Transport Vehicle Escape/Rescue Requirements

The Prime Transport Vehicle, which may be nuclear or chemically powered, is the basic carrier for normal Earth-Moon personnel and cargo flights. It is also the candidate vehicle for a rescue mission from the Earth vicinity.

Rescue Mission with a Prime Transport Vehicle

For the rescue mission the prime transport vehicle should be equipped with a fueled tug and additional crew compartments to accommodate all the lunar personnel being rescued. The maximum response time for rescue of orbiting lunar station personnel from Earth orbit is 14 days based on the following conditions:

- 10 days waiting in Earth orbit for Earth/Moon alignment
- 2-1/2 days translunar flight time (60 hours)
- 1 day for lunar orbit injection, including time for 24-hour elliptical plane change maneuver to provide a 90° plane change, if necessary, for alignment with the plane of the orbiting lunar station
- 12 hours for phasing, rendezvous, and docking of the tug with the orbiting lunar station.

The maximum 10 days waiting in Earth orbit could be reduced to 24 hours by launching from the Earth surface into a suitable Earth orbit for translunar injection.

The crew compartment should contain provisions for the rescued crew return time of 14 days to allow waiting in lunar orbit for Earth orbit alignment. The ΔV requirements for a rescue of personnel from an orbiting lunar station by a rescue vehicle coming from Earth orbit are:

Translunar Injection (60-hr flight):	10,250 ft/sec
Lunar Orbit Insertion (3-burn 90° plane change):	4,500 ft/sec
Transearth Injection (3-burn 90° plane change):	4,500 ft/sec
Earth Orbit Insertion (60-hr flight):	10,250 ft/sec
	29,500 ft/sec

Crew Rotation Flight with a Prime Transport Vehicle

The crew compartment of the prime transport vehicle used for normal crew rotation flight must be equipped with an autonomous escape capability to be used in the event the prime transport vehicle ends up on an escape or lunar impact trajectory as a result of malfunction during lunar arrival or departure maneuvers. This escape capability must include the ability to detect the existence of a dangerous trajectory, separate from the prime transport vehicle, and inject into a lunar orbit to await rescue. In addition to autonomous guidance, attitude control, communications, and power, a propulsion system with a minimum ΔV capability of 1,000 ft/sec is required.

Special Requirements for a Nuclear Prime Transport Vehicle

If the prime transport vehicle is nuclear-powered, the escape/rescue plan requires an auxiliary stabilization system to arrest any tumbling and hold the PTV stable long enough for an escape or rescue operation to be completed within the forward safe-radiation shield cone angle, and the crew to be moved away to a safe distance.

2.2.1.2 Orbiting Lunar Station Escape/Rescue Requirements

The Orbiting Lunar Station as a Rescue Base and Safe Haven

The orbiting lunar station is the primary rescue base and safe haven following escape from other lunar areas. Consequently it must be able to support all personnel in the lunar area for a period long enough to allow rescue from the Earth vicinity, nominally 14 days.

Survival Provisions at the Orbiting Lunar Station

In order to insure survival of a crew following a critical accident, the orbiting lunar station should have two pressure compartments - separate but interconnected. Each compartment shall be capable of supporting the entire normal maximum number of crewmen in an emergency for a period of time commensurate with rescue -- nominally 14 days from Earth vicinity.

Escape Provisions at the Orbiting Lunar Station

A fully fueled tug to be used only for escape/rescue missions shall be attached to the orbiting lunar station. During initial activation of the lunar station and preceding establishment of a permanent Lunar Surface Base, this tug will be the primary means of escape from the lunar area. The requirement for a dedicated tug means that the initial activation and orbital operations requires the presence of at least two tugs - the second for normal orbital operations; and a minimum of three tugs are required before lunar surface operations can start.

2.2.1.3 Space Tug Escape/Rescue Requirements

The tug has been designated as the primary escape/rescue vehicle for all lunar areas with the exception of some lunar traverse operations where it is considered a backup rescue vehicle.

Escape Provisions with a Space Tug

The tug must be capable of accommodating the orbiting lunar station crew and returning it to the Earth vicinity. This mission requires a ΔV of 15,000 ft/sec and provisions for four days (nominal flight time of 60 hours). For the Lunar Surface Base the lunar landing tug is the primary means of escape. It must accommodate the lunar surface base crew for a maximum waiting time of 14 days for alignment with the plane of the orbiting lunar station, ascent, and rendezvous with the station (nominal ΔV of 6,900 ft/sec). The waiting time could be decreased by increasing ΔV capability.

Lunar Surface Rescue Provisions with a Space Tug

A fully fueled tug for rescue must have a nominal ΔV capability of 15,000 ft/sec with all rescue equipment and crew on board. For surface rescue this includes a 3-man EVA rover. The 15,000 ft/sec ΔV capability is sufficient to rescue a crew from any lunar surface situation and return them to at least a temporary safe haven.

Because the 15,000 ft/sec ΔV capability is not sufficient to immediately return the rescued crew to a permanent safe haven for all situations, provisions must be made to accommodate them for a period of up to 14 days before a permanent safe haven can be attained.

Rescue tugs must be able to land on the lunar surface under all conditions of lighting and sun elevation. To facilitate these landings, tracking beacons, boundary markers, and area lighting should be available at the emergency site.

Lunar Orbit Rescue Provisions with a Space Tug

The basic ΔV capability of 15,000 ft/sec provides the tug with the ability to complete all rescue missions for any lunar orbital situation. The most stringent ΔV requirement is rescue of a crew on a hyperbolic escape trajectory, which can be accomplished provided the delay in initiating the rescue is no more than two hours from the time the distressed craft passed periselene.

For rescue of the crew of another vehicle in lunar orbit, an AMU is recommended to facilitate the transfer of injured crewmen from a damaged or dangerous vehicle such as a tug/propellant depot accident. Additional special rescue equipment common to all rescue missions is described in a succeeding section.

Survival Provisions with a Space Tug

The space tug will be used for both orbital and surface operations. Certain equipment and procedures are necessary to insure survival and provide escape capability.

The survival requirements vary with the tug missions. For operations in the local area of the orbiting lunar station, prime transport vehicle, and propellant depot, a survival time of 3 hours is sufficient for rescue. For longer duration orbital missions such as scientific satellite placement, a minimum survival time of 20 hours is required. For lunar surface sorties a survival time of 12 hours is required, and 48 hours is recommended. The survival provisions are for cabin pressure, oxygen, and thermal protection only. Food and water are not considered necessary for these time spans.

The tug should have two pressure compartments - separate but interconnected. Each compartment should have a dedicated and separate emergency life support system that will provide a survivable atmosphere and ambient condition for a minimum of 12 hours.

Each tug should be supplied with pressure suits, backpacks, and emergency pressure suits to support the entire crew for a minimum of 12 hours.

2.2.1.4 Orbital Propellant Depot Escape/Rescue Requirements

An escape device such as an Astronaut Maneuvering Unit (AMU) is needed for emergency use by an EVA crewman under critical emergency conditions at an orbital propellant depot. A cold gas propulsion and attitude control reaction system with mechanical linkage control would permit virtually instantaneous actuation of the AMU followed by separation from the depot and translation to a safe range.

In order to eliminate EVA during refueling of the tug, it is recommended that interchangeable propellant modules, that would not require EVA for coupling and connecting of supply lines, be considered.

2.2.1.5 Lunar Surface Base (LSB) Escape/Rescue Requirements

The lunar surface base is a semi-permanent installation with a nominal crew of six men. Supporting equipment located at the base may include a lunar lander tug, EVA rover vehicle, cabin rover vehicle, and propellant depot.

At least one lunar lander tug will be parked about 1-1/4 nm from the LSB at all times. This LLT shall be fully fueled ($\Delta V = 15{,}000$ ft/sec) and available for escape and rescue missions at all times. This imposes a requirement for propellant resupply on the lunar surface. During any EVA traverses beyond the immediate vicinity line-of-sight, a rover vehicle shall be available for rescue missions.

2.2.1.6 Lunar Surface Traverse Escape/Rescue Equipment Requirements

Traverses on the lunar surface will be conducted in either the EVA mode or by using cabin rovers. In the latter case, provision for survival in the EVA mode must be provided in case cabin integrity is lost.

Backpack Life Support System Requirements for Survival

In order to provide survival time, a backpack life support system of 6,000 BTU capacity and a 12-hour pack is necessary. This unit, when used with a pressure suit or emergency pressure garment, can provide 12 hours life support for a man at rest awaiting rescue. The backpack systems should be designed so that a second EVA crewman could plug into a unit worn by a "buddy" crewman. The time span required for plug-in and switchover should be in the order of seconds.

Emergency Pressure Garment Requirements for Survival

A simple lightweight emergency pressure garment that can be donned in five seconds or less should be available to all crewmen on surface traverses at all times. The crewman must be able to don the pressure garment whether in pressure suit or not, and the garment should be convertible to a stretcher by the addition of rods or poles.

EVA Walking Traverse Equipment Requirements for Survival

All EVA walking traverses beyond the immediate line-of-sight vicinity of the base or tug should be done in pairs. The maximum distance should be 4 nm. A hand cart should be taken along carrying a spare backpack unit and two emergency pressure garments. This will provide an additional 6 hours survival time for both crewmen using the same backpack while awaiting rescue.

EVA Rover Requirements for Survival

All rover vehicles should be capable of carrying a minimum of two passengers plus the driver. The capability must include the case of incapacitated men in pressurized stretchers. All EVA rovers should include an extra backpack unit and emergency pressure garment for each crewman, thus providing an additional 12-hour survival time at rest. The nominal speed and range of an EVA rover is 3 knots and 12 nm, respectively.

Pressurized Cabin Rover Requirements for Escape/Rescue

The nominal speed of a cabin rover is 5.4 knots, and the range is 270 to 400 nm with life support for 14 to 24 days, respectively. The pressurized cabin rover is the preferred rescue vehicle for surface traverses. The cabin should have a minimum capacity of 3 crewmen, whether they are in pressure suits, emergency garments, or pressurized stretchers. A pressurized cabin rover vehicle used for rescue should have dual controls - one set inside the cabin, and the other outside the cabin, and so arranged that a crewman in a pressurized suit can control the vehicle.

2.2.2 Escape/Rescue Operations Plan

The primary emphasis of the escape/rescue plan is on providing the endangered crew with the capability to escape to a permanent safe haven. Because there is always the possibility of the entire crew being incapacitated and not capable of self help, provisions are also made for survival and for rescue by outside help to remove the crew to a permanent safe haven.

The escape/rescue plan is divided into three general operational areas including lunar orbit arrival and departure, lunar orbit, and the lunar surface. The plan is summarized in Table 2-2.

2.2.2.1 Lunar Orbit Arrival/Departure Escape/Rescue Operations

The lunar arrival/departure has two phases: the initial manning and activation, and the routine logistics flights involving crew rotation.

Initial Manning Operations

The initial orbiting lunar station manning flight should have the crew transported in a fully fueled tug capable of either autonomous return to Earth orbit or autonomous lunar orbit insertion and rendezvous with the orbiting lunar station, in the event of a Prime Transport Vehicle malfunction during lunar orbit insertion.

If the tug is used to escape to the orbiting lunar station, it is then kept on standby for possible escape to Earth until a second Prime Transport Vehicle arrives from Earth orbit to provide any required support.

TABLE 2-2 LUNAR MISSION ESCAPE/RESCUE PLAN

Dedicated Escape/Rescue Location and Element	Advanced Lunar Program Rescue Situations						
	Lunar Arrival & Departure		Lunar Orbit		Lunar Surface		
	Initial: Prime Transport Vehicle	Routine: Prime Transport Vehicle	Orbiting Lunar Station	Orbital Tug Sorties	Lander Tug Sorties	Lunar Surface Base	Lunar Surface Traverses
Prime Transport Vehicle: Crew Compartment (CC) or Tug	Escape to lunar orbit or to Earth orbit in the tug	Escape to lunar orbit in CC, then rescue from orbit by tug	NA	NA	NA	NA	NA
Earth Vicinity: Special Rescue Vehicle	Rescue (Escape in tug preferred)	NA	NA	NA	NA	NA	NA
Lunar Orbit, at OLS: Tug	NA	Rescue	Escape to lunar orbit or Earth vicinity	Rescue	Rescue	Rescue	Rescue
Lunar Surface: Tug	NA	NA	Rescue, if orbital tug inoperative	NA	Escape to lunar orbit	Escape to lunar orbit	Not recommended
Lunar Surface: Roving & Flying Vehicles	NA	NA	NA	NA	NA	Escape to tug	Rescue or Escape to tug or LSB

Routine Arrival/Departure Operations

For routine crew rotation flights, personnel should be transported to and from lunar orbit in a crew compartment with an autonomous escape capability. In the event of lunar orbit insertion failure, the crew compartment can be detached from the prime transport vehicle and moved to a safe lunar orbit to await rescue by a tug from the orbiting lunar station.

2.2.2.2 Escape/Rescue Operations in Lunar Orbit

For lunar orbit operations from the orbiting lunar station, two tugs are necessary; one as a dedicated escape/rescue vehicle, and the other to be used for normal orbital operations including orbital sorties.

Orbiting Lunar Station Escape/Rescue Operations

If the orbiting lunar station has to be abandoned, the standby tug is used for escape to Earth orbit or to lunar orbit. Prior to the establishment of a permanent lunar surface base, the Earth vicinity is the only source of outside help for the orbiting lunar station crew. Consequently, if rescue is required, it must be initiated from the Earth vicinity. Provisions must therefore be made to survive for 14 days in the orbiting lunar station/tug combination while awaiting rescue from Earth orbit.

Following establishment of the permanent lunar surface base, rescue of the orbiting lunar station crew by the lunar lander tug from the surface base is preferred for critical emergencies requiring a fast response time. A fully fueled lander tug can ascend, make up to a 90° plane change, and rendezvous with the orbiting station in 5 hours, including 2 hours for phasing. The maximum ΔV requirement is less than the recommended 15,000 ft/sec tug capability. After rendezvous and rescue of the crew, the tug should remain in lunar orbit for a PTV rescue mission from Earth orbit (up to 14 days). The tug can then transfer the crew to the PTV, refuel, and return to the lunar surface base to support crewmen left on the surface. If propellant is available to the tug from a depot in orbit, the tug has the option of refueling and returning the distressed crewmen to Earth orbit without waiting for arrival of a rescue PTV.

Tug Escape/Rescue Operations in Lunar Orbit

Two classes of operations will be conducted in lunar orbit by the tug; close-in operations consisting of the movement of supplies and propellant involving the prime transport vehicle and the propellant depot, and extended-duration sorties such as the placement of scientific satellites. A dedicated tug at the orbiting lunar station is the primary rescue vehicle during these operations. Emergency survival provisions must be available in the operating tug to allow time for the rescue tug to arrive. This time varies from three hours for local rescue to 20 hours for extended orbital sorties.

2.2.2.3 Lunar Surface Escape/Rescue Operations

In order to provide escape/rescue capability for lunar surface operations, a minimum of three tugs capable of landing on the lunar surface are required:

1. A dedicated escape/rescue tug at the orbiting lunar station
2. A tug for surface sorties
3. A tug for routine logistics and operations in lunar orbit

The lunar surface missions will involve three types of operations: lunar lander tug sorties, lunar surface base operations, and lunar surface traverses.

<u>Lander Tug Sortie Escape/Rescue Operations</u>

The lunar lander tug may conduct surface sorties up to 28 days duration. The escape/rescue plan must handle two types of emergency: accident during descent or ascent, and critical accident during routine operations.

<u>Descent and Ascent</u> - The most dangerous time of the lunar surface sortie is during descent and ascent. A critical accident may require immediate rescue. An activated and manned tug on alert at the orbiting lunar station during these operations can descend in one orbital period (2 hours) because the station is essentially overhead and in plane at the time of planned descent or ascent. If the crew in the lunar lander is suited and on backpacks during the critical takeoff and landing phases, then survival time is sufficient, even if the cabin is ruptured.

<u>Routine Operations</u> - During the normal 28 days operation, rescue from the orbiting lunar station could take as long as 10 hours including communications, rescue tug activation, phasing, descent, landing, and traverse to the surface tug. Survival provisions for a minimum of 12 hours duration on the surface must therefore be assured. The rescue tug from orbit will have insufficient ΔV capability to return to lunar orbit if it made a substantial plane change during descent. Therefore, it must contain sufficient provisions to remain on the lunar surface until the third tug can arrive (up to 14 days) and remove the crew and/or refuel the rescue tug.

Lunar Surface Base Escape/Rescue Operations

The permanent lunar surface base should have enough fully fueled tugs standing by to remove the entire lunar surface base crew to the orbiting lunar station. As a backup rescue mode in case the lunar surface base crew cannot help themselves, a rescue tug from the orbiting lunar station could effect a rescue in no more than 11 hours. During landing and takeoff of tugs, the same precautions should be taken as were described for the lunar lander tug sorties.

Lunar Surface Traverse Escape/Rescue Operations

Lunar surface traverses are assumed to be conducted by the following means of locomotion and their corresponding distance from surface base together with travel speeds.

- Walking - 4 nm/2 knots
- EVA Rovers - 8 nm/3 - 4 knots
- Pressurized Cabin Rovers - 270 - 400 nm/ 5 knots
- Flyers (1- and 2-man) - 5 and 15 nm/180 knots
- Ground Effects Machine (1-man) - 11 nm/14 knots

All traverses are under EVA conditions except for those in the pressurized cabin rovers. The basic life support for EVA traverses is provided by 6,000-BTU backpacks. The recommended escape/survival/rescue plan is based on the availability of a fresh backpack at the time of the emergency.

This emergency backpack will provide a 12-hour survival time while awaiting rescue (500 BTU/hr while resting) or the capability to walk back if there are no other impediments such as injuries, damaged suit, or lack of direction.

Walk Back - A single 6,000-BTU packpack will allow a man to walk back 8 nm at an average speed of 2 knots (1,400 BTU/hr while walking). This capability will allow the distressed crew on a walking or EVA rover traverse to return to base by walking if they are not injured or incapacitated and their suits are in good condition. For the one-man ground effect machine, it is recommended that the distance from base be limited to the 8-nm walk-back capability. The 1- and 2-man flyers will probably be used only for traverses involving rough or mountainous terrain, and the crew may not be able to negotiate the return trip on foot.

In general, a distressed crew should not initiate a walk-back escape until they have contacted the base and informed them of their status and plans. If communications cannot be established, they should stay with their equipment and await rescue which will be initiated automatically by their failure to report. For a walking traverse, the emergency backpacks and pressure garment should be carried on a hand cart. In order to reduce weight for walking traverses, which are limited to a 4-nm radius, the emergency backpack need only be of 3,000 BTU capacity.

EVA Traverse Rescue - The primary vehicle for rescuing a crew on an EVA traverse is a rover - either pressurized or EVA. The pressurized cabin rover is recommended because the distressed crew can be placed in a safe haven and administered medical treatment at the scene of the emergency. For the EVA rover the distressed crewmen are on EVA during the return trip. The 12-hour survival time is adequate for rescue and return within the 8-nm radius of the base. As mentioned earlier for flyer traverses, a rover vehicle may not be able to negotiate the lurain to reach a distressed flyer. Consequently a rescue flyer should be available for all flyer traverses over lurain that cannot be traversed by a rover vehicle within the 12-hour survival time.

Pressurized Cabin Rover Traverse Rescue - The cabin rover traverse may range up to 400 nm from the point of departure. The recommended procedure is to operate with "buddy" rovers and avoid need for rescue. If a cabin rover is sent on a long traverse and a rescue need arises, the crew should normally remain with the rover and await rescue from orbit. A single backpack per crewman will provide 12 hours of survival time, which exceeds the time for a tug from lunar orbit to complete a rescue operation. To avoid excessive plane change requirements for the rescue tug, the traverse should be carefully coordinated with the orbiting lunar station.

2.2.3 Escape/Rescue Plan Summary

Three areas are of primary interest in the proposed escape/rescue plan. These are:

1. The critical time spans for escape/survival/rescue, which were found to be 12 hours and 14 days
2. The equipment required for escape/survival/rescue; and
3. The deployment of equipment required for escape/survival/rescue.

These three areas are summarized as follows:

2.2.3.1 Critical Time Spans for Escape/Rescue

The critical times for rescue were found to fall into two distinct spans: 12 hours, and 14 days. These time spans are discussed below.

12-Hour Escape/Survival/Rescue Time Span - Escape or rescue of a distressed crew (that is, transfer to at least a temporary safe haven) can be accomplished in 12 hours or less for all lunar situations with the possible exception of a high-altitude lunar orbit tug sortie such as the placement of a scientific satellite. In the case of extreme altitudes, rescue may take up to 20 hours. Initial survival is predicated on at least the availability of a pressure garment with a 6,000-BTU 12-hour battery, backpack which will provide 12 hours survival time. An additional switchable backpack will provide sufficient survival time for the tug sorties requiring up to 20 hours rescue time.

14-day Escape/Survival/Rescue Time Span - In some situations, performance limitations may require the escape/rescue tug to wait for additional help after the distressed crew has attained a temporary safe haven. This waiting period could be as long as 12 days. Consequently, each escape/rescue tug must be able to support its own crew and any rescued crew members for up to 14 days.

2.2.3.2 Escape/Rescue Equipment Requirements

Equipment required for escape, survival, and rescue includes the following:

1. Space tugs with:
   a. 15,000 ft/sec ΔV capability
   b. 14-day life support capability
   c. landing legs and equipment
   d. two (2) pressurized compartments
   e. manual control capability
   f. operability by space-suited astronaut
2. An orbiting lunar station with:
   a. two (2) or more pressurized compartments
   b. capability to support all crewmen in the lunar area for 14 days in an emergency

3. Prime transport vehicles with:
   a. 30,000 ft/sec ΔV capability
   b. 14-day reaction time from Earth orbit to lunar orbit
   c. redundant stabilization for a nuclear powered vehicle

4. Prime transport vehicle crew compartments with:
   a. 1,000 ft/sec ΔV capability
   b. autonomous navigation, guidance, communications, and life support

5. A propellant depot in lunar orbit

6. EVA rovers with:
   a. 3-man capacity, minimum
   b. 16-nm range
   c. surface speed of 3 to 4 knots

7. Cabin rovers with:
   a. 4-man capacity
   b. surface speed of 5 knots

8. Rescue astronaut maneuvering units (AMU's) with:
   a. 2-man capacity
   b. 90-minute life support
   c. 400 ft/sec ΔV capability

   (rescue AMU required only if AMU's are used for normal operations)

9. Pressure suits with:
   a. backpack switching capability during EVA
   b. RF and visual locator beacons

10. Life support backpacks with:
    a. 6,000 BTU capability
    b. 12-hour life support capability
    c. "buddy" sharing provisions for all functions
    d. switching capability during EVA

11. Emergency pressure garments with:
    a. 5-second don time
    b. emergency oxygen supply attached

12. Oxygen masks with emergency oxygen supply

13. Portable airlocks
14. Pressurized stretchers
15. First aid kits
16. Emergency communications equipment, including:
    a. rocket-propelled radio beacons
    b. tracking beacons
    c. landing and touchdown location aids
17. Handcarts with capability to carry a pressurized stretcher and crewman, or an incapacitated crewman in a pressure suit
18. Rescue location aids
19. Lunar backside communications satellite prior to landings on the back side
20. Propellant depot or tug propellant resupply capability at each lunar surface base
21. Rescue lunar flyer to back up any operational flyer sent into an area inaccessible by other means of transportation

2.2.3.3 Escape/Rescue Equipment Deployment Requirements

The equipment required by the rescue plan is deployed as follows:

1. An orbiting lunar station in lunar orbit (assumed 60 nm circular, polar)
2. A dedicated rescue tug at the orbiting lunar station, carrying an EVA rover, portable airlock, pressurized stretcher, first aid equipment, cabin breaching tools, and handcart
3. An operational tug in lunar orbit, which is capable of surface rescue.
4. A fully fueled tug at each lunar surface base
5. A 3-man EVA rover with each surface sortie tug, at each lunar surface base, and on each rescue tug. The rover should be capable of carrying and supporting 4 men in an emergency.

6. Two (2) prime transport vehicles in Earth orbit/lunar orbit area, with crew compartments attached when carrying personnel, or when used for rescue
7. A propellant depot in lunar orbit
8. A propellant depot, or resupply capability, for tugs at a lunar surface base
9. A cabin rover at each lunar surface base
10. Pressure suits and life support backpacks where always accessible to each crewman
11. An emergency pressure garment always accessible to each crewman
12. Oxygen masks for each crewman in each pressurized compartment
13. A portable airlock with each rescue tug
14. A rescue AMU located wherever a basic AMU is used
15. A pressurized stretcher with each vehicle, station, and base
16. First aid kits accessible to each crewman at all times
17. Handcarts with each surface vehicle and base
18. Rescue location aids with each surface vehicle
19. Lunar backside communication satellites located to provide continuous communications between lunar surface backside, lunar orbiting station, and Earth
20. Emergency communications equipment on each lander tug and each surface sortie vehicle.
21. A rescue flyer at point of origin of any operational flyer sent into an area inaccessible by other means of transportation.

2.3 ESCAPE/RESCUE GUIDELINES AND REQUIREMENTS

The following paragraphs present the escape/rescue guidelines and requirements recommended for advanced lunar exploration. The Hazard Study and specific hazards generating the requirement for escape/rescue are cross-referenced with the hazards presented in Section 3 of this document. The escape/rescue guidelines are separated by area of operation and include: arrival/departure, orbital operations, and surface operations. Justification for the guidelines may be found in MSC-03978.

2.3.1 Safety Requirements for Rescue

A safe rescue operation is an inherent requirement. The stress, short time span, and short response time are all characteristics of a rescue operation that tend to decrease the mission safety levels. The following specific requirements are intended to enhance the rescue operation safety.

1. All lunar mission personnel must receive specific safety training including rescue procedures and techniques, hazard identification and equipment operation.

2. Emergency equipment to maximize crew survival following the occurrence of an emergency must be available during every manned mission or operation. Tugs, orbiting lunar stations, and surface bases may require emergency equipment, such as oxygen masks, emergency pressure garments, pressure suits, and backpack units, in more than one location. This will be dependent on vehicle size, number of compartments, arrangement, crew size and dispersion, etc.

3. Pressure suits, backpack units and emergency pressure garments must be available for each crewman at each manned site. In addition, surface or orbit vehicles assigned for rescue duty must have pressure garments on-board for the assigned crew and for the maximum number of men that could be involved in a rescue operation.

4. Prior to initiation of a rescue operation a go-ahead must be received from a designated rescue operations coordinator. Suggested stations for the coordination are at the LSB and at the orbital station.

5. RF frequencies and monitoring equipment shall be assigned and dedicated for rescue support.

6. No backside surface landings or traverses shall be made unless a backside communications satellite has been activated and has achieved full operational status.

2.3.2 Lunar Orbit Arrival/Departure Escape/Rescue Guidelines

The arrangement of personnel and equipment for the Initial Manning Flight is quite different from the subsequent routine crew rotation flights. Consequently, two distinct sets of guidelines arise as given in the following. The Initial Manning Flight guidelines pertaining to the tug are for the initial tug only.

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
	INITIAL MANNING FLIGHT		
1	The initial manning flight should transport the crew to lunar orbit in a tug which is fueled and provisioned to make an autonomous escape from the Prime Transport Vehicle (PTV) and either rendezvous with the Orbiting Lunar Station or return to Earth orbit.	1	HA-1
2	Prior to lunar orbit insertion, the tug carrying the initial manning crew must be manned and activated for immediate escape.	1	HA-1 HA-2

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
3	The guidance system of the initial manning tug must be activated and capable of warning the crew of any maneuvers that place them on a trajectory requiring escape.	1 11 25	HA-1 HN-1
4	The initial manning tug guidance and navigation system must be capable of generating the commands for escape maneuvers from a disabled prime transport vehicle.	1	HA-1 HA-3
5	The initial manning tug should be able to return to, and rendezvous with, the orbiting lunar station following an escape from the prime transport vehicle.	1	HA-1
6	The prime transport vehicle must contain a redundant attitude control system capable of overcoming any tumbling sufficiently for the crew to escape in either the tug or crew compartment.	3	HA-2 HA-3
7	The prime transport vehicle redundant attitude control system shall be activated and operated from the tug or crew compartment.	3	HA-2 HA-3
8	A nuclear prime transport vehicle should have an autopilot/attitude control system capable of holding the PTV in a stationary attitude long enough for the crew to escape to a distance safe from radiation.	36	HA-4

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
	ROUTINE CREW ROTATION FLIGHTS		
9	The Crew Compartment (CC) of the Prime Transport Vehicle should have its own propulsion system, including attitude control, which will allow the crew to escape to an elliptical lunar orbit in the event of a disabled PTV. This propulsion system should have quick activation time coupled with long dormant storage life, and must be able to provide a minimum ΔV of 1000 ft/sec to the CC.	1	HA-1
10	The crew compartment of the prime transport vehicle should contain an autonomous Guidance and Navigation (G&N) System capable of monitoring the effect of any maneuver in the lunar area.	1 3	HA-1 HA-3
11	The G&N system in the Crew Compartment carried by a prime transport vehicle should be able to generate commands for escape maneuvers including placing the CC on a safe trajectory.	1 3	HA-1 HA-3
12	The crew compartment on a prime transport vehicle should have a communications system capable of signaling the orbiting lunar station of the need for rescue.	1 3	HA-1 HA-3
13	The crew compartment on a prime transport vehicle should have aids, both electronic and visual, to allow a rescue vehicle to locate, track, and rendezvous.	1 3	HA-1 HA-3

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
14	During routine lunar orbit arrival and departure maneuvers, the tug at the orbiting lunar station should be manned and activated in the event that rescue is needed.	1 3	HA-1 HA-3

2.3.3 Lunar Orbital Operations Escape/Rescue Guidelines

RESCUE FROM EARTH VICINITY

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
15	A dedicated rescue vehicle should be maintained in the Earth vicinity during orbital lunar station activation and deactivation. The vehicle and crew must be on a ready-alert status with a total response time less than the probable survival time of the stranded crew.	1	HA-1 HA-3
16	During routine orbiting lunar station operation, a critical station emergency that makes it impossible for the crew to use docked tugs for escape will result in a need for rescue either from the lunar surface or from the Earth vicinity. In addition to picking up the stranded station crew, the rescue vehicle from the Earth vicinity must refuel the tug for its return to support crewmen left on the surface. Note that a surface-based tug that is used for a rescue mission to lunar orbit will probably not have sufficient remaining velocity capability to either return to a lunar surface site or to reach Earth orbit without refueling.	4	HB-1 HB-2 HB-3

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.	
17	At least two crewmen should remain in the docked tug as a dedicated rescue team during orbiting lunar station activation and deactivation.	4	HB-1 HB-2	HB-3 HB-4

ORBITING LUNAR STATION

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.	
18	At least two crew compartments must be available in the orbiting lunar station. Each compartment must be self-contained with respect to the station subsystems and must, as a minimum, include the following capabilities:	4 38	HR-1 HB-1 HB-2	HB-3 HB-4

a. Life Support

b. Environmental control

c. Electrical power

d. Communications with Earth vicinity, tugs - whether docked or orbital - Prime Transport Vehicle - whether in lunar area or between Earth and Moon - lunar surface sites, and to rescue crews inside the station

e. Lighting

f. Airlock into station interior

g. Emergency equipment (See Items 19, 22, & 23)

h. Operable by one crewman, whether injured or in good health

i. Atmospheric filters and atmospheric recirculating capability to clear any contaminants that might enter with a crewman

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
	j. Instrumentation displays, both in the compartment and outside, to aid the rescue crewmen in determining conditions in the compartment.		
	k. The life support system must include capability to reduce the compartment ambient pressure, and to control the mixture ratio of O_2 to any inert dilutent gas		
19	Emergency portable oxygen masks and supply bottles and pressure garments with a built-in portable oxygen supply should be strategically located throughout the orbiting lunar station.	4	HB-1 HB-3 HB-4
20	The orbiting lunar station design must provide a means for the crewmen to find their way to emergency gear, alternate compartments, or docked vehicles under extreme conditions of smoke, lighting, motion, or toxic gas.	4	HB-3 HB-4 HB-5
21	The alternate compartment communication system of an orbiting lunar station must include the capability for the rescue crew and stranded crew to converse regardless of the ambient atmospheric conditions in the compartment and in the station.	4	HB-1 HB-3

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
22	The orbiting lunar station alternate compartment equipment must include first aid supplies, portable oxygen masks and pressure garments with built-in portable oxygen supplies, and pressurized stretchers for moving injured men who cannot don protective garments or pressure suits.	4	HB-1 HB-3 HB-2 HB-4
23	The following types of emergency equipment must be available for use by orbiting lunar crewmen for rescue purposes: a. Oxygen masks and portable O_2 supplies b. Pressure garments with built-in O_2 supplies c. Lighting equipment d. Pressurized stretchers e. Radiation monitoring equipment f. Portable airlock (including equipment for attaching the airlock and cutting through a wall or bulkhead) g. First aid supplies	4 8 20	HB-1 HB-4 HB-2 HJ-1 HB-3 HJ-3
24	The alternate compartments in an orbiting lunar station must provide survival capability for a span of time greater than the Earth-vicinity-based rescue vehicle response time. It is estimated that this survival time should be greater than 14 days.	4	HB-1 HB-3 HB-2 HB-4

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
25	The possibility of radiation contamination must be taken into account in the design and performance requirements for all emergency gear, including pressure suits and backpack units.	4	HB-3 HB-4
26	Crew safety training must include operation of all emergency equipment and compartments, as well as the interpretation of radiation monitoring instrumentation.	4 31 9 36 20	HB-1 HB-4 HB-2 HQ-1
27	Emergency first aid kits must include the capability for the treatment of radiation sickness, and crewmen must be trained to recognize and treat exposed crewmen.	4 31 9 36 20	HB-3 HB-4 HQ-1
28	An emergency, backup, manually controlled attitude control system is needed to arrest orbiting lunar station tumbling motion, or at least to reduce it to a level that permits tug docking and undocking operations.	4	HB-5
29	The orbiting lunar station is the leading candidate for acting as the primary lunar area escape/rescue base and safe haven. It follows that the station must be able to accommodate the assigned station crew, crews being rotated- including surface crews - plus any crewmen using the station as a safe haven following an escape/rescue operation.	-	-

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
30	The orbiting lunar station orbit altitude must be high enough to provide a suitably large area of station-to-surface line-of-sight coverage for communications and tracking purposes. A minimum altitude of 60 nm is recommended.	-	-
31	The orbiting lunar station orbit inclination must be equal to, or greater than, the latitude of any surface site or exploration party traverse track in order that escape/rescue operations could be carried out with no plane change required. Rescue without plane change will still require a wait of from 0 to 14 days before starting the tug descent or ascent.	-	-
32	In order for the orbiting lunar station-based tugs to conduct escape/rescue operations, the station ephemeris must be known at all times. This knowledge will provide a precisely known point in space from which the tug ephemeris in turn can be computed.	15	HC-4 HC-5
33	The rescue tug in lunar orbit must be provided with navigational updates after making plane changes or other orbital maneuvers that introduce significant errors into the tug guidance system	15	HC-4 HC-5

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
34	In order for the rescue tug to operate autonomously in the lunar area, a correct lunar gravitational model must be determined, and the exact location of all manned surface sites must be known in terms of a coordinate grid system that is compatible with the tug navigational computer algorithm.	-	-
	ORBITAL EVA		
35	An EVA crewman in orbit should be tethered to the station at all times.	7 35	HK-1 HK-5 HK-4
36	The primary source of life support, power, environmental control, and communication capability for an EVA crewman in orbit should be by means of an umbilical connection to the station. A backpack should be worn by the crewman or a backup life support system.	7	HK-1 HK-4
37	External umbilical connections should be strategically located on an orbiting lunar station both in equipment areas needing planned periodic maintenance attention and also close to equipment needing attention in the event of a malfunction or failure.	7	HK-1 HK-4

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
38	If orbiting lunar station exterior equipment clearances preclude the wearing of a normal backpack by the EVA crewman performing routine maintenance, he should at least have a minimum 90-minute duration emergency life support capability.	7	HK-1 HK-4
39	A backup, standby rescue crewman must be suited and be in a position outside the orbiting lunar station so that he has a direct line-of-sight to a working EVA crewman at all times.	7 39	HK-1 HK-4 HK-6
40	The backup, standby rescue crewman for an EVA crewman at an orbiting lunar station must have a normal backpack, a 90-minute duration emergency life support system, be tethered to the station, and have an umbilical connection into the station so that he has the full potential life support capability if a rescue operation is required.	7 39	HK-1 HK-4 HK-6
41	The umbilical connection of the standby rescue crewman for an EVA crewman at an orbiting lunar station must be capable of quick disconnection by the crewman at the point of connection into his suit.	7 39	HK-1 HK-4 HK-6
42	All pressure suits must have a separate, self-contained voice communications link operating on a carrier frequency that is reserved for emergency use.	7	HK-4

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
43	All pressure suits must have a self-contained and powered RF beacon and flashing light possibly located on the crewman's helmet.	7 35	HK-2 HK-5
44	Emergency equipment should be capable of being activated either manually by the EVA crewman or automatically activated in the event of such conditions as suit power loss, umbilical failure, activation of the crewman's emergency life support system, or decrease in suit static pressure below some minimal level.	7	HK-1 HK-4 HK-2 HK-5
45	The emergency EVA life support system must have an operational capability at least as long as the rescue response time plus a contingency allowance. 90 minutes is the recommended minimum operational capability.	7	HK-1 HK-4
46	If the EVA crewman uses an Astronaut Maneuvering Unit (AMU) to translate around the station to perform maintenance, the backup standby rescue crewman must also be in an AMU with sufficient additional velocity and life support capability to perform a rescue operation.	7 39	HK-1 HK-4 HK-6
47	The rescue AMU must have a velocity capability of approximately 3 to 4 times the capability of the EVA crewman's AMU to be able to perform a rescue operation for the situation in which the EVA crewman's AMU sustains an unplanned full duration, propulsion burn and the AMU is in an uncontrolled trajectory away from the station.	7	HK-3

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
48	The AMU must have a self-controlled capability to prevent or stop tumbling motion. This capability should be in the form of 3 axis reaction control jets.	7	HK-3

ORBITAL TUG

(Has capability to land)

49	A dedicated Escape/Rescue Lander Tug stationed at the OLS is required in addition to an operational Lander Tug. This dedicated E/R Tug must be equipped with appropriate emergency equipment, life support supplies and other necessary expendables, and must be docked to or standing by near the OLS, fully serviced and fueled at all times. Lunar surface operations require a third Lander Tug, which can be used as an escape vehicle from the lunar surface. The operational Tug should also be a Lander Tug as it can be called upon to evacuate "rescued and rescue crews" under certain emergency situations.	4	HB-1 HB-4 HB-2 HB-5 HB-3
50	Properly positioned omni antennas should be used for short-range space tug voice and data communications to ensure no loss of signal due to the aspect angle or attitude relative to the orbiting lunar station, prime transport vehicle, propellant depot, surface site, or Earth vicinity. This capability is particularly important to maintain continuous communications with a tumbling vehicle.	30	HC-1

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
51	Any spacecraft in the lunar vicinity should have external attach points by which a rescue vehicle such as a tug could attach rigid couplings and maneuver or provide thrust vector control as required. Rescue tug crewmen will probably require visual, direct line-of-sight capability or remote optical sensors and visual displays to maneuver relative to the stranded vehicle and complete the hookup.	6 10	HC-1 HC-3
52	Passive thermal control garments are needed for use by the crew following either an electrical power or environmental control subsystem (ECS) failure. There would be ample time to don such a garment because cabin cool-down would be relatively slow. A less desirable alternative is to insulate the crew compartment walls to maintain a livable temperature for a minimum of 3 hours after an ECS or power failure.	10	HC-2
53	Sudden depressurization of a crew compartment requires rapid response emergency techniques and/or equipment to prevent subjecting the crew to dangerously low ambient pressure. a. The crew should be in pressure suits during those operations in which the tug or spacecraft is maneuvering close to other spacecraft, the orbiting lunar station, or propellant depot.	8 10 27 33 38	HC-1 HR-1 HO-3 HJ-2

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
	b. If helmets cannot be worn because of visibility requirements, the helmets should be so designed and so located relative to the crewmen that they could be donned at least to the extent that suit ambient pressure integrity is assured within 5 seconds after occurrence of the emergency.		
	c. Visual and aural warning signals are needed to inform the crew of a critical broaching of cabin ambient pressure integrity.		
	d. Emergency pressure garments should be available that could be donned even over a pressure suit, and that would attain pressure integrity within about 5 seconds.		
54	An emergency thruster subsystem, manually controlled, is needed in the event a space tug subsystem failure occurred leaving the tug on a collision course with another spacecraft. The thruster subsystem might need a throttling capability, depending on thrust-to-weight variations (and consequent acceleration variations) due to payload and/or propellant weight variations.	8 11 12 25	HC-4 HN-1 HJ-2
55	A routine space tug crew report-in sequence is needed as a backup alarm system. A recommended report-in sequence is a minimum of one contact every 30 minutes with an automatic rescue alarm if communications contact is not made within 5 minutes after the scheduled contact time.	10 22 30	HC-2 HP-1 HL-2

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
56	The space tug ambient atmospheric recirculation and purification loop should include the capability to remove noxious or toxic contaminants that may be present due to failure, fire, or a critical situation.	10	HC-1
57	The space tug and other manned spacecraft should be designed with two or more separate and independent pressure compartments. Each compartment should have a dedicated and separate emergency life support and ECS subsystem that will provide a survivable atmosphere and ambient condition for a minimum of 3 hours This approach would increase the possibility for the functional survival of at least one compartment.	8 33 38	HB-1 HI-1 HR-1 HJ-2
58	Cargo modules to be carried by the space tug should be so designed that they can be selectively jettisoned with a ΔV, with respect to the tug of at least 10 ft/second. Modules that could be jettisoned should be equipped with corner reflectors or transponders to aid in their search and recovery following the end of the emergency period.	14 20	HM-1

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
59	The crew compartment ambient atmosphere should be maintained at 3.5 psi and of a pure oxygen composition to prevent possible crew disablement in the event of cabin depressurization and the need to switch rapidly to pressure suits and backpack units.	8 38 39	HC-2 HR-1 HJ-2
60	Space tug design should include provisions for manual control, through mechanical linkages or cables, of an emergency attitude control and propulsion subsystem.	12 11 15 25 38	HC-6 HN-1 HR-1
61	Some means is needed to rigidly link a rescue vehicle to a distressed vehicle to provide a stable platform from which a forced entry could be made into a distressed vehicle. Attachment points should be clearly marked, and potential rescue crews instructed in their location and the methods for attaching linkup devices.	3 6	HB-6 HB-7 HB-8
62	A portable airlock is needed that can be handled by two EVA crewmen, and that is large enough to accommodate an injured crewman and at least one other crewman.	3 6	HB-6 HB-7 HB-8
63	Portable instrumentation is needed, together with some technique for determining the pressure and composition of the stranded vehicle's crew compartment ambient atmosphere. If there was no compartment pressure, access could be made by direct cutting through the spacecraft wall.	3 6	HB-6 HB-7 HB-8

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
64	On all spacecraft, areas acceptable for entry by either direct means or by means of a portable airlock should be clearly identified and marked. Structural design must provide for sufficient space between primary load-carrying structural members so that entry could be made using simple skin-cutting tools rather than torches or heavy-duty cutters. It is assumed that insulation and micrometeoroid barriers can be removed quickly by simple hand tools. One possibility is to provide pyrotechnic installations that would cut the skin between structural members by means of an applied electric current. The cut-through area should be sized to be consistent with the requirements for handling injured crewmen in emergency pressure garments.	5 6	HB-7 HB-8 HB-9
65	The space tug crewmen should be able to monitor and evaluate their ephemeris in order to detect a potential or actual undesirable trajectory condition.	10 15 12 16	HC-1 HC-5 HC-3 HC-6 HC-4
66	Pressure suits, backpacks, or emergency pressure garments must provide a minimum of 20 hours of survival time. Under emergency conditions, a crewman could be provided with a potential survival capability of up to 48 hours by a combination of a passive thermal garment, emergency pressure garment, and oxygen sufficient to maintain 3.5 psi ambient pressure and a breathable atmosphere within the pressure garment.	4 8 33	HB-1 HB-3 HI-1 HJ-2

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
67	Techniques and materials are needed to quickly find and seal holes, rips, or jagged tears in the crew compartment pressure cell walls.	8 33	HI-1 HJ-2
68	Emergency manual control of the tug propulsion and attitude control subsystem would permit a manually controlled emergency landing in the event of a guidance system failure after powered descent initiation.	15 16	HC-5 HC-6
	ORBITAL PROPELLANT DEPOT		
69	The propellant depot must include emergency locator devices such as flashing lights, running lights, RF or optical beacons, corner reflectors, and active transponder.	13	HE-1 HE-3
70	An escape device such as an AMU is needed for emergency use by an EVA crewman under critical emergency conditions at an orbiting propellant depot. A cold gas propulsion and attitude control reaction system with mechanical linkage control would permit virtually instantaneous actuation of the AMU followed by separation from the depot and translation to a safe range. After a safe position was reached, the escaping crewman could activate more complex and slower reacting electronic guidance, navigation, power, and communications hardware. The escape device would also need locator devices such as flashing lights, RF or optical beacons, and active transponder.	13	HE-2

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
71	An emergency despin system (3-axis) is needed to counteract tumbling torques or rates and reduce angular rates of a propellant depot to safe levels conducive to completion of docking and undocking maneuvers.	13	HE-2
72	An emergency kit should be available on the propellant depot, with equipment items available such as: a. First aid supplies b. Emergency pressure garments c. Oxygen masks (for use in the emergency compartment, or with pressure garments) d. Portable lights e. Flares - perhaps similar to photographic flashcubes, only larger in size and power f. Passive thermal garments	13	HE-2
73	Propellant depot docking mechanisms should be designed so that a docked vehicle could be uncoupled by actuating mechanical releases or pin pullers. It would be acceptable if the jammed docking mechanical emergency uncoupling system could be disengaged with part of the depot docking mechanism remaining locked to the tug mechanism,	13	HE-1 HE-2

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
74	An emergency decoupling system is needed on the propellant depot to sever servicing lines connected to the tug. This system should be powered and controlled from either the tug or depot side of the interface.	13	HE-1 HE-2

2.3.4 Lunar Surface Operations

The following guidelines summarize the equipment and operational requirements for the escape and rescue of crews on the surface of the Moon. The guidelines are keyed to major operational phases of the surface mission. Implicit in this summary is the selection of the most acceptable concepts as derived in the preceding analysis.

LANDER TUG LOCAL SURFACE OPERATIONS

75	A minimum of one dedicated and serviced lunar lander rescue tug must be docked at the orbiting lunar station at all times during a lander tug sortie operation.	17	HD-1
76	A lander tug assigned to rescue in support of a lander tug sortie mission must have the capability to land at a planned site at any time during the lunar day or night.	18	HD-1
77	The lander tug used on sortie missions should contain pressure suits, backpack units, pressurized stretcher, and pressure bags or garments adequate to support the crew.	18	HD-2 HD-4 HD-3 HD-5

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
78	The lander tug should have a handcart capable of carrying a pressurized stretcher and crewman, or an incapacitated crewman in a pressure suit.	18	HD-4 HD-5
79	A rescue alert signal system is needed in the lander tugs that will automatically initiate a "rescue needed" signal based on sensed critical items such as a hard landing, unplanned loss of crew compartment pressure, fire, explosion, or other situations with a high probability of crew incapacitation.	18	HD-1
80	The lunar lander tug design should include at least one emergency access door that is compatible with the portable airlock design, or could be used for egress/ingress when the tug is depressurized.	17 18	HD-1 HD-4 HD-2 HD-5
81	If the lunar lander tug design is such that the crew compartment is significantly above the lunar surface, an elevator and emergency power supply are needed to enable a rescue crew to easily and quickly enter a disabled tug and remove incapacitated crewmen.	18	HD-4
82	An uprated backpack is needed with a minimum metabolic capacity of 6,000 BTU's and a battery lifetime of at least 12 hours.	17	HD-1

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
83	It is highly desirable that the lunar lander tug have the velocity capability to ascend to orbital velocity, make up to a 90-degree plane change, and complete rendezvous and docking with the orbital station.	-	-
84	As an alternative or backup to Guideline 83 above, the tug must have the life support capability to remain on the lunar surface until the ascent velocity (and plane change) requirements are within its performance limitations.	18	HD-1 HD-5 HD-3 HD-7 HD-4
85	One of the first crew tasks, after a landing has been completed, is to deploy the rescue location aids. As a minimum these should include: a. A tracking beacon for use by a rescue tug b. Marker lights to designate the emergency landing site and desired touchdown point c. A kit of rocket-propelled rescue beacons d. Emergency communication system	18	HD-1 HD-5 HD-3 HD-7 HD-4
86	A lunar backside communications satellite is needed prior to initiation of surface landings on the backside.	17	HD-1
87	The lander tug should have a capability for maintaining ambient atmospheric pressure above 3.5 psi. This capability could be in the form of a separate compartment, or even emergency pressure garments.	17 18	HD-1 HD-3

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
	TRAVERSE OPERATIONS		
88	Pressure suits must have the capability for autmatically sealing suit rips or tears.	22	HL-1
89	Each crewman needs an emergency pressure garment available at all times (including when in pressure suits and on EVA). These garments should be capable of being converted to a stretcher by the addition of rods or poles.	18 22 23	HD-2 HL-3 HD-4 HL-5
90	Backpack units must be so designed that a second EVA crewman could plug into a unit worn by a "buddy" crewman to permit transfer of all critical functions such as life support, power, and communications. The time span required for plug-in and switch-over should be on the order of a few seconds.	22 23	HD-4 HL-3
91	An emergency secondary life support system or oxygen supply system is required to extend the survival time of a traverse crew. The choice and design of each will be a function of the required survival time needed to satisfy the requirements of a particular traverse mission.	17 22 18 23 21	HD-1 HG-3 HD-3 HL-3
92	Rover vehicles that are to be used as potential rescue vehicles must have the payload capability for carrying the stranded crewmen whether they are in pressure suits, emergency garments, or on a pressurized stretcher.	21 22 23	HG-1 HG-2 HG-4

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
93	A pressurized cabin rover vehicle used for rescue should have dual controls: one set inside the pressurized cabin; the other outside the cabin and so arranged that a crewman in a pressure suit could control the vehicle.	21	HG-1 HG-2
94	The pressurized cabin should have a minimum capacity for three crewmen. The vehicle should have a minimum payload capability of four crewmen, including the driver.	21	HG-1 HG-2
95	All rescue mobile vehicles should have the capability for hoisting and carrying an incapacitated man in a pressurized stretcher. Implied here is the capability of interconnection between the vehicle life support system and the stretcher.	21 22 23	HG-1 HG-2 HL-5
96	A handcart, similar to that used on Apollo 14, should be carried by each lander tug. The handcart should be capable of carrying an incapacitated man either in a pressure suit or a pressurized stretcher.	21 24	HG-2 HH-1
97	Mobile vehicles used for traverse missions should carry the following types of emergency communications equipment: a. Rocket-propelled radio beacons b. Tracking beacon to aid a rescue tug in locating an emergency site c. Landing and touchdown location aids	21	HG-1

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
98	Lunar flyers used on missions into rough lurain areas that are inaccessible for surface vehicles should be sent in pairs, with each capable of returning the crews of both vehicles.	24	HH-1 HH-2
99	The time required for activation of the rescue mission (time span from receipt of rescue alert communication to departure of the rescue vehicle and crew) must be no more than two hours.	24	HH-2
100	A flyer that is used as a rescue vehicle must have a minimum range radius greater than the traverse radius of the surface vehicles that it is supporting.	24	HH-2
101	The flyer must be capable of acquiring and tracking the location beacons to be carried by all traverse and flyer vehicles.	24	HH-2
102	All rover vehicles should be capable of carrying a minimum of two crewmen plus the driver. The additional capability must include the care of incapacitated men in pressurized stretchers.	21	HG-2
103	All rover and flyer vehicles must be capable of activation in no more than two hours.	24	HH-2

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
104	Any vehicle that is designed for automatic (hands-off) operation must be capable of full manual operations and control by a crewman in a pressure suit.	18	HD-7
105	A lunar flyer used for rescue should have a payload capability of a minimum of three men - one pilot, plus two incapacitated men in either pressurized stretchers or normal pressure suits.	24	HH-2
106	A wheeled "stretcher" cart should be carried by a rescue flyer as standard equipment	24	HH-1
107	The cargo capacity of a flyer on the outbound leg of a rescue mission should be used to carry special gear such as tools, stretcher cart, etc. This equipment can be abandoned for the return trip, thereby providing additional cargo capability.	24	HH-1 HH-2
108	A lunar lander tug used as an orbital rescue vehicle for surface rescue missions must carry an EVA type rover vehicle with a three-man capacity, including the driver.	18 21 19 24 20	HD-5 HG-2 HF-4 HH-2
	LUNAR SURFACE BASE		
109	Planned logistics flights to and from the lunar surface base (LSB) should be made when the LSB surface site is in-plane with the station orbital plane.	16 19	HC-6 HF-1

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
110	An automatic (with manual override) rescue signal alert system is needed to transmit alarm signals to the Earth vicinity, orbital station, PTV, or other orbital elements (including foreign spacecraft). This system should be triggered by such items as: o Unplanned depressurization o Base atmospheric contamination by toxic gases o Fire o Explosion o Bacteria o Temperature extremes o Radiation	19 20	HF-3 HF-5 HF-4 HF-8
111	Provision must be made for a redundant, independently powered emergency communication system with the capability of direct communication with the Earth from a lunar surface base.	19 20	HF-2 HF-4 HF-8
112	The lunar surface base should be located on the Earth side of the Moon to ensure continuous communication with the Earth vicinity.	19	HF-1 HF-4 HF-3 HF-5
113	Rescue operations in the near vicinity of the lunar surface base would be materially aided by the capability of direct unit-to-unit communications linked through the LSB as a repeater station.	19 20	HF-3 HF-7 HF-4 HF-8 HF-5

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.	
114	One or more lander tugs with crew-carrying capacity equal to the number of men in the lunar surface base area must be in a standby condition at the base at all times.	19 20	HF-3 HF-4	HF-8
115	The normal logistics vehicle landing site and a backup site 1/2 n.m. (approximately) from the lunar surface base must be marked with landing aids and equipped with location and tracking beacons to enable a landing at either site during both day and night conditions.	20 28	HF-6 HO-4	
116	Any lander tug parked at the lunar surface base must have the life support capability to remain on the surface with a capacity load of escaped crewmen for a minimum of 14 days to ensure takeoff conditions with no plane-change required.	19 20	HF-3 HF-4 HF-8	
117	Emergency power and external control must be provided for any elevator or other means at the lunar surface base for ingress/egress into the LSB crew compartment.	19 20	HF-2 HF-3 HF-4	HF-5 HF-8
118	The lunar surface base airlocks should accommodate a minimum of two men in pressure suits, or one man in a pressure suit and one man in a pressurized stretcher.	19 20	HF-3 HF-4	HF-8
119	An emergency internal communication system must be provided so that a rescue crewman can talk to stranded crewmen inside the lunar surface base regardless of the internal ambient atmospheric conditions.	19 20	HF-3 HF-4	HF-5 HF-8

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
120	At least one emergency sealed door is needed in the external shell of the lunar surface base. This door should be operable from either side, and should be compatible with the portable airlock, and sized to handle a pressurized stretcher and suited crewmen.	19	HF-5
121	All airlocks should be equipped with power, controls, instrumentation, and life support capability that is independent of the primary systems and operable regardless of the primary systems functional status.	19	HF-5
122	Alternate support compartments are needed in the lunar surface base to provide crew temporary safe havens. These compartments must be self-contained with respect to base subsystems. The minimum compartment life support capability span is 48 hours to enable an orbit rescue tug to complete a 90-degree plane change utilizing a 24-hour period elliptical orbit to minimize descent Δ velocity requirements.	19 20 38	HF-1 HF-4 HF-2 HF-8 HF-3 HR-1
123	The emergency gear carried by a rescue crew must include instrumentation for determining the base atmospheric composition, including the level and type of any radiation that might be present. An external connector should be provided that ties into the base instrumentation system. An emergency backup system should be available at the vicinity of each airlock and emergency access hatch in case the primary instrumentation system has failed. Portable instruments should be carried by the rescue crew for use after access into the base has been obtained.	19 20	HF-3 HF-4 HF-8

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.		Hazard No.	
124	Emergency gear of the following types is required on board the rescue tug for use by the rescue crew for rescue operations at the lunar surface base: o Oxygen masks and portable oxygen supplies o Pressurized stretcher o Emergency pressure garments o Emergency communication gear o Portable airlock o Portable instrumentation o Cutting tools o Three-man rover vehicle o First aid supplies	19 20		HF-1 HF-3 HF-4	HF-5 HF-8
125	The rescue tugs must be capable of completing rendezvous and docking with the orbiting lunar station regardless of orbital position and lighting conditions.	19 20 28		HF-1 HF-2 HF-3	HF-4 HF-8 HO-4
126	A rescue capability from orbit is required at all times that a crew is on the lunar surface	9 20 21 22 23	31 34 36 37	HG-1 HG-2 HG-3 HL-3	HL-4 HQ-1 HS-1 HT-1
127	An EVA rover vehicle with a 3-man capacity must be carried by the rescue tug from lunar orbit. The rover vehicle must carry at least two men in suits, plus an incapacitated man in a pressurized stretcher.	19 20 21	22 23 24	HF-3 HF-4 HF-8 HG-2	HH-1 HL-4 HM-2
128	The rescue tug must be capable of landing within 1/2 n.m. of a surface base under all lighting and night conditions.	28		HO-4	

Escape/Rescue Guideline No.	Guideline	Reference Hazard Study No.	Hazard No.
129	Floodlights are needed on a rescue rover vehicle to provide light during night operations and ingress to the base.	26	HO-1 HO-2
130	An advanced type suit and backpack is needed with a 6,000 Btu and 12 hour power capability.	23	HL-6 HL-7

Section 3
HAZARDS ANALYSIS RESULTS

This section extracts and summarizes the major hazards identified and the recommended safety guidelines from those developed in Section 2 of MSC-03977.

The definitions of four terms used during the hazards analyses are important to a clear understanding of the data presented. These are:

1. Hazard - Presence of a potential risk situation caused by an unsafe condition, environment, or act.

2. Hazard Group - A specific classification selected to identify the general nature of a hazard. The Hazard Groups defined for this study are: Explosion/Implosion; Fire; Pressure Excursions; Collision; Contamination; Illness/Injury; Personnel Isolation; Motions/Accelerations; Human Error; Hostile Environment; Radiological Hazards; System or Subsystem Malfunctions. (The term Hazard Group does not appear elsewhere in this volume, but is used in the appendix to Report MSC-03977.)

3. Hazard Study - A technical analysis of an operation, events, phenomenon, environment, condition, situation, or action with the objective of identifying potential hazards, describing hazards effects, developing preventive and remedial corrective measures and safety guidelines, and identifying situations requiring escape or rescue. (The individual Hazard Studies are presented in MSC-03977.)

4. Hazard Study Group - A grouping of Hazard Studies by equipment element, mission operation or activity, environmental condition, situation, or phenomenon. (Major hazards identified, and the associated safety guidelines recommended for implementation, are presented in this volume as a function of Hazard Study Group.)

The user of this section will find hazards and guidelines presented by Hazard Study Group as shown in Table 3-1. If interested in all hazards and guidelines associated with a particular equipment item, such as an orbiting lunar station, the user should also consult the groups which interface with that item; for example, the user of Hazard Study Group B of Table 3-1 will also wish to refer to groups A, B, C, E, I, J, K, M, N, O, and P through T for interface effects and requirements.

In Sections 3.1 and 3.2 that follow, the user will find hazards, guidelines, and supporting Hazard Studies cross-referenced. Where a similar hazard is identified for more than one equipment element, and the recommended safety guideline is applicable to either element, the guideline is stated only once and then specified by reference. Thus the user is cautioned to examine the list of Major Hazards Identified in order that proper directions to all pertinent guidelines may be found.

The probability of occurrence of a hazard may be high or extremely low, and this must be considered before certain restrictive or costly guidelines and requirements are implemented. Probability was not a subject for the current study.

For additional information, Report MSC-03977 presenting the individual Hazard Studies, should be consulted.

Table 3-1

HAZARD STUDY GROUPS

Group		Ref. Hazard Study Nos.
A	Prime Transport Vehicles	1, 2, 3
B	Orbiting Lunar Stations	4, 5, 6
C	Orbiting Tugs and Landers	10, 12, 15, 16
D	Landers on the Lunar Surface	17, 18
E	Propellant Depots	13
F	Lunar Surface Bases	19, 20
G	Roving Vehicles	21
H	Flying Vehicles	24
I	Pressure Cabins	33
J	Science Equipment and Unmanned Satellites	8, 20
K	Orbital EVA	7, 35, 39
L	Surface EVA	22, 23, 35, 39
M	Cargo and Equipment Handling	14, 20
N	Collision in Orbit	11, 25
O	Lighting	26, 27, 28
P	Communications Loss	29, 30
Q	Natural and man-made radiation	9, 20, 31, 36
R	Meteoroids	38
S	Hazardous Materials	34
T	Human Error	37

3.1 LUNAR MISSION HAZARDS

The hazards presented here are those which, in the general sense of equipment and operations interfaces, may be present in future lunar exploration missions. They were selected by examination of each Hazard Study documented in MSC-03977, and represent the identified hazards believed to merit serious attention in preparing for advanced lunar exploration.

In the following paragraphs the hazards are grouped, and are assigned an identifying number within each group. Alongside each hazard description, the corresponding Hazard Study which presents details of analysis (in Section 2 of MSC-03977) is referenced. In addition, the recommended Safety Guidelines and Requirements to cope with the hazard are also referenced, and are presented in Section 3.2 of this report.

MAJOR HAZARDS IDENTIFIED

Hazard No.	Hazard	Hazard Study No.	Recommended Safety Guidelines
	GROUP A. HAZARDS WITH PRIME TRANSPORT VEHICLES (PTV's)		
HA-1	Personnel on board a disabled PTV that is on an escape trajectory may be stranded or lost.	1	GA-1 GA-11 GA-2 GB-11 GA-3 GB-12 GA-4 GC-4 GA-5
HA-2	A PTV which has become disabled in lunar orbit presents a collision hazard.	3	GA-6 GA-9 GA-7 GC-8 GA-8
HA-3	Personnel on board a disabled PTV in lunar orbit may be stranded, and may be lost if the PTV has failed with excessive angular rates.	3	GA-10 GB-12 GA-11 GC-4 GB-11 GC-8
HA-4	A nuclear PTV which has become disabled in lunar orbit presents a radiation hazard.	3	GA-6 GA-10 GA-7 GB-11 GA-8 GB-12 GA-9 GC-8
HA-5	A nuclear PTV on a free Earth return or lunar surface impact trajectory presents a radiation hazard.	1 3	GA-12 GC-8
	GROUP B. HAZARDS WITH ORBITING LUNAR STATIONS (OLS's)		
HB-1	Insufficient time to don space suits or escape to an adjacent, safe crew compartment following sudden loss of cabin atmosphere results in death of crewmen.	4	GB-1 GB-2 GB-3 GB-4
HB-2	Inadequate backup or emergency power and life support supply to allow time for a subsystem repair, transfer to a nearby safe haven, or to await rescue assistance results in death of crewmen.	4	GB-4 GB-5

Hazard No.	Hazard	Hazard Study No.	Recommended Safety Guidelines
HB-3	Contamination of cabin atmosphere presents a threat of illness, incapacitation, deprivation of oxygen, or death	4	GB-1, GB-2, GB-3, GB-4, GB-6
HB-4	An explosion or fire on board a space vehicle presents a threat of injury, deprivation of life support, and death.	4	GB-1, GB-2, GB-3, GB-4, GB-5, GB-7, GB-8, GB-9, GB-10
HB-5	A high angular rate following loss of space vehicle attitude stabilization presents a threat of injury or death.	4	GA-11, GB-4, GB-11, GB-12, GB-13, GB-14, GC-4
HB-6	A malfunctioning hatch isolating an EVA crewman outside a crew cabin, constitutes a threat of life support depletion and death.	6	GB-15, GB-16, GB-17
HB-7	A malfunctioning hatch or other obstruction which prevents a crewman from making an emergency exit from a crew cabin constitutes a threat of injury, life support deprivation, and death.	6	GB-15, GB-17, GB-23
HB-8	A malfunctioning inner hatch which prevents a crew member in shirtsleeves from returning from an airlock to the cabin presents a threat of isolation.	6	GB-17, GB-18, GB-19, GB-20
HB-9	Orbital assembly of modules and deployment of appendages by EVA subjects crewmen to risks of accident and injury.	5	GB-21, GB-22
	GROUP C. HAZARDS WITH ORBITING TUGS AND LANDERS		
HC-1	A crew stranded in lunar orbit in a tug without propulsion and/or attitude control is faced with the risk of isolation, life support deprivation, and possibly illness or death from excessive rotation rates or duration.	10	GC-1, GC-2, GC-3, GC-4, GC-5, GC-6, GC-8, GB-11, GB-12, GB-14

Hazard No.	Hazard	Hazard Study No.	Recommended Safety Guidelines
HC-2	A tug in lunar orbit with primary propulsion and/or attitude control or other critical subsystem failed has been rendered unavailable for use in rescue situations.	10	GC-7 GC-8
HC-3	A derelict tug in lunar orbit presents a risk of collision	10	GA-7 GA-9 GA-8 GC-8
HC-4	Maneuvering errors or failures with a manned tug in the vicinity of a nuclear propulsion stage exposes the crew to risk of injury, illness, or death from nuclear radiation.	12	GC-8 GC-11 GC-9 GC-12 GC-10
HC-5	A manned lunar lander tug placed on an unplanned impact trajectory with the lunar surface may lead to an unplanned landing, to a landing at the wrong site, or to a crash.	15	GC-13 GC-14 GC-15
HC-6	A failure leading to loss of propulsion or attitude control of a lunar lander tug while on an ascent or descent impact trajectory will lead to a catastrophic crash.	16	GC-8 GC-18 GC-16 GC-19 GC-17
	GROUP D. HAZARDS WITH LANDERS ON THE LUNAR SURFACE		
HD-1	A total failure of any critical function, such as propulsion, attitude control, or electrical power, on a solo lunar lander tug on the lunar surface will isolate the crew. Death will result if insufficient life support supplies are not available to await rescue.	17	GD-1
HD-2	Insufficient time to don space suits or escape to an adjacent, safe crew compartment following sudden loss of cabin atmosphere results in death of crewmen.	18	GD-2 GD-3 GB-1

Hazard No.	Hazard	Hazard Study No.	Recommended Safety Guidelines
HD-3	Inadequate power and life support supply to allow time for either subsystem repair, return to a safe haven, or rescue results in death of crewmen	18	GD-5 GB-5
HD-4	Contamination of cabin atmosphere presents a threat of illness, incapacitation, deprivation of oxygen, or death.	18	GB-2 GB-3 GB-6
HD-5	An explosion or fire on board a lunar tug presents a threat of injury, deprivation of life support, and death.	18	GB-2 GB-9 GB-7 GB-10 GB-8
HD-6	Unscheduled return of a lunar lander tug to lunar orbit, leaving behind crew members on traverse, threatens the traverse crew with isolation, exhaustion of life support, and death.	18	GD-6 GD-7 GD-8
HD-7	Inability for crewmen to operate a tug while in pressure suits presents a threat of isolation, exhaustion of life support, and death.	18	GD-4
	GROUP E. HAZARDS WITH PROPELLANT DEPOTS		
HE-1	A detached propellant depot in lunar orbit presents a risk of collision with other spacecraft.	13	GA-7 GN-3 GA-8 GN-4 GA-9 GN-5 GN-1 GN-6 GN-2
HE-2	Explosion of a propellant tank or depot presents a threat of injury, damage to adjacent vehicles, and death.	13	GE-1 GE-3 GE-2 GE-4
HE-3	An unsecured propellant tank which escapes in lunar orbit presents a collision hazard.	13	GA-8 GE-5

Hazard No.	Hazard	Hazard Study No.	Recommended Safety Guidelines
	GROUP F. HAZARDS WITH LUNAR SURFACE BASES		
HF-1	Insufficient time to don space suits or escape to an adjacent, safe crew compartment following sudden loss of cabin atmosphere results in death of crewmen.	19	GB-1 GB-2 GB-3
HF-2	Inadequate backup or emergency power and life support supply to allow time for a subsystem repair, transfer to a nearby safe haven, or to await rescue assistance results in death of crewmen.	19	GB-5
HF-3	Contamination of cabin atmosphere presents a threat of illness, incapacitation, deprivation of oxygen, or death.	19	GB-1 GB-5 GB-2 GB-6 GB-3 GF-1
HF-4	An explosion or fire on board a lunar surface base presents a threat of injury, deprivation of life support, and death.	19 20	GB-1 GB-10 GB-2 GF-1 GB-3 GF-6 GB-5 GF-7 GB-7 GF-8 GB-8 GF-9 GB-9
HF-5	Loss of access from a lunar surface base to the lunar surface, or vice versa, constitutes a hazard.	19	GF-2
HF-6	Ejecta thrown up by the engine plumes of a landing tug can injure crew members or damage crew shelters and other equipment.	20	GF-3
HF-7	Tip-over or collision accident while handling and setting up modules and large surface structures can injure crew members.	20	GF-4 GF-5

Hazard No.	Hazard	Hazard Study No.	Recommended Safety Guidelines
HF-8	An accident with a nuclear-electric power generator presents a threat of excessive radiation dose to crewman of a lunar surface base.	20	GF-10 GF-11
	GROUP G. HAZARDS WITH ROVING VEHICLES		
HG-1	Stranding of crewmen beyond walk-back distance in a lunar rover presents a threat of isolation and death.	21	GG-1 GG-7 GG-2 GG-8 GG-3 GG-9 GG-4 GG-11 GG-5 GG-12 GG-6
HG-2	Injury of crewmen on traverse in a lunar rover presents a threat of isolation and death.	21	GG-4 GG-9 GG-6 GG-10 GG-8 GG-11
HG-3	Life support system failure on a lunar roving vehicle presents a threat of death. (See Hazards HD-1, HD-2, HD-3, HD-4, HD-5, HD-6 and associated guidelines, which also apply to cabin-type rovers.)	21	GB-5 GG-11 GG-2 GG-12 GG-9
	GROUP H. HAZARDS WITH FLYING VEHICLES		
HH-1	High velocity impact of a lunar flying vehicle will result in injury or death to crewmen.	24	GH-1 GH-2 GH-3
HH-2	Stranding of crewmen on a lunar flyer mission following landing damage or subsystem failure presents a threat of death.	24	GH-1 GH-7 GH-2 GH-8 GH-3 GH-9 GH-4 GH-10 GH-5 GH-11 GH-6

Hazard No.	Hazard	Hazard Study No.	Recommended Safety Guidelines
	GROUP I. HAZARDS WITH PRESSURE CABINS		
HI-1	Loss of cabin atmosphere results in death of crewman. (See Hazards HB-1, HB-3, HB-4, HD-2, HD-4, HD-5, HF-1, HF-3, HF-4, and associated guidelines, which also apply to pressure cabins.)	33	GI-1 GI-3 GI-2 GI-4
	GROUP J. HAZARDS WITH SCIENCE EQUIPMENT AND UNMANNED SATELLITES		
HJ-1	Propellant spillage, ignition or electrical fire during servicing, checkout, or launch of an unmanned satellite at an orbiting lunar station can bring injury, illness, or death to crewmen.	8	GJ-1 GJ-5 GJ-2 GJ-6 GJ-3 GJ-7 GJ-4
HJ-2	Satellite capture presents a risk of collision.	8	GJ-8
HJ-3	Handling of science equipment presents a risk of injury from hazardous materials or operations.	20	GF-5 GF-8
	GROUP K. HAZARDS WITH ORBITAL EVA		
HK-1	Malfunction or loss of oxygen supply or pressurization during EVA will result in death of an astronaut.	7	GK-1 GK-4 GK-2 GK-5 GK-3 GK-6
HK-2	Communications loss during EVA leads to lack of information exchange which may be vital to navigation, vital signs monitoring, or rescue assistance.	7	GK-4 GK-7 GK-8 GK-9
HK-3	Malfunction of an astronaut maneuvering unit during EVA may lead to uncontrolled trajectory, tumbling, disorientation, nausea, illness, isolation, and death.	7	GK-5 GK-12 GK-6 GK-13 GK-9 GK-14 GK-10 GK-15 GK-11

Hazard No.	Hazard	Hazard Study No.	Recommended Safety Guidelines
HK-4	Loss of electrical power during EVA results in loss of primary communications, temperature control, automated oxygen flow, and atmosphere cleansing, and propulsion capability.	7	GK-4 GK-5 GK-9
HK-5	Nausea and vomiting during EVA operations presents a risk of death to the astronaut.	35	GK-5 GK-18 GK-6 GK-19 GK-16 GK-20 GK-17
HK-6	Improper ingress/egress procedures and preparations when transitioning from one atmosphere composition and pressure to another can result in the hazards of dysbarism.	39	GK-21 GK-24 GK-22 GK-25 GK-23 GK-26
	GROUP L. HAZARDS WITH LUNAR SURFACE EVA		
HL-1	Malfunction or loss of oxygen supply or pressurization during EVA will result in death of an astronaut.	22	GK-1 GK-4 GK-2 GL-1 GK-3 GL-14
HL-2	Communications loss during EVA leads to lack of information exchange which may be vital to navigation, vital signs monitoring, or rescue assistance.	22	GK-7 GK-8
HL-3	Loss of life support functions during EVA presents a threat of illness and death.	22 23	GL-1 GL-5 GL-2 GL-6 GL-3 GL-7 GL-4 GL-19
HL-4	EVA involving heavy or hazardous equipment or rough lurain presents a risk of injury.	22 23	GL-8 GL-11 GL-9 GL-12 GL-10 GL-20
HL-5	Corrosive fluids fumes, and dust present a threat of spacesuit damage and of injury to an EVA astronaut.	22 23	GL-8 GL-10 GL-13

Hazard No.	Hazard	Hazard Study No.	Recommended Safety Guidelines
HL-6	Switching backpacks during EVA presents a threat of accident, loss of life support, and death.	23	GL-4 GL-5
HL-7	Lack of mobility and the presence of external protuberances present a risk of accident, injury, and loss of life support for an EVA astronaut.	23	GL-15 GL-16 GL-17
HL-8	Damage or loss of the glare and heat reflective coating on spacesuit face masks presents a threat of astronaut injury or impariment. (See Hazards HK-5, HK-6 and associated guidelines, which also apply to surface EVA.)	23	GL-18
	GROUP M. HAZARDS WITH CARGO AND EQUIPMENT HANDLING		
HM-1	An escaped or improperly handled cargo package in lunar orbit may strike and injure a crew member or damage and disable a vital subsystem.	14	GM-1 GM-4 GM-2 GM-5 GM-3
HM-2	Accidents while handling equipment or cargo on the lunar surface can result in injury to crewmen or damage to vital subsystems.	20	GF-4 GF-5 GF-8
	GROUP N. COLLISION IN ORBIT		
HN-1	Collision in lunar orbit presents risks varying from negligible to catastrophic.	11 25	GN-1 GN-7 GN-2 GN-8 GN-3 GA-7 GN-4 GA-8 GN-5 GA-9 GN-6

Hazard No.	Hazard	Hazard Study No.	Recommended Safety Guidelines
	GROUP O. HAZARD WITH LIGHTING		
HO-1	Failure to see a crevasse or other obstruction may result in damage, entrapment, and injury to a lunar rover and crewmen.	26	GO-1 GO-2
HO-2	Inability to navigate on the lunar surface because of poor lighting presents a risk of isolation, life support depletion, and death.	26	GO-1 GO-3
HO-3	Docking in lunar orbit under poor lighting conditions may result in collision.	27	GO-4 GO-5
HO-4	Poor lighting or obscuration by dust during lunar landing may result in accident and injury.	28	GO-6 GO-10 GO-7 GO-11 GO-8 GO-12 GO-9
	GROUP P. COMMUNICATIONS LOSS		
HP-1	Failure of communications may lead to isolation, lack of vital information and support, and insufficient information to perform a rescue mission.	29 30	GP-1 GP-9 GP-2 GP-10 GP-3 GP-11 GP-4 GP-12 GP-5 GP-13 GP-6 GK-4 GP-7 GK-7 GP-8 GK-8
	GROUP Q. HAZARDS WITH NATURAL AND MAN-MADE RADIATION		
HQ-1	Exposure to excessive amounts of nuclear radiation presents a threat of illness, injury, and death.	9 20 31 36	GA-13 GQ-7 GF-10 GQ-8 GQ-1 GQ-9 GQ-2 GQ-10 GQ-3 GQ-11 GQ-4 GQ-12 GQ-5 GQ-13 GQ-6

Hazard No.	Hazard	Hazard Study No.	Recommended Safety Guidelines	
	GROUP R. HAZARDS FROM METEOROIDS			
HR-1	Meteoroid penetrations can result in mild or violent decompression, damage or destruction of pressure cabins and vital subsystems, fire, explosion, injury, and death.	38	GR-1 GR-2 GR-3	GR-4 GR-5 GR-6
	GROUP S. HAZARDOUS MATERIALS			
HS-1	Improper handling, securing, or use of hazardous materials presents a risk of injury, illness, and death to crewmen.	34	GS-1 GS-2 GS-3 GS-4	GS-5 GS-6 GS-7
	GROUP T. HUMAN ERROR			
HT-1	Human error can generate hazards leading to isolation, injury, illness, and death.	37	GT-1 GT-2	GT-3 GT-4

3.2 SAFETY GUIDELINES

This section presents the safety guidelines recommended as preventive or remedial measures for the hazards described in Section 3.1.

The guidelines are grouped and assigned an identifying number within each group. Alongside each guideline the corresponding Hazard Study which presents details of analysis(in Section 2 of Report MSC-03977) is referenced and the identifying group and number of the hazards which are corrected by the guideline are listed.

RECOMMENDED SAFETY GUIDELINES

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
	GROUP A. GUIDELINES FOR PRIME TRANSPORT VEHICLES		
GA-1	The crew of a prime transport vehicle shall be provided with navigation update information, and with the capability to manually direct the vehicle to the target position.	1	HA-1
GA-2	If the crew module of a prime transport vehicle (PTV) is mounted on a propulsion vehicle, such as a Tug, that Tug shall be in a powered-up state at the time of lunar orbit insertion or departure and shall be capable of rapid separation from the PTV to function as a crew escape vehicle.	1	HA-1
GA-3	During each manned prime transport vehicle arrival or departure at the Moon, other operations in orbit and on the lunar surface shall be restricted to activities with low risk of generating a rescue requirement	1	HA-1

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GA-4	Crew modules, serving essentially as replacement-crew delivery shelters, shall have the capability (as a minimum) to quickly separate and move away from a disabled (stable or tumbling) prime transport vehicle, provide a delta velocity of approximately 1000 ft/sec to achieve an elliptical lunar orbit, and maintain coarse attitude control, and communications (beacon and voice) and life support while awaiting rescue.	1	HA-1
GA-5	During each manned prime transport vehicle arrival and departure at the Moon a rescue vehicle, manned and ready, and with a ΔV capability of at least 4,400 ft/sec, shall be standing by in lunar orbit (assumed to be 60 nm circular).	1	HA-1
GA-6	Prime transport vehicles, whether chemical or nuclear powered, shall not be brought into the same or intersecting orbit with other operational elements such as an orbiting lunar station, and shall always operate from a higher orbital altitude.	3 11	HA-2 HA-4
GA-7	Each manned vehicle in lunar orbit shall be constantly mointoring other traffic, emergencies, or malfunctions that could present a hazard and shall have the ability to maneuver to avoid collision.	3 10 11 13 25	HA-2 HA-4 HC-3 HE-1 HN-1
GA-8	Orbital tug vehicles shall have the capability to capture and control or dispose of any derelict vehicle or object in an unsafe lunar orbit	3 10 11 13 25	HA-2 HE-1 HA-4 HE-3 HC-3 HN-1

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GA-9	Any derelict vehicle in an unsafe lunar orbit must be captured and either repaired or disposed of by placing it in a safe lunar orbit, returning it to Earth orbit, or injection to heliocentric orbit.	3 10 11 13 25	HA-2 HA-4 HC-3 HE-1 HN-1
GA-10	Rescue crewmen shall not approach a tumbling nuclear vehicle unless protected by a specially prepared and radiation shielded vehicle.	3	HA-3 HA-4 HB-5
GA-11	The crew of a space vehicle shall be able to assume manual control of vehicle attitude in order to avoid or stop tumbling. Appropriate means to detect and control failures causing attitude control loss shall be provided.	1 3 4	HA-1 HA-3 HB-5 HC-1
GA-12	Nuclear PTV's shall not be placed on a free Earth return or lunar surface impact trajectory.	1 3 31 36	HA-5 HQ-1

GROUP B. GUIDELINES FOR ORBITING LUNAR STATIONS (OLS's)

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GB-1	Each crew cabin shall have more than one pressurized compartment capable, at least in an emergency, of supporting the crew. Hatches to interconnecting passageways or airlocks shall be kept open at all times, but quickly sealable in an emergency.	4 18 19 20	HB-1 HD-4 HB-3 HF-1 HB-4 HF-3 HD-2 HF-4
GB-2	Each crew cabin shall provide oxygen masks and emergency pressure garments, 2-gas and independent of spacecraft ECS, at each crew station; pressure suits and PLSS units for each crew member; and immediate use of one or more of these or escape to a separate compartment following explosion, fire, loss of pressure, or detection of contaminants in the atmosphere.	4 18 19 20	HB-1 HD-5 HB-3 HF-1 HB-4 HF-3 HD-4 HF-4

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GB-3	Where multiple primary pressure compartments are provided in a system, crew members shall not normally all occupy one compartment at one time	4 18 19 20	HB-1 HF-1 HB-3 HF-3 HB-4 HF-4 HD-4
GB-4	Each orbiting lunar station shall have docked to it, or in the immediate vicinity, and immediately accessible, space tug vehicles with crew compartments, propulsion modules, and instrument units capable of housing and supporting the entire remaining station crew.	4	HB-1 HB-2 HB-3 HB-4 HB-5
GB-5	Each space vehicle or base mission sequence shall be planned such that a backup or emergency source of power, life support, and communications capability is available at all times so that following loss of a primary source the crew can proceed to a safe haven unassisted or await rescue, whichever time is is greater.	4 18 19 20 21	HB-2 HB-4 HD-3 HF-2 HF-3 HF-4 HG-3
GB-6	Cabin atmosphere shall be monitored continuously to detect contaminants such as solid particles, excessive CO_2, vaporized chemicals, and immediate action shall be taken to use either oxygen masks, emergency pressure garments, pressure suits, or separate compartment and ECS as appropriate, before illness, incapacitation, or oxygen deprivation can occur.	4 18 19	HB-3 HD-4 HF-3
GB-7	High pressure gas storage bottles, pyrotechnics, and hazardous experimental devices shall be separated from the main cabin of an orbiting lunar station and from critical subsystems components by enclosing in compartments vented to space and in structures design to help control an explosion or fire.	4 18 19	HB-4 HD-5 HF-4

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GB-8	High pressure storage vessels shall be equipped with reliable pressure relief valves vented to space and with thrust modifiers. Pressures shall be monitored to provide warning of an impending explosion, and procedures shall be developed to correct potential hazards so detected.	4 18 20	HB-4 HD-5 HF-4
GB-9	Provision shall be made in space vehicles or base design for quickly sealing each pressurized compartment separately and then remotely exhausting the atmosphere to extinguish a fire. (See note Page 3-29)	4 18 20	HB-4 HD-5 HF-4
GB-10	Manual fire extinguishers of the appropriate type shall be provided in each pressurized compartment of manned vehicles.	4 18 20	HB-4 HD-5 HF-4
GB-11	Attitude control thrusters for space vehicles shall be designed to fail "off" to prevent excessive angular rates from developing.	1 3 4 10	HA-1 HB-5 HA-3 HC-1 HA-4
GB-12	Space vehicles shall be provided with backup or emergency attitude stabilization system to arrest tumbling and allow repair or capture by an assisting vehicle.	1 3 4 10	HA-1 HB-5 HA-3 HC-1 HA-4
GB-13	Space tug vehicles docked to an orbiting lunar station shall be capable of providing emergency attitude stabilization for the entire system.	4	HB-5
GB-14	Development of safe and effective means for arresting the rotation of any tumbling vehicle in orbit by outside means shall be a prime objective.	4 10	HB-5 HC-1

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GB-15	Each orbiting lunar station shall have a minimum of two airlocks to use for EVA purposes. The second airlock need not be an integral part of the OLS.	6	HB-6 HB-7
GB-16	An outer hatch shall remain open on a space vehicle while crewmen are on EVA.	6	HB-6
GB-17	Design of hatches shall include provision for forced opening from either side.	6	HB-6 HB-7 HB-8
GB-18	Crew members in shirtsleeves should not carry on airlock activities with the inner hatch closed. If unavoidable, then pressure suits and PLSS's should be available in the airlock.	6	HB-8
GB-19	The ECS operations for airlocks shall be supported by the spacecraft's main ECS and have emergency separate environmental controls as well. Each airlock should have self-contained regulatory controls both for ECS supplied from the main cabin supply and for airlock emergency ECS.	6	HB-8
GB-20	All airlocks shall be connected to the spacecraft communications loop. Moreover, it should be possible to contact other members of the lunar complex using airlock communications.	6	HB-8
GB-21	Orbital assembly, if required, shall be planned to avoid EVA.	5	HB-9

Guidelines No.	Guideline	Hazard Study No.	Reference Hazard No.
GB-22	Major appendages for an orbiting lunar station, including solar arrays, antennae, scientific experiment booms, and other, shall be deployed by means not requiring EVA.	5	HB-9
GB-23	Alternate escape routes that do not terminate in a common module area shall be provided.	6	HB-7
	GROUP C. GUIDELINES FOR ORBITING TUGS AND LANDERS		
GC-1	Two independent reaction control systems shall be provided on each manned tug.	10	HC-1
GC-2	A small secondary maneuvering propulsion system, oriented in the same direction as the primary engines and operating off the main propellant supply, shall be provided to back up the primary propulsion system of any tug in lunar orbit.	10	HC-1
GC-3	Where rescue assistance cannot be available, such as during initial manning of an orbiting lunar station, the crew compartment of a manned tug in lunar orbit shall be carried on two complete tug propulsion modules and instrument units mounted in tandem	10	HC-1
GC-4	The crew of a manned space vehicle shall be provided the capability for manual control of each RCS thruster separately.	1 3 4 10	HA-1 HA-3 HB-5 HC-1

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GC-5	Each crew compartment and instrumentation unit, including RCS, on a tug in lunar orbit must be provided the capability to separate from a failed propulsion module and proceed to a safe haven or await rescue.	10	HC-1
GC-6	Each manned tug on a solo mission in lunar orbit shall carry expendables adequate to support the crew for a period of seven days beyond the planned mission time. (The time anticipated for rescue, with a margin.)	10	HC-1
GC-7	When lunar surface missions are being performed, a minimum of three vehicles capable of supporting an escape or rescue mission must be provided; one is a standby rescue vehicle in lunar orbit; one is a mission vehicle in lunar orbit; one is a mission/escape vehicle on the lunar surface.	10	HC-2
GC-8	No single function failure of any system or subsystem on board a space vehicle shall result in loss of capability to control attitude and velocity of that vehicle.	1 3 10 12 16	HA-1 HC-1 HA-2 HC-2 HA-3 HC-3 HA-4 HC-4 HA-5 HC-6
GC-9	Normal tug operating procedures shall require phasing termination, in the vehicle radiation shield cone, at a distance of at least 1150 ft. from a nuclear powered prime transport vehicle.	12	HC-4
GC-10	Tug operations in the vicinity of a nuclear prime transport vehicle shall be constrained by adequate procedures, such as rigid control of approach path-velocity-distance parameters, to prevent inadvertent intrusion into the nuclear vehicle radiation zone during normal transfer and phasing maneuvers.	12	HC-4

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GC-11	No activity shall be planned around a nuclear stage until it is stabilized and the nuclear engine has been shut down for at least 24 hours.	12	HC-4
GC-12	Tug vehicles shall be equipped with on-board radiation sensors and instrumentation with provision for auto-alarm whenever the tug vehicle is penetrating a region of increasing radiation level.	12	HC-4
GC-13	The crewmen of a lunar lander tug must be provided with manual navigation capability and must be trained in manually controlling the tug trajectory at all points from orbit to landing and return to orbit. The option to assume manual control must be immediately available at all times.	15	HC-5
GC-14	All lunar lander tug ascent and descent trajectories shall be tracked from Earth or OLS, if possible, and status confirmed.	15	HC-5
GC-15	Upon detection or notification of a navigation malfunction or trajectory error, standard procedure shall call for assumption of manual control by the tug crew and re-direction of the vehicle to a safe orbit.	15	HC-5
GC-16	The critical nature of lunar lander tug descent and ascent maneuvers demands special attention to items such as redundancy, backup, manual override, propellant reserves, control authority, and any-time abort where feasible, in all critical functions and subsystems associated with control of velocity and attitude.	16	HC-6

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GC-17	The main propulsion engines for the tugs in the lunar complex shall be designed such that failure of a single engine does not deprive the tug of the ability to provide velocity and attitude control.	16	HC-6
GC-18	The pilot of a lunar lander tug must be provided the capability to assume manual attitude control at any time.	16	HC-6
GC-19	The attitude controls on the tug for lunar operations should be separable so that either main propulsion (i.e., gimballing engines) or the RCS or both could be used for the attitude control function.	16	HC-6
	GROUP D. GUIDELINES FOR LANDERS ON THE LUNAR SURFACE		
GD-1	The crew compartment of a solo lunar lander tug on the lunar surface must be provisioned to support the crew for a period of time following a planned return to orbit until a rescue mission can be accomplished. This time is estimated to be 14 Earth days.	17	HD-1
GD-2	Each lunar lander tug shall be provided with emergency pressure garments which can be donned more quickly than full pressure suits.	18	HD-2
GD-3	Crewmen in a solo lunar lander tug on the lunar surface shall remain in pressure suits at all times if quickly accessible separate pressure compartments and emergency pressure garments cannot be provided.	18	HD-2

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GD-4	The lunar lander tug must be flyable by crew members in pressurized space suits.	18	HD-7
GD-5	A rescue vehicle fully fueled and ready, should be standing by in lunar orbit at all times during a solo lunar lander tug mission on the lunar surface.	18	HD-3
GD-6	Standard operating procedures shall require that crew members, on EVA traverse from a solo lunar lander tug, return to base without delay following notification of an emergency at the tug.	18	HD-6
GD-7	Emergency life support capability on board a solo lunar lander tug shall always exceed the time required for return of all crewmen to the tug plus return to a safe haven in lunar orbit. This capability must be established uniquely for each mission.	18	HD-6
GD-8	Each EVA crew on traverse shall be provided with life support and other necessities calculated to assure a safe stay time exceeding rescue time.	18	HD-6
	GROUP E. GUIDELINES FOR PROPELLANT DEPOTS		
GE-1	Propellant depot tankage should be designed with maximum meteoroid shield protection commensurate with engineering feasibility and cost and penetration depth probability.	13	HE-2
GE-2	A propellant depot attached to an orbiting lunar station should be placed between the OLS and the lunar surface, in order to lessen the area of depot exposed to meteoroid strikes.	13	HE-2

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GE-3	When a propellant depot is attached to an orbitng lunar station, keep one tug docked at a transverse port on the side of the OLS away from the depot to prevent debris from striking the tug in the event of explosion of a propellant tank.	13	HE-2
GE-4	To prevent a collision of large pieces of debris with an orbiting lunar station following a propellant tank explosion, design and emplace a grid between the propellant depot and the OLS. The grid should shadow the OLS-docked tugs at the end port.	13	HE-2
GE-5	Always tether propellant tanks to the depot during delivery or to tug during removal, to prevent these tanks from becoming a collision hazard in orbit.	13	HE-3
	GROUP F. GUIDELINES FOR LUNAR SURFACE BASES		
GF-1	Each lunar surface base shall have parked near the site space tug vehicles with crew compartments, propulsion modules, and instrument units capable of housing and supporting the entire base crew and escaping to orbit.	19 20	HF-3 HF-4
GF-2	Each lunar surface base shall be provided with alternate access ports, alternate access/ escape routes, and alternate means for transporting incapacitated crewmen from surface to base and base to surface.	19	HF-5
GF-3	Landing pads should be prepared for tugs visiting a Lunar Surface Base at the earliest possible time after initiating LSB activity.	20	HF-6

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GF-4	The movement of large pieces of equipment or of modules on the lunar surface should be accomplished with the astronaut nearby and guiding and controlling such movement but not aboard the carrying vehicle. Thus in the event of module transport vehicle upset, tipover, etc., he will not be trapped or injured.	20	HF-7 HF-2
GF-5	The buddy-system should be used in setting up large equipments on the lunar surface so that EVA astronaut entanglement (e.g. wires) is minimized, and so that immediate aid is available if needed.	20	HF-7 HJ-3 HM-2
GF-6	Careful attention should be given to the use of non-flammable materials in the lunar surface base design, and the atmosphere provided should be two-gas. Hazardous materials should be handled in a specially designated area.	19 20	HF-4
GF-7	Enough tugs should always be available at a lunar surface base to evacuate the entire crew to lunar orbit should the LSB have to be abandoned.	19 20	HF-4
GF-8	The following items are forbidden in or very close to the LSB: a. handling or storage of hypergolic fluids. b. handling or storage of pyrotechnic devices. c. combustible fluids in the thermal control system. d. dangerous chemicals. e. bacteriological experiments. f. nuclear materials/systems	19 20	HF-4 HJ-3 HM-2
GF-9	Crew smoking shall be prohibited at all times on lunar missions.	19 20	HF-4

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GF-10	A nuclear power source used to generate electrical power shall be stationed at least 2000 feet from the LSB; preferably in a crater whose walls are higher than the reactor container and that have been thickened by moving soil.	20 31	HF-8 HQ-1
GF-11	Secondary electrical power sources should be available for the LSB in the event of nuclear source malfunction. Such secondary sources should be adequate to maintain all life support and essential communications functions until repairs are made or rescue or return to orbit is effected.	20	HF-8

NOTE:

Following the completion of the technical study effort, the advisability and effectiveness of evacuating a cabin atmosphere to extinguish fire was questioned. Tests discussed in Ref. (1) have shown that in an open-celled polyurethane-foam fuel in pure oxygen (5 to 16.2 psia), the cells trapped oxygen and the ignited fuel continued to burn until the pressure was dropped to 0.12 psia in two minutes.

It is recommended that further testing be carried out in mixed gas and in pure oxygen atmospheres with materials now considered acceptable for use in space cabins.

Reference (1) also describes the test of a high-expansion breathable, foam extinguishing agent composed of approximately 300 parts gaseous oxygen (the ambient gas in the test chamber) to one part of water-based solution. This agent was found to be quite effective and to show promise for future applications.

Ref (1) "Fire Extinguishment in Hyperbaric and Hypobaric Environments." J. Howard Kinzey, NASA Manned Spacecraft Center, presented to NASA Conference on Materials for Fire Safety, Houston, Texas, May 6-7, 1970.

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
	GROUP G. GUIDELINES FOR ROVING VEHICLES		
GG-1	Non-cabin lunar surface rovers shall not operate beyond walk-back distance to a safe haven, unless such rovers are operated in pairs with each capable of supporting the other and returning all crewmen to safe haven.	21	HG-1
GG-2	The use of two independent vehicles, each capable of assisting the other should an emergency occur, is recommended for long traverses with cabin type rovers. Each rover must be capable of returning all crewmen to a safe haven.	21	HG-1 HG-3
GG-3	All lunar surface rovers shall be capable of operation, driving, life support, communication, etc., with crewmen wearing pressurized suits.	21	HG-1
GG-4	Each roving vehicle shall be completely operable and drivable by a single crewman.	21	HG-1 HG-2
GG-5	It is recommended that an emergency driving station be provided in the airlock of cabin type rovers.	21	HG-1
GG-6	Methods and devices for detecting hidden cavities in the lunar surface ahead of a moving lunar rover should be developed.	21	HG-1 HG-2
GG-7	Navigation aids to lunar surface crews shall be capable of continuing operation even in the event of complete communications loss.	21	HG-1

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GG-8	Lunar surface roving vehicle design features should include lap belts and shoulder restraints, roll bars or similar protection from injury in the event of vehicle overturn, and surface slope warning indicators.	21	HG-1 HG-2
GG-9	A rescue plan shall be available in detail prior to each operational surface traverse mission.	21	HG-1 HG-2 HG-3
GG-10	Doors, hatches, and airlocks on cabin type roving vehicles shall be capable of accommodating a stretcher case plus a fully suited crewman.	21	HG-2
GG-11	Lunar surface rovers shall carry redundant communications equipment, radio beacons, and visual and auditory signalling devices to aid in rescue.	21	HG-1 HG-2 HG-3
GG-12	A series of depots or caches where critical supplies are stored along a planned lunar traverse route shall be considered in mission planning.	21	HG-1 HG-3

GROUP H. GUIDELINES FOR FLYING VEHICLES

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GH-1	Lunar flying vehicles shall have fully redundant propulsion and control systems, except for propulsion tankage and propellant. Fail-operational, fail-operational, fail-safe philosophy shall be observed.	23	HH-1 HH-2
GH-2	Each lunar flyer vehicle shall carry a communications beacon and voice transmitter capable of withstanding any crash survivable by a crewman.	23	HH-1 HH-2

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GH-3	Special protection from low velocity impacts should be provided for EVA backpacks used on lunar flyer missions, and an additional emergency oxygen supply capable of withstanding the impact without impairing its function should also be provided.	23	HH-1 HH-2
GH-4	Lunar flyers shall be prohibited from landing in any area which cannot accommodate a second flyer.	24	HH-2
GH-5	All lunar flyers shall be capable of carrying at least one pilot, plus one passenger who may be incapacitated.	24	HH-2
GH-6	Use of two flying vehicles on each flyer mission, each capable of returning the crewmen of both vehicles, is strongly recommended.	24	HH-2
GH-7	Continuous communication with the base is required for the entire period of all lunar flyer missions.	24	HH-2
GH-8	In planning flying missions into potentially dangerous locations a rescue plan shall always be determined beforehand. The range/time capability of the rescue mode shall determine the maximum allowable range/time-away-from-base of any lunar flyer mission.	24	HH-2
GH-9	Mission planners must have a precise knowledge of the limitations in performance of the flyer/crewman combination and detailed information on landing site topography prior to initiating a lunar flyer mission.	24	HH-2

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GH-10	Lunar flyers shall be operated only when solar lighting conditions will be favorable for both the outbound and inbound legs of a mission, unless on an emergency mission.	24	HH-2
GH-11	All solo lunar flyer missions shall have a crew of at least 2 men with the vehicle flyable by one man.	24	HH-2

GROUP I. GUIDELINES FOR PRESSURE CABIN LEAKS

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GI-1	Instantaneous warning and detection/location information for cabin leaks above nominal shall be provided.	33	HI-1
GI-2	Maximum feasible access to the cabin pressure walls, ceiling, and floor shall be provided in all space vehicles in order to expedite repair of leaks. Insofar as it does not seriously compromise equipment functions, all equipment should be mounted away from vehicle, spacecraft and base pressure-containing walls in order to permit such access as will be necessary for repairs.	33	HI-1
GI-3	Provide capability for supplying emergency oxygen, within seconds, to all crew members, in the event of excessive leaks in a space vehicle cabin.	33	HI-1
GI-4	Kits and procedures for repairing damaged cabin walls, and seals at cabin wall interior/exterior interfaces, shall be provided.	33	HI-1

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
	GROUP J. GUIDELINES FOR SCIENCE EQUIPMENT AND UNMANNED SATELLITES		
GJ-1	Satellite deployment and initiation of operations considered hazardous shall be made ready from a remote location before exposing crewmen to potential hazards.	8	HJ-1
GJ-2	Refueling of satellites shall be accomplished by use of prepackaged fuel and oxidizer container with built-in valves which open only after final installation.	8	HJ-1
GJ-3	Servicing of satellite propulsion shall only be accomplished after thorough system venting and purging.	8	HJ-1
GJ-4	Vacuum venting of immediate area where system piping or tubing is opened shall be accomplished for each system breaching operation involving dangerous liquids or gases.	8	HJ-1
GJ-5	All solid propellant installations shall be designed to accept a complete prepackaged solid propellant module designed to be "no-fire" safe until satellite is armed for deployment.	8	HJ-1
GJ-6	Specific warning instrumentation and sensors designed for the satellite propellant fluids to be handled, shall be installed in area where such fluids are to be stored or handled.	8	HJ-1

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GJ-7	Automatic fault detection equipment utilization shall be employed as the first step in the test and checkout of satellites. The sudden rise of current above test limit shall cause power cut-off to the test-and-check-out setup as a means of preventing electrical fires.	8	HJ-1
GJ-8	Satellite capture for data return and reuse shall be accomplished via a tug specifically equipped for the task, in order to avoid potential collision problems for the OLS.	8	HJ-2
	GROUP K. GUIDELINES FOR ORBITAL EVA		
GK-1	All EVA astronauts shall carry a thirty minute emergency oxygen supply to be used only in the event of failure of the main oxygen supply. Switchovers may be manual or automatic, but a signal of automatic switchover must be provided the astronaut.	7 22	HK-1 HL-1
GK-2	The emergency oxygen supply feed shall be capable of manual control by an EVA astronaut.	7 22	HK-1 HL-1
GK-3	An EVA astronaut using his emergency oxygen supply shall have an immediate and mandatory requirement to return to his spacecraft or base.	7 22	HK-1 HL-1
GK-4	All spacecraft and bases shall have plugs strategically located on their surfaces so that an EVA astronaut can attach umbilicals for oxygen, electrical power, and communications.	7 22 29 30	HK-1 HK-2 HK-4 HL-1 HP-1

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GK-5	The buddy system or presence of a safety man, is mandatory when EVA astronauts are assigned tasks in which they are operating detached from the spacecraft or station.	7 35	HK-1 HK-3 HK-4 HK-5
GK-6	The buddy system or presence of a safety man, is desirable for an EVA astronaut assigned to a task on the surface of a spacecraft to which he is tethered.	7 35	HK-1 HK-3 HK-5
GK-7	An EVA astronaut shall have a communications (May-day) alarm, self-powered, and activated automatically should his communications subsystem or his electrical power subsystem fail.	7 22 35	HK-2 HL-2 HP-1
GK-8	A communications failure shall lead to an immediate and mandatory return to the EVA astronaut's spacecraft or base.	7 22 29 30	HK-2 HL-2 HP-1
GK-9	In the event of loss of primary electrical power by an orbital EVA astronaut an emergency battery pack shall supply power to: a. run the astronaut propulsion unit for a minimum of ten minutes, b. keep suit temperature below 90°F for thirty minutes, c. run a May-day communications alarm for one hour, d. run a flashing light (wattage to be determined) for at least one hour.	7	HK-2 HK-3 HK-4
GK-10	EVA astronaut propulsion must fail "off".	7	HK-3

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GK-11	EVA astronaut attitude control subsystem shall be capable of being used to keep the astronaut in the vicinity of his spacecraft in the event of a runaway propulsion system.	7	HK-3
GK-12	As astronaut shall be capable of disabling any or all AMU attitude control thrusters at all times.	7	HK-3
GK-13	AMU attitude control thrusters for an EVA astronaut shall be disabled whenever he is tethered and not translating. Tethers must be impervious to damage from hot gas or other AMU exhaust products.	7	HK-3
GK-14	All spacecraft shall have hand-holds and tethering places strategically located on their surfaces so that an EVA astronaut may use these in the course of those tasks in which he is located on the spacecraft surface.	7	HK-3
GK-15	Untethered EVA should be prohibited until an astronaut maneuvering unit (AMU) is developed to the extent of being very reliable.	7	HK-3
GK-16	Astronaut candidates must be carefully screened to eliminate personnel who are susceptible to motion sickness or nausea.	35	HK-5
GK-17	Training and simulation programs should continue to acclimatize astronaut personnel to the types of extreme motions anticipated with lunar rover traverses or abnormal EVA motions.	35	HK-5

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GK-18	The diet of astronauts prior to EVA operations should continue to preclude large food particles.	35	HK-5
GK-19	Astronauts should continue to be indoctrinated relative to the hazards of nausea within the confines of a space suit and enjoined to refrain from EVA activities when indisposed, regardless of mission priorities, unless required by an emergency condition.	35	HK-5
GK-20	Suit design progress should evolve in the following directions: a. Provide increased astronaut mobility. b. Incorporate redundant features to preclude catastrophic failure of any suit/back-pack element. c. Include a positive collection method including a debris/vomitus trap or bag. d. Investigate the feasibility of including a backup system within the suit or back-pack. e. Provide means to open the face mask to render aid in a vacuum environment. f. Provide higher suit pressures to eliminate need for denitrogenization. g. Provide integrated suit-back pack design.	35	HK-5
GK-21	Adequate provisions for simultaneously denitrogenating EVA personnel should be provided in the OLS, the Space Tug and the Lunar Base.	39	HK-6
GK-22	Crew activity schedules should allow sufficient time for adequate denitrogenation when a transition must be made from a higher pressure, 2 gas cabin to a lower pressure pure oxygen suit environment.	39	HK-6

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GK-23	Astronaut selection criteria should continue to stress relative immunity from the symptoms of dysbarism.	39	HK-6
GK-24	Astronaut training programs should continue to indoctrinate candidates on the symptomology of dysbarism.	39	HK-6
GK-25	Drug therapy as a means for preventing or increasing tolerance for bends symptoms should be investigated.	39	HK-6
GK-26	Compression therapy techniques and devices, such as the pressure bag, should be developed for space applications to treat dysbarism symptoms.	39	HK-6

GROUP L. GUIDELINES FOR SURFACE EVA

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GL-1	The buddy system, or presence of a safety man, should be mandatory for EVA astronauts under normal conditions unless they are within a few tens of meters of the LSB or of the cabin rover or of the landed tug, and standby help is immediately available.	22 23	HL-1 HL-3
GL-2	Back-pack design shall permit buddy system attachment and operation for all life support functions and power and communications.	22 23	HL-3
GL-3	Failure or degradation of his life support back pack should make return to a safe haven mandatory and immediate for an EVA astronaut.	22 23	HL-3

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GL-4	Back-pack switching in the lunar vacuum environment shall not be required as a means for normal extension of mission duration.	22 23	HL-3 HL-6
GL-5	Back-pack switching aids shall be provided only for emergency-switching of backpacks.	22 23	HL-3 HL-6
GL-6	All back-packs and inter-related equipment should be designed to fail-operational, fail-operational, fail-safe.	22 23	HL-3
GL-7	All hose connections should have automatic, self-sealing ports for the eventuality of inadvertent hose-disconnection.	22 23	HL-3
GL-8	A means shall be provided for a single astronaut to move an unconcious EVA astronaut from an accident location to a nearby safe haven.	22 23	HL-4 HL-5
GL-9	Erection of large structures/instruments should be automatic insofar as is reasonable without seriously compromising function or costs for the lunar complex.	22 23	HL-4
GL-10	All corrosive fluids should be handled by EVA astronauts wearing a protective overgarment and protective boots or boot covers.	22 23	HL-4 HL-5
GL-11	No EVA astronaut should be outside and in the immediate vicinity of any vehicle on the lunar surface during the initiation of motive power.	22 23	HL-4

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GL-12	Scientific mission activities shall be organized to avoid tripping over emplaced scientific equipment and its connecting cables.	22 23	HL-4
GL-13	EVA astronauts using the lunar flyer should wear a protective garment during the interval that the flyer's engines are turned on in order to prevent contamination from engine exhaust.	22 23	HL-5
GL-14	Repair kits, analogous to the tire repair kit, should be available for all EVA astronauts (in general, for all suited astronauts) in order to be able to repair minor and medium suit leaks. Means should be provided for determination and detection of leaks.	22	HL-1
GL-15	Space suit design efforts should continue to stress increased astronaut mobility performance capabilities, integration of separate suit elements into one garment, increased resistance to tear and abrasion, and emergency corrective measures to prevent catastrophic suit leaks.	23	HL-7
GL-16	External protuberances such as hoses, electrical lines, etc., on all space suits should be eliminated by improved design.	23	HL-7
GL-17	Lunar hardware systems must be designed to preclude accidental damage to suits and backpacks. Such measures include development of safe vehicle/shelter ingress/egress provisions and aids, avoidance of abrasive hardware edges and protrusions which can snag suits or hoses.	23	HL-7

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GL-18	The gold plated, heat reflective layer on the spacesuit face masks should be sealed between two layers of plastic in order to protect that layer from scratching, abrasion, or peeling.	23	HL-8
GL-19	It is recommended that the lunar surface base have provisions to permit shirtsleeve transfer to and from the cabin rover.	22 23	HL-3
GL-20	The airlocks, doors, hatches, elevators, etc., for the lunar surface base shall be large enough to accommodate at least one stretcher case plus one crewman wearing a total EVA mobility unit.	22 23	HL-4

GROUP M. GUIDELINES FOR CARGO AND EQUIPMENT

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GM-1	It is strongly recommended that cargo packages whose dimensions exceed 20" x 30" x 40" or whose Earth weight exceeds 1000 pounds be moved from the cargo module to the lunar space station, or to a tug, using a restraint/transport method.	14	HM-1
GM-2	A package whose Earth weight is greater than 500 pounds but less than 1000 pounds and whose dimensions do not exceed 20" x 30" x 40" should be handled by two crew members when in a zero-g, shirtsleeve environment.	14	HM-1
GM-3	In order for a package to be handled by one man in a zero-g, shirtsleeve environment, it should: (a) have dimensions permitting comfortable handling and, (b) be less than 500 pounds Earth weight.	14	HM-1

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GM-4	Cargo containers/packages should be designed to provide generous grasping points or handholds.	14	HM-1
GM-5	In order to minimize hazards associated with cargo handling in orbit, the pantry technique is recommended for receiving cargo. In such a method the cargo module is docked to a logistics port at the station, cargo is removed on an as-needed basis, the cargo containers are opened in the module and the contents removed in separate pieces as needed. This technique requires entry to the module on a daily (or more frequent) basis but the handling is reduced, in large part, to removal of small packages.	14	HM-1

GROUP N. GUIDELINES FOR AVOIDING COLLISION IN ORBIT

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GN-1	No two space vehicles or structures shall be based in near-identical or intersecting orbits.	11 13 25	HN-1 HE-1
GN-2	No two space vehicles shall be permitted to approach each other on a collision course either with main propulsion "on" or with a closing velocity greater than about 2 ft/second.	11 13 25	HN-1 HE-1
GN-3	A vehicle intending to dock in orbit shall not be placed on a collision course with the primary propulsion burning.	11 13 25	HN-1 HE-1

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GN-4	To accomplish docking following rendezvous of two vehicles in orbit, altitude adjustment shall occur first followed by establishment of an intercept trajectory. Only docking thrusters shall be used for velocity adjustment, and closing velocity shall be limited to a maximum of about 2 ft/second until about 200 ft from contact. From 200 ft to contact the closing velocity shall be limited to less than 1 ft/second.	11 13 25	HN-1 HE-1
GN-5	Docking areas on space vehicles shall be kept free of vehicle or subsystem appendages, such as engines, antennae, and solar cells.	11 13 25	HN-1 HE-1
GN-6	Docking mechanisms shall be designed to absorb twice the normal maximum expected docking impact energy without damage.	11 13 25	HN-1 HE-1
GN-7	Spacecraft departing from a second vehicle shall first make an altitude adjustment sufficient to ensure that orbits are non-intersecting before initiating main thrust.	11 25	HN-1
GN-8	The positions of all objects in lunar orbit, including space debris, shall be monitored, Debris shall be removed at the earliest opportunity should any significant possibility of collision exist. If debris removal is not practical, the orbit of vehicles threatened with collision shall be appropriately altered.	11 25	HN-1

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
	GROUP O. GUIDELINES FOR LIGHTING		
GO-1	Navigation and hazard avoidance techniques must be developed for use on the lunar surface with lunar rovers, and with lunar flyers, which are independent of any and all lighting conditions on the surface.	26	HO-1 HO-2
GO-2	A device, analogous to mine detectors, should be designed in order to determine hidden crevasses and roofed holes on the lunar surface. This device, if needed, should be attached to the front of all lunar rovers on a long enough extension (truss) so that the rover may be stopped in time, at its highest speed, if such a hazard is detected.	26	HO-1
GO-3	As aids to navigation on the lunar surface 'buoys' should be developed containing coded radio beacons and flashing light(s), and powered by radioisotope power sources of at least 5 years lifetime. Radio beacons should be detectable at a distance of at least 50 miles using omni antennas on the lunar rovers.	26	HO-2
GO-4	During daylight docking with an orbiting vehicle, the sun line should be maintained within the limits described in Hazard Study 27.	27	HO-3
GO-5	Problems of sun orientation during docking may be avoided by completing the maneuver on the dark side of the orbit while using artificial lighting.	27	HO-3

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GO-6	Routine lunar landings shall be planned with a preference for times of low angle sun lighting. In particular, landings at unexplored sites during lunar night or times of high angle sun lighting should be avoided except for emergencies.	28	HO-4
GO-7	Surface crews shall aid incoming landers by site preparation and/or selection, identification of obstacles, lighting, and steering information where possible.	28	HO-4
GO-8	The use of various optical filters in lander viewing ports should be tested in an effort to find means for reducing the effects of glare on vision.	28	HO-4
GO-9	Rescue landers shall be provided with flares and floodlights for use during night landings.	28	HO-4
GO-10	Surface crews shall be provided with lighting equipment, signal devices, and radio beacons as well as voice communication equipment for assisting a manned landing at their surface site.	28	HO-4
GO-11	The dynamics of landing should be studied to determine whether an abort or hovering maneuver can be automatically programmed to occur at any time the lander tilt attitude exceeds some preselected safe angle.	28	HO-4
GO-12	Means for leveling vehicles following landing on the lunar surface shall be provided.	28	HO-4

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
	GROUP P. GUIDELINES FOR COMMUNICATIONS LOSS		
GP-1	Each EVA astronaut shall have independent, highly reliable primary, secondary, and emergency backup communications systems. Loss of the primary system yields an immediate and mandatory requirement for the astronaut to return to his spacecraft or base.	29	HP-1
GP-2	Each rover and flyer shall have independent primary and secondary communication systems. For traverses beyond 1 nm from the base, an emergency system shall be added.	29	HP-1
GP-3	Rover and flyer traverses beyond 1 nm from the base shall be aborted immediately following any communications failure which reduces the total capability to two transmitters and two receivers.	29	HP-1
GP-4	Each communication system shall be checked at frequent, fixed intervals.	29 30	HP-1
GP-5	Communications with an EVA astronaut shall be monitored and checked at frequent, fixed intervals by a crewman in the nearby tug or space station.	29 30	HP-1
GP-6	It is strongly recommended that EVA activity be carried out using the buddy-system, or with the presence of a safety man.	29 30	HP-1
GP-7	Each space tug shall have a minimum of three independent, highly reliable communication systems.	29 30	HP-1
GP-8	All tugs shall have external beacons (lights) for use as a backup signalling device.	29 30	HP-1

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GP-9	Each space tug in lunar orbit shall be able to dock to the space station in order to re-establish communications by using the station facilities, or by having repairs made to its own system, or by a combination of these methods.	30	HP-1
GP-10	The tug shall be returned from an orbital mission to the orbiting lunar station for repair following any communications failure that cannot be corrected on board.	30	HP-1
GP-11	The lunar space station shall have some capability to perform scheduled maintenance, and repairs and replacement for communications and subsystems.	30	HP-1
GP-12	Space tugs should be designed to be able to act as the emergency communications center for the lunar space station.	30	HP-1
GP-13	Plans for action to be followed in the event of partial or complete communications failure shall be prepared prior to any mission. Plans will be revised as necessary during the mission.	29 30	HP-1

GROUP Q. GUIDELINES FOR NATURAL AND MAN-MADE RADIATION

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GQ-1	The radiation shielding incorporated in a nuclear power system module shall be capable of attenuating the radiative energy and particle release, for the postulated maximum credible nuclear source accident, to levels which do not exceed the allowable crew dose, per duty tour, in the orbiting lunar station.	9	HQ-1

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GQ-2	The nuclear source shielding integrity shall be such that it will survive, in an integral condition, all assaults resulting from source system mechanical malfunctions, thermal shock, and vehicle collision. Further, the shielding area facing the station shall survive intact the postulated maximum credible nuclear source accident.	9	HQ-1
GQ-3	It shall not be possible for a failed or failing power module to inhibit access to, or escape or rescue from, the orbiting lunar station by reason of direct exposure from gamma or neutron radiation.	9	HQ-1
GQ-4	A nuclear energy source (reactor) shall be capable of positive shut-down in any orientation and under all conditions of mechanical malfunction. The source reactor shall fail-safe to a shut-down condition for all credible nuclear transient conditions.	9	HQ-1
GQ-5	A nuclear power system module shall incorporate design features which permit remote detachment of the module by a tug vehicle for disposal purposes.	9	HQ-1
GQ-6	Flight operations in and around an orbital station shall be constrained to avoid the restricted volume around a nuclear power module for a distance determined to be safe.	9	HQ-1
GQ-7	The station telemetry link to Earth shall sample, and report the ambient radiation level in the station at any time when the radiation values exceed an established background nominal. TM shall regularly report dose and dose rate at selected station areas.	9	HQ-1

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GQ-8	Replacement of nuclear fuel for the reactor or replacement of the reactor itself will be accomplished using techniques that ensure that the crew members involved do not receive an injurious radiation dose. Actual permissible dose, in the light of the importance of this operation, should be determined.	9	HQ-1
GQ-9	Each crew member shall always wear a dosimeter, changed at regular intervals so as to keep accurate records of radiation exposure. Dosimeter readings will be reported regularly, or on demand, to Earth stations to the LSB or to other appropriate spacecraft.	9	HQ-1
GQ-10	Consideration of "crew radiation-exposure accountability" must be included in the administrative procedures devised for lunar exploration mission planning. It must be possible to update each crewman's exposure record at least once each 24 hours.	31 36	HQ-1
GQ-11	Serious consideration shall be given to the implementation of a mission planning function, which will thoroughly evaluate the "crew radiation exposure potential" for each phase and activity of the planned missions.	31 36	HQ-1
GQ-12	Specific crew safety studies shall be required for each item of mission equipment capable of emitting ionizing radiation. The studies shall be conducted in the context of the mission(s) for which the equipment use is intended. Where several such equipments are to be employed, the study shall account for the sequential and/or simultaneous use of the involved equipments.	31 36	HQ-1

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GQ-13	All nuclear and isotope source units shall have been demonstrated to be safely contained against impact, weldment leakages, or containment melt-through, prior to flight qualification. Where the unit is to be employed continuously in close proximity to crew quarters and shelters, the unit shall be double contained to avoid all possibility of leakage and local environment contamination.	31	HQ-1
	GROUP R. GUIDELINES FOR METEOROIDS		
GR-1	Every effort shall be made to provide a two-gas atmosphere in spacecraft cabins, using a diluent such as nitrogen in order to suppress vaporific flash during meteoroid penetrations.	38	HR-1
GR-2	All critical hardware directly exposed to the space environment shall have protection against meteoroids as required to meet acceptable risk probability criteria.	38	HR-1
GR-3	Kits shall be devised for the quick repair of small holes in manned cabins caused by meteoroid punctures.	38	HR-1
GR-4	Lunar bases and spacecraft shall be designed, where feasible, to have two or more compartments, each capable of maintaining the cabin atmosphere which supports the crew life functions.	38	HR-1
GR-5	All optics in hardware critical to support, protection, and survival of crew members shall have protective shields, such as iris-type closures, when not in use.	38	HR-1
GR-6	All spacecraft, lunar surface bases, and other vehicles in the lunar complex shall carry medical equipment for the treatment of burns. Crewmen shall be trained in the treatment of burns.	38	HR-1

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
	GROUP S. GUIDELINES FOR HAZARDOUS MATERIALS		
GS-1	Primary containers for hazardous material shall be designed to permit safe storage and transfer of the contained material under all conditions of use and storage in lunar orbit and on the lunar surface. Ascertain the conditions of safe stowage, handling and use of all materials considered to be hazardous both in lunar orbit and on the lunar surface.	34	HS-1
GS-2	Secondary bulk cargo storage containers shall be designed to permit safe transfer and handling of primary hazardous material containers under all conditions of transport to lunar orbit and the lunar surface.	34	HS-1
GS-3	The tug vehicle, Lunar Orbiting Station and Lunar Surface Base design reviews shall specifically examine the stores stowage safety features and assess the hazards effects countermeasures incorporated (i.e., fire, explosion, vapor control, contamination control, etc.).	34	HS-1
GS-4	Considering mission activity sequences, the optimum manner of stowage for hazardous stores shall be ascertained, consistent with safety and availability for use.	34	HS-1
GS-5	The actual need for hazardous materials in achieving mission and program objectives shall be established. For each hazardous material needed, alternate materials shall be reviewed to ascertain the possibility of reducing the hazard potential by alternate selection. Alternate techniques for achieving desired program objective and eliminating the more hazardous materials are extremely desirable.	34	HS-1

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GS-6	For hazardous materials required, insure and certify (prior to flight approval): a. Necessity for hazardous material use. b. That all hazards involved in materials use are known. c. That safeguards provided for material use are adequate for personnel safety. d. That procedures for material use are accurately documented and thoroughly understandable. e. That disposal of hazardous material in lunar orbit or on lunar surface can be safely accomplished if necessary.	34	HS-1
GS-7	Personnel shall be experienced and trained in the handling of hazardous materials both in zero-g and on the lunar surface.	34	HS-1
	GROUP T. GUIDELINES FOR HUMAN ERROR		
GT-1	Lunar flight operations shall require two crewmen at the flight station during all critical flight maneuvers such as docking, landing, ascent, and orbit change burns. The second crewman shall function as a judgement error monitor and shall assist the pilot in the execution of the maneuvers as necessary.	37	HT-1
GT-2	A "buddy-system" mode of operation, or presence of a safety man, shall be implemented for all hazardous activities where a crewman may be jeopardized by an equipment or environment induced or self-induced malfunction or mishap.	37	HT-1

Guideline No.	Guideline	Hazard Study No.	Reference Hazard No.
GT-3	The probable sources of human error likely to be encountered in the expanded lunar exploration program should be identified. These sources should be considered in program element design refinement for safety enhancement. The effort should include as necessary, work-rest ratios, fatigue buildup, reaction error studies and such other human factors and engineering aspects as may be required to suppress the potential for human error to minimum levels.	37	HT-1
GT-4	Specific efforts are recommended to enlarge upon the use of simulators and full-scale mockup equipments for the configuration evolution of program element control and work stations.	37	HT-1

Section 4
CONCLUSIONS AND RECOMMENDATIONS

The study generated the following basic data:

1. Hazard studies were performed in 39 individual areas in which hazards were identified and analyzed, and corrective measures proposed.
2. Over 200 safety guidelines were proposed and recommended for implementation, based on the significant hazards identified.
3. Escape and rescue situations and requirements were identified and analyzed.
4. Escape/survival/rescue concepts were proposed and defined to cope with each escape/rescue situation.
5. A lunar mission escape/rescue plan was prepared.

Highlights from the two study tasks are presented below.

4.1 ESCAPE/RESCUE ANALYSIS

The Integrated Program Plan (IPP) elements under consideration appear feasible for escape and rescue use in all situations examined, provided crew survival can be assured and the elements are equipped for such missions. The surface mobility vehicles and the tug can function as the primary escape/rescue vehicles simply by the addition of situation-peculiar kits. The feasibility of the proposed escape/rescue plan is predicated on the deployment of the IPP elements in a manner that makes them available for escape/rescue missions during the Advanced Lunar Program and on the assumption of a minimum ΔV capability of 15,000 ft/sec for the dedicated tugs based in lunar orbit or on the lunar surface.

It is strongly concluded that the primary emphasis should be on survival and escape provisions, with rescue required only where self-help cannot bring the endangered crewmen to a permanent safe haven. The reaction times for escape are usually much shorter than for rescue - in many cases, minutes or hours vs days.

The required elements, their deployment, and escape/rescue missions, are shown in Table 2-2. The key program impact items involving deployment and basic capability are:

- If a rescue capability is demanded for the initial manning and activation of an orbiting lunar station, the rescue must originate from the vicinity of Earth. The preferred solution is to provide tugs with the initial manning mission with the capability to escape to Earth orbit in the event of a Prime Transport Vehicle or orbiting lunar station failure.

- A minimum of three tugs are required in the lunar area when surface missions are underway: one dedicated rescue tug in orbit; one operational tug in orbit with capability to perform surface rescue if required; and one operational/escape tug on the surface.

- An orbital lunar station capable of serving as a rescue base and safe haven is a necessary part of the proposed escape/rescue plan.

- The crew compartment of the Prime Transport Vehicle must be provided with the capability for autonomous escape to a safe lunar orbit. This requires a *minimum* ΔV capability of 1,000 ft/sec.

- The tug must have the capability to return to Earth orbit from lunar orbit.

To ensure crew survival and the ability to complete effectively a rescue operation for the various emergency situations that may occur, the study results recommend many additions, modifications, and restrictions in both design and operation of the IPP elements. These recommendations are in the areas of Communications, Crew Survival Provisions, Rescue Response Time, ΔV Requirements, and Rescue Equipment.

Communications

A relay satellite for communications is necessary for safe lunar surface operations on the farside. This system can be either a libration point relay or a satellite system operating in lunar orbit. In addition, improved and dedicated emergency communication capabilities are recommended, such as rescue alerting, locating, and landing aids.

Crew Survival Provisions

In any rescue situation, a fundamental tradeoff exists between providing crew survival time versus rescue time. In order to keep rescue requirements within reasonable bounds, provision must be made for crew survival within the basic program elements and operations. Major considerations are:

- Vehicles accomodating astronauts in shirtsleeves should have two pressure compartments - separate but interconnected, with each capable of supporting the entire crew in an emergency for a period of time commensurate with the rescue time.

- A simple, lightweight emergency pressure garment that can be donned in five seconds or less should be developed. The ability to convert this emergency garment into a stretcher, while being worn, by the addition of handles or rods, should be considered a goal.

- An uprated backpack is needed with a minimum metabolic capacity of 6,000 BTU and a battery lifetime of at least 12 hours.

- A crew compartment or module will probably be used for ferrying crews to and from the moon. This compartment may or may not be mated to a tug propulsion module. Situations in which the arriving or departing primary transport vehicle (PTV) injects into an undesirable trajectory, including lunar surface impact or lunar escape, place excessive response and Δ V requirements on any rescue vehicle. To avoid these excessive requirements, the crew compartment should have the capability to detect the existence of a dangerous trajectory, separate from the Prime Transport Vehicle, and inject itself into a lunar orbit to await rescue. In addition to autonomous guidance, attitude control, communications, and power, a propulsion system with a minimum Δ V capability of 1,000 ft/sec is required to attain a safe lunar orbit.

- Each vehicle or base should provide sufficient space suits, backpacks, emergency pressure garments, and emergency oxygen masks for all crewmen.

<u>Rescue Response Time</u>

The time for a rescue team to arrive at the site of an emergency can vary from a few hours, say from lunar orbit down to the lunar surface base, to several days for an Earth-based rescue. In order to <u>minimize response times</u>, the following initial conditions are necessary:

- If a rescue capability from Earth vicinity is required, it should be based on the surface.

- Rescue tugs in lunar orbit should have the capability to make a 90-degree plane change prior to landing on the lunar surface. The rescue tug should be fully loaded with propellant and in standby condition in orbit.

- Rescue tugs must be able to land on the lunar surface under all conditions of lighting and sun elevation, and landing aids such as tracking beacons, boundary markers, and area lighting should be available on the surface to mark the landing area.

ΔV Requirements

The Escape/Rescue plan is predicated on a lander tug with a nominal ΔV capability of 15,000 ft/sec. Such a tug can accomplish the following escape/rescue operations when starting with full propellant tanks:

- Return to the Earth vicinity from lunar orbit
- Descend to the lunar surface and return to an orbital lunar station (with no plane changes)
- Execute a 90-degree plane change and descend from orbit to the lunar surface. Provide a temporary safe haven while awaiting a further rescue mission
- Ascend from the lunar surface, execute a 90-degree plane change, rendezvous, and dock with an orbiting lunar station
- Rescue a crew compartment from lunar orbit or from a lunar escape trajectory and return to an orbiting lunar station

These operations are all that are required to rescue a crew from any lunar situation and return them to a temporary or permanent safe haven. The 15,000 ft/sec capability is sufficient to complete all escape/rescue missions and arrive at a permanent safe haven for all except two of the situations examined; the two exceptions are:

1. Rescue of the crew in the orbiting lunar station by a tug from the lunar surface
2. Rescue of a crew on the lunar surface, by a tug from the orbiting lunar station, in a situation requiring a large plane change.

For the first case, once a temporary safe haven is provided in the rescue tug, from the lunar surface, the tug must remain in lunar orbit to await aid from the Earth vicinity. For the second case, the tug must wait on the lunar surface until a second orbital tug can make a descent without a plane change, which may be as long as 14 days, and can either bring additional propellant or return the rescued crew to the orbital station.

Escape/Rescue/Survival Equipment

In addition to the requirements and operational restrictions given in the preceding sections, the need for specific devices and procedures to aid rescue is pointed out in the study.

One of the major items of new equipment is a portable airlock to allow crewmen in an EVA mode to enter a shirtsleeve compartment without destroying the ambient atmosphere. The portable airlock should be small and light enough to be handled by no more than two crewmen, but should be expandable to a large enough size to accommodate an incapacitated man in a pressurized stretcher and a second man in a pressure suit with backpack.

Other recommendations include portable instrumentation, locator aids, attachment and docking aids, handcarts, and emergency access doors. In order to eliminate EVA during refueling of the tug, it is recommended that interchangeable propellant modules, that would not require EVA for coupling and connecting of supply lines, be considered.

4.2 HAZARDS ANALYSIS

The results of the Hazards Analysis task are in the nature of hazards identified, corrective measures and safety guidelines proposed to counter those hazards, and recommendations for additional study and safety technology development.

Hazards Analysis results having major program impact are summarized in the following seven areas.

Extravehicular Activity

The Hazards Analysis led to a clear conclusion that disproportionate risks are present in extravehicular activity (EVA). These risks result from the inherent limitations of any current or projected space suit and life support backpack design, and include: lack of astronaut mobility; lack of access to permit aiding an ill, injured, or vomiting astronaut; critical consequences of suit rupture or backpack failure; and short sortie lifetime for EVA backpacks. These risks should be minimized by:

1. Limiting EVA to those functions which cannot be efficiently performed by means not requiring EVA
2. Requiring use of the buddy system or presence of a safety man for all EVA activities
3. Developing new pressurized suits and backpacks with integrated design, increased mobility, increased sortie lifetime, access through the face mask to render aid, and easy repair of minor suit damage
4. Developing means for switching backpacks safely, but not using this as a normal means for extending EVA
5. Devising means for a single astronaut to move an unconscious EVA astronaut from an accident location to a nearby safe haven
6. Developing means for an EVA astronaut to share all backpack functions with a buddy astronaut
7. Developing means for supplying all power, communication and metabolic needs for an EVA astronaut through external plug-ins on the exterior of a station or base (this must be accomplished without undue risk of losing station or base atmosphere through introducing additional leak paths.)
8. Designing doors, hatches, and airlocks on all pressure cabins to accommodate a stretcher case plus a fully suited crewman
9. Designing all vehicles to permit operation by a single crewman in a pressurized suit.

While the risks accompanying EVA are recognized, it is also evident that EVA will be useful and necessary in advanced lunar exploration. In addition, the pressurized suit is desirable as a backup during occupancy of a pressurized cabin. This leads to the requirement that all vehicles be designed to permit operation by a single crewman in a pressurized suit. Also, each vehicle, station, or base should provide space suits, backpacks, emergency pressure garments, and emergency oxygen masks for all crewmen.

Crew Training

Recent NASA planning information suggests that a mix of highly trained astronauts and lesser trained technical specialists may be considered for lunar exploration in the 1980's. The same information shows lunar station and base complements varying from four to eight or twelve men. This means that when men are sent on sorties from orbit to orbit, orbit to surface, or surface to surface, or when emergencies requiring rescue missions arise, few men will be available at each station, lander, base, and surface transportation vehicle. The analysis showed that each crewman must continue to be highly trained in all aspects of the mission and hardware until such time as the lunar exploration personnel complement is much larger than four-to-twelve men.

Failure Modes

Certain functions were determined to be so critical to safety that they should be designed to fail-operational, fail-operational, fail-safe philosophy. These functions include propulsion, attitude control, and power for lunar landers and lunar flyers; all functions for life support backpacks; and power navigation, and life support for lunar rovers.

Cabin and Suit Atmospheric Pressures

Compatibility of pressures in cabins and space suits is a potential major problem. An increase in the pressure of pure oxygen in present suits from 3.5 psia, and a corresponding decrease in total pressure of oxygen and nitrogen in cabins to less than 14.7 psia, are necessary in order that the transition from cabin to suit can be made without a delay for denitrogenization. This will require detailed study to establish the most desirable compromise pressure, taking into consideration the design problems, disadvantages, and hazards of a suit with increased pressure.

Pressurized Compartments

Each space vehicle or cabin accommodating astronauts in shirtsleeves must have at least two pressure compartments, separate but interconnected, with each capable of supporting the entire crew in an emergency for a period of time commensurate with rescue time. This is necessary in order that - in the event of fire, explosion, meteoroid puncture, or other damage which renders a compartment uninhabitable - a safe haven is immediately at hand.

Surface Transportation

A critical requirement derived from the analysis is that each surface transportation vehicle must be able to carry at least one pilot or driver, plus one passenger who may be incapacitated. It is also recommended that surface transportation vehicles beyond walk-back distance should be used in pairs, with each vehicle capable of carrying and supporting all crewmen of both vehicles in an emergency. All rover vehicles should be capable of carrying a nominal crew of three, including the driver. Each rover should have a minimum emergency capability to support and transport four crewmen, including the driver, and should provide for care of two men in pressurized stretchers. The normal operating mode would then be to send two rovers on sortie with two crewmen plus disposable payloal on each (or three crewmen on one, one crewman on the other, and disposable payload on each).

In the event that a 4-man emergency capability is found to impose an unreasonable burden on the lunar equipment delivery systems, an acceptable alternate is a 2-man nominal capacity rover with 3-man emergency capability. This rover could be operated in a buddy mode, with two men on one vehicle and one man plus disposable payload on the other.

4.3 IMPLICATIONS FOR RESEARCH

Research or technology development efforts that could lead to improved safety in advanced lunar missions were identified in several areas. The following are recommended for consideration.

1. An integrated suit and backpack should be developed to eliminate external protuberances and hoses, to eliminate concern for sequence of activation or deactivation, and to provide increased astronaut mobility performance capabilities. The backpack should be designed to share all functions with a buddy astronaut in an emergency.
2. Pressure suits should be developed/designed to operate at pressures which would eliminate the need for denitrogenization.
3. Backpack switching aids and procedures should be developed, in conjunction with integrated suit and backpack development, to permit safe switching by an unassisted EVA astronaut.
4. Means should be developed for safely opening an EVA astronaut's face mask to render aid.
5. Means should be developed for detecting strains and potential failure of face masks during use.
6. Emergency pressure garments, designed to be donned in five seconds or less, should be developed. Consideration should be given to use of this garment as a pressurized stretcher.
7. A pressurized stretcher should be developed - together with means for handling and hoisting of an unconscious crewman. The emergency pressure garment suggested in 6 above, should be considered as a potential stretcher.
8. A repair kit analogous to the tire repair kit should be developed for on-the-spot remedy of a small- and medium-size suit leaks during EVA.
9. A "clock" should be developed to inform a backpack wearer how much EVA time remains as a function of remaining oxygen supply and current use rate.

10. Hatch designs should be developed to provide for normal and forced opening from either side.
11. Design and development of a dust collector applicable to cleaning dust from space suits, equipment surfaces, etc., in external lunar environment should be initiated.
12. The dynamics of lunar landing should be studied to determine whether an abort or hovering maneuver can be automatically programmed to occur at any time the lander tilt attitude exceeds some pre-selected safe angle.
13. Techniques for navigation and obstacle avoidance on the lunar surface during poor sun elevation or azimuth conditions should be improved. This might include study of polarizing filters for attenuation of light reflected from the lunar surface.
14. Means for detecting hidden cavities or surface structure weaknesses on the lunar surface from a moving vehicle should be investigated.
15. Additional data are required to define the incidence, size, velocity, and direction of large meteroids in the vicinity of the moon.
16. For use with large, permanent orbital stations, a cherry-picker-like device should be developed for exterior repair, maintenance, and service functions. This device would obviate the need for use of backpacks and long umbilicals.
17. Tests should be initiated to establish the merits of (a) evacuating cabin atmosphere to extinguish a fire, and (b) introducing an inert gas while reducing cabin pressure to extinguish a fire.
18. It is recommended that further flammability testing be carried out in mixed gas and in pure oxygen atmospheres with materials now considered acceptable for use in space cabins.
19. Drug therapy as a means for preventing or increasing tolerance for bends symptoms should be investigated.
20. It is recommended that compression therapy techniques, such as the pressure bag, be developed for space applications to treat dysbarism symptoms.

4.4 SUGGESTED ADDITIONAL EFFORT

The Lunar Mission Safety and Rescue Study was limited in scope and depth through the changing nature of the proposed Integrated Program Plan, lack of hardware designs, and budget constraints. It is therefore important that safety analyses continue in parallel with program and hardware definition, design, and development. Some specific suggestions are:

1. A detailed study of the safety aspects of the Apollo lunar landings and surface exploration would be most helpful in preparing for the hazards of landing, navigation, dust effects, sun angle effects, surface physical conditions, including hidden crevasses and roofed holes, etc.
2. An extensive study of means for arresting angular motion of a space vehicle with attitude control failed should be initiated. This study should include the full range of vehicle sizes anticipated in advanced lunar exploration; disabled vehicles that are manned and unmanned; rescue vehicles that are manned and unmanned; rotation rates from low to high; vehicles that are chemical and nuclear powered.
3. Means for safely capturing and disposing of derelict vehicles or debris in lunar orbit should be studied and developed.
4. Additional study of the safety tradeoffs of propellant depots is recommended. This should include depot designs, basing schemes, liquid transfer, depot vs no depot, and other pertinent parameters.
5. Specific studies to identify the probable sources of human error likely to be encountered in advanced lunar exploration are recommended. The error source information should then be used in program element design refinement for safety enhancement. The effort should include as necessary, work-rest ratios, fatigue buildup reaction error studies, and such other human factors and engineering aspects as may be required to suppress the potential for human error to minimum levels.

Section 5

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