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LUNAR MISSION SAFETY AND RESCUE

PREPARED FOR
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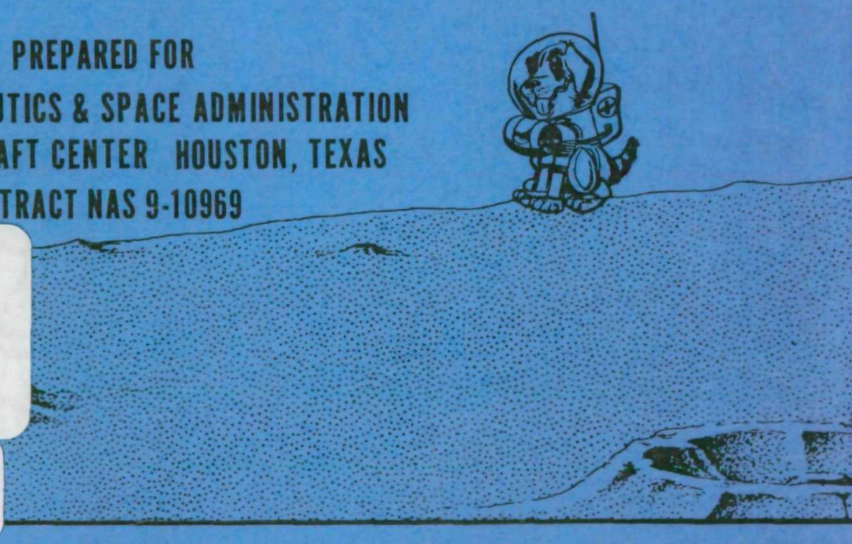

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EXECUTIVE SUMMARY

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

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Revision 1

LUNAR MISSION SAFETY AND RESCUE
EXECUTIVE SUMMARY

Prepared for
National Aeronautics and Space Administration
Manned Spacecraft Center
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Under

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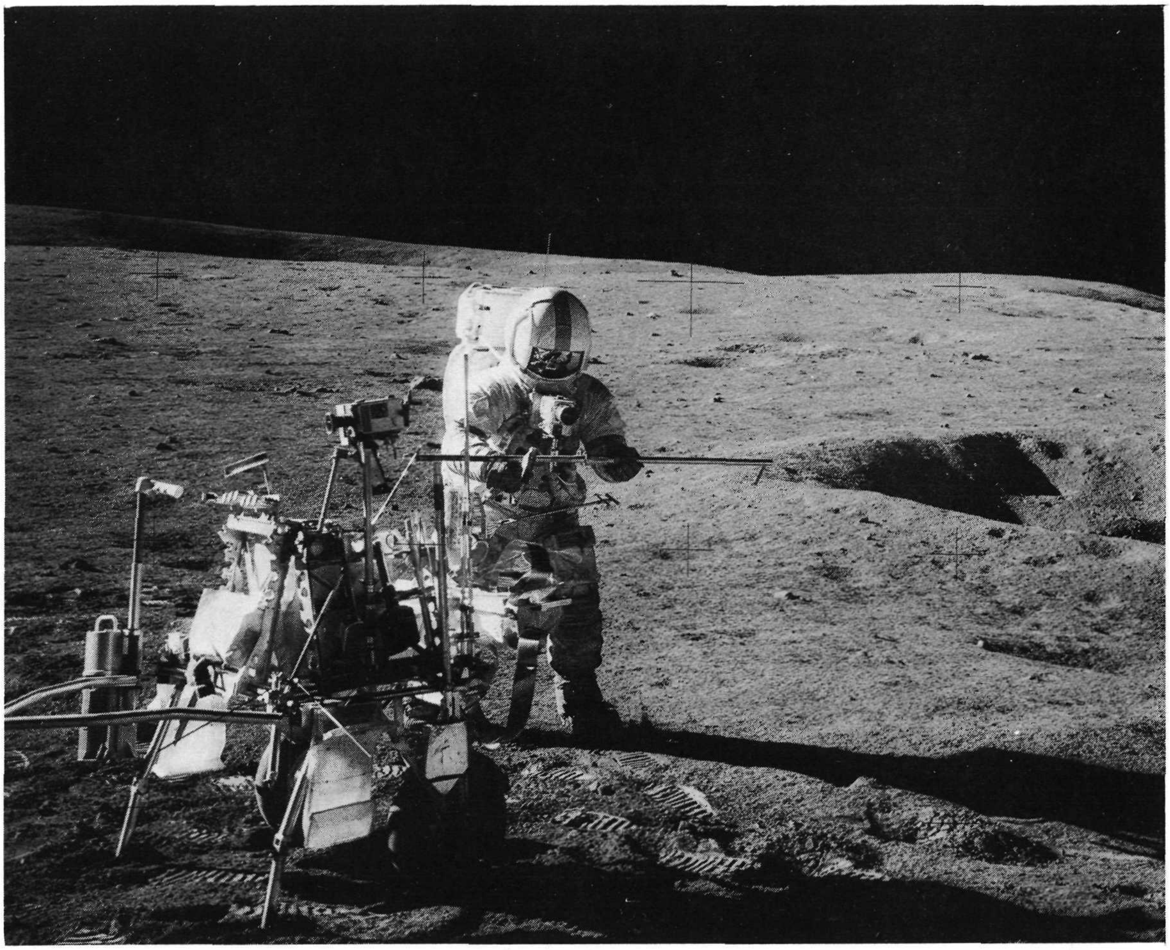

Lunar Surface EVA - Apollo 14 Mission

FOREWORD

This volume highlights the major results of the Lunar Mission Safety and Rescue Study. It was prepared for the National Aeronautics and Space Administration Manned Spacecraft Center, by Lockheed Missiles & Space Company, under Contract NAS 9-10969. The study was performed during the period 15 June 1970 to 30 June 1971, under the direction of Mr. N. R. Schulze, COR, of the Manned Spacecraft Center, and a management committee representing NASA Headquarters, Lewis Research Center, and Marshall Space Flight Center. This is one of four reports listed below which document the contract findings.

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

CONTENTS

Section 1
INTRODUCTION

Lunar exploration in the 1980's is expected to be extended well beyond the level of the Apollo program. It will require new, reusable items of exploration equipment, longer-duration missions, and more complex operations. Some of the proposed new items of equipment are illustrated in Fig. 1.

This study was performed at an early date so that the results might help guide planning and development of advanced lunar exploration concepts. Two primary goals of the study were:

1. To obtain a better understanding of the hazards and risks associated with the presence and operation of projected future lunar space flight and crew equipment, and to propose methods for eliminating or reducing such risks.
2. To develop escape and rescue requirements and concepts and a rescue plan.

During this study the hazards associated with lunar exploration were identified, preventive and remedial measures were proposed, and rescue concepts and a rescue plan developed.

Section 2
STUDY SCOPE AND OBJECTIVES

The primary objectives of the study were, 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 may require a rescue mission; and (3) developing escape, survival, and rescue mission requirements, techniques, and concepts, and an escape/rescue plan.

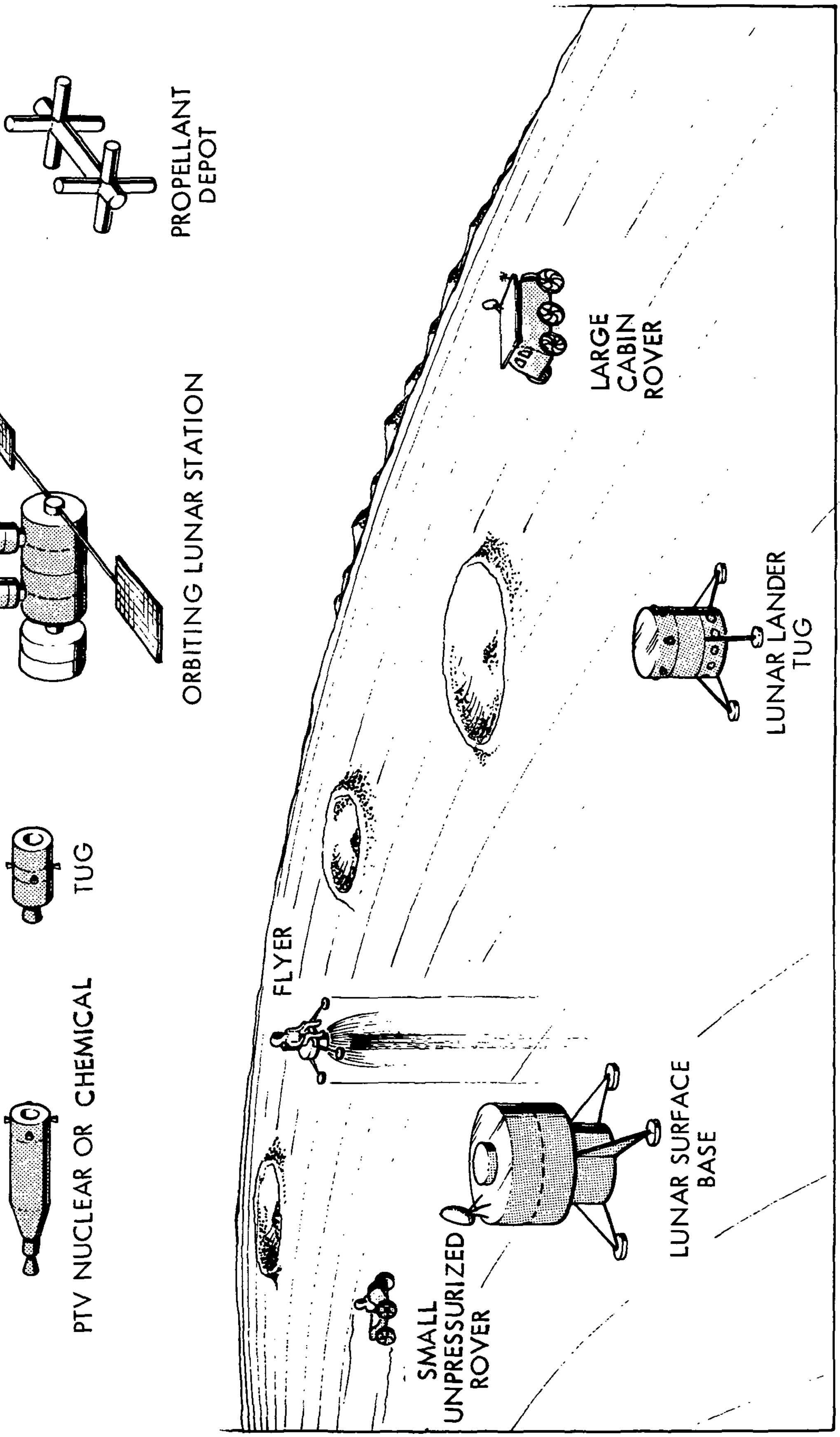

Fig. 1 Exploration Equipment Elements

This study covered the full range of hazards and escape/rescue situations that might occur in the High Budget Baseline Integrated Program Plan (IPP) under study by NASA-MSC in May 1970. This baseline was chosen because it introduces a wide range of advanced lunar transportation systems and provides the highest level of exploration activity for analysis.

The study results are expected to provide major inputs to current and planned advanced lunar mission design and operations studies. Results are intentionally kept general so that the safety guidelines and escape/rescue plan will be valid although advanced lunar exploration hardware elements and operations change.

Section 3
RELATIONSHIP TO OTHER NASA EFFORTS

This study provides major safety inputs to advanced lunar mission, design, and operation studies related to advanced lunar programs. The effort was coordinated with the Orbiting Lunar Station, Space Tug, Nuclear Shuttle, and Space Rescue studies throughout the contract.

Section 4
METHOD OF APPROACH AND PRINCIPAL ASSUMPTIONS

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

1. Hazards analyses leading to safety guidelines and recommendations, identification of need for rescue missions, and safety technology development recommendations.
2. Escape/rescue analyses leading to escape/rescue requirements and concepts, and a lunar mission escape/rescue plan.

A summary of the study approach is shown in Fig. 2. The Hazards Analysis task approach is summarized in Fig. 3, and the Escape/Rescue task approach in Fig. 4.

The study was confined to the lunar sphere of influence, and it was assumed that design and routine internal operations of major hardware elements are optimized, and that other studies have or will address the safety aspects of these elements. The results of Apollo flights, and of past and current studies, were freely used throughout the study.

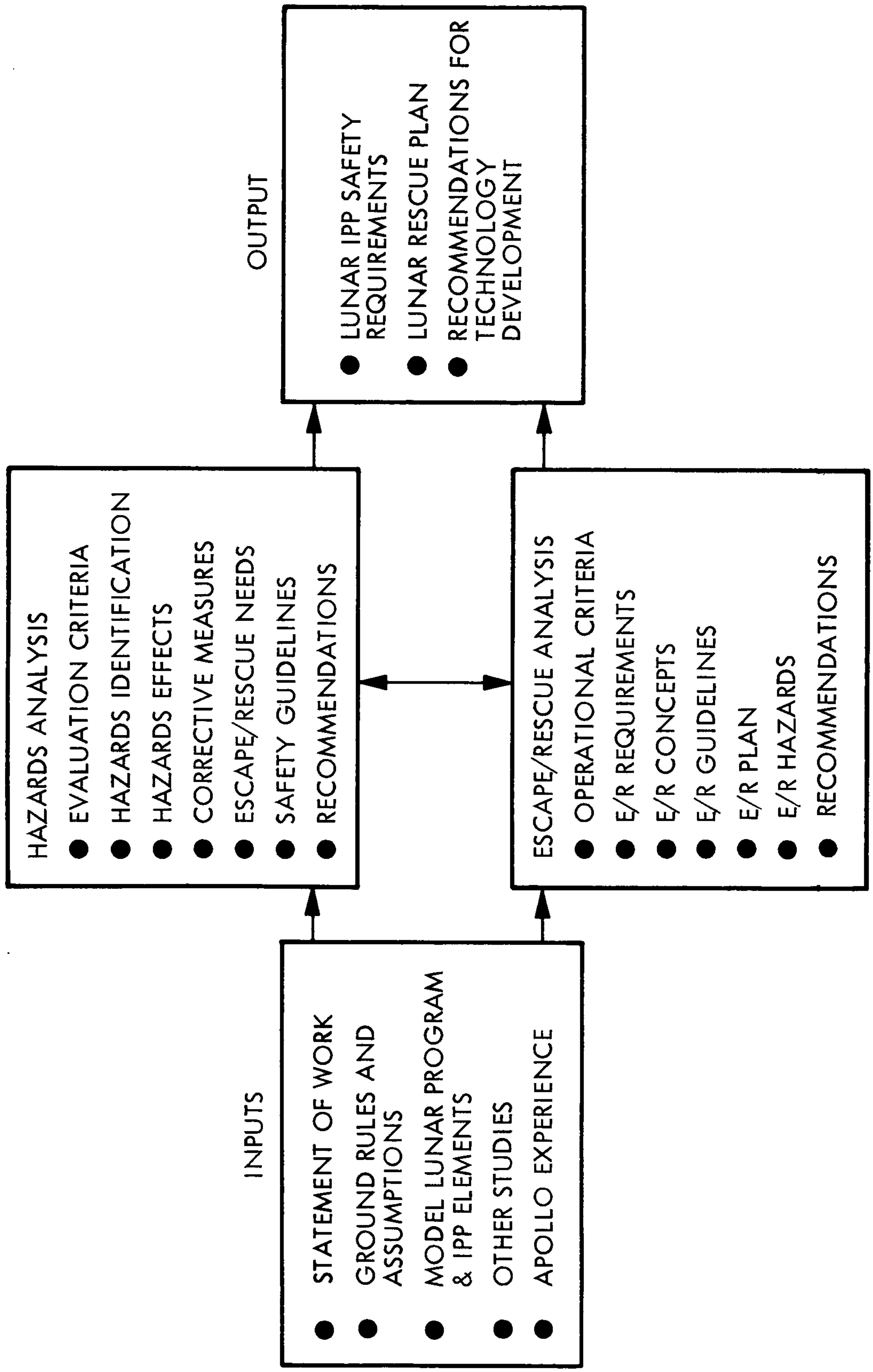

Fig. 2 Summary of Study Approach

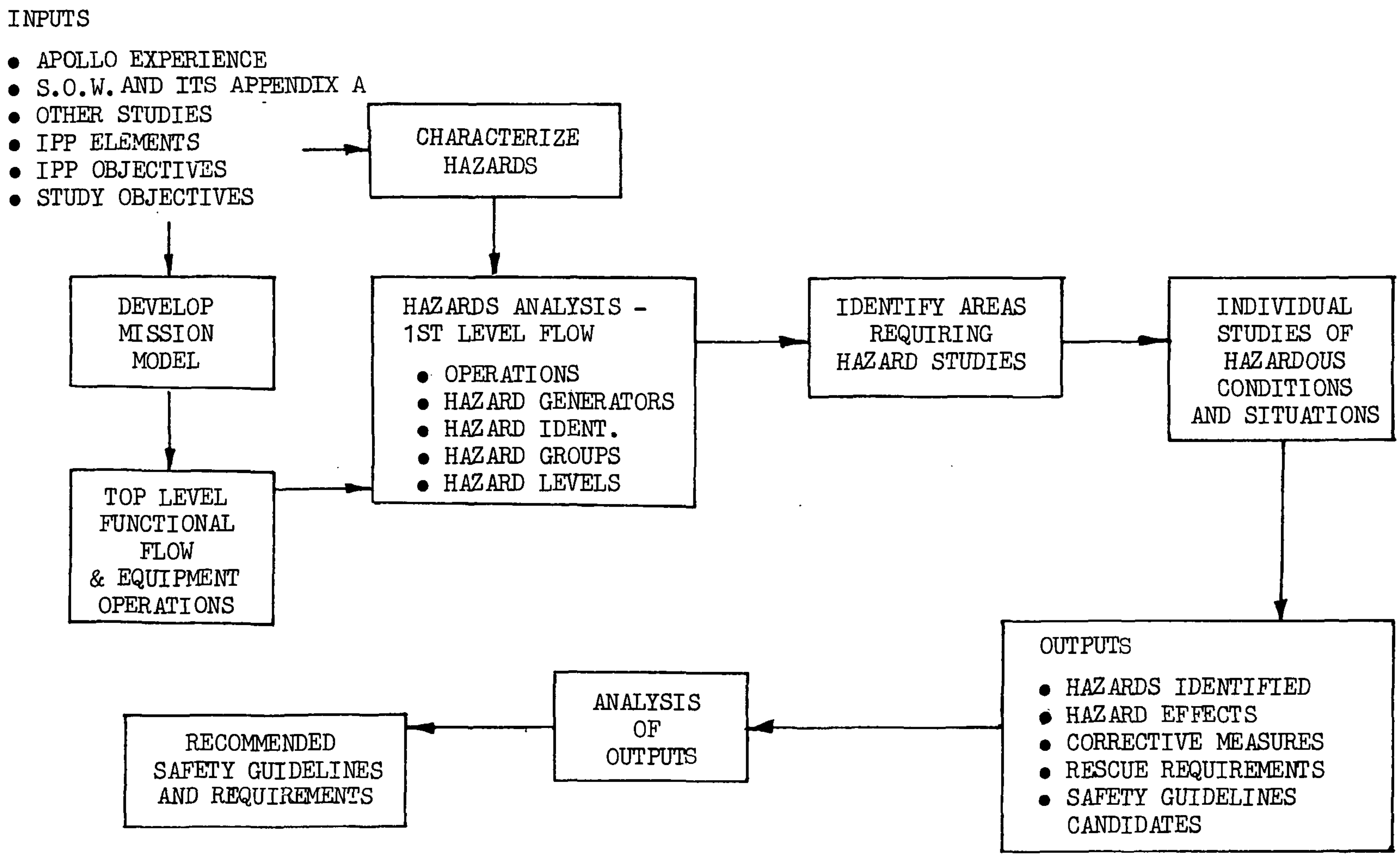

Figure 3 Hazards Analysis Approach

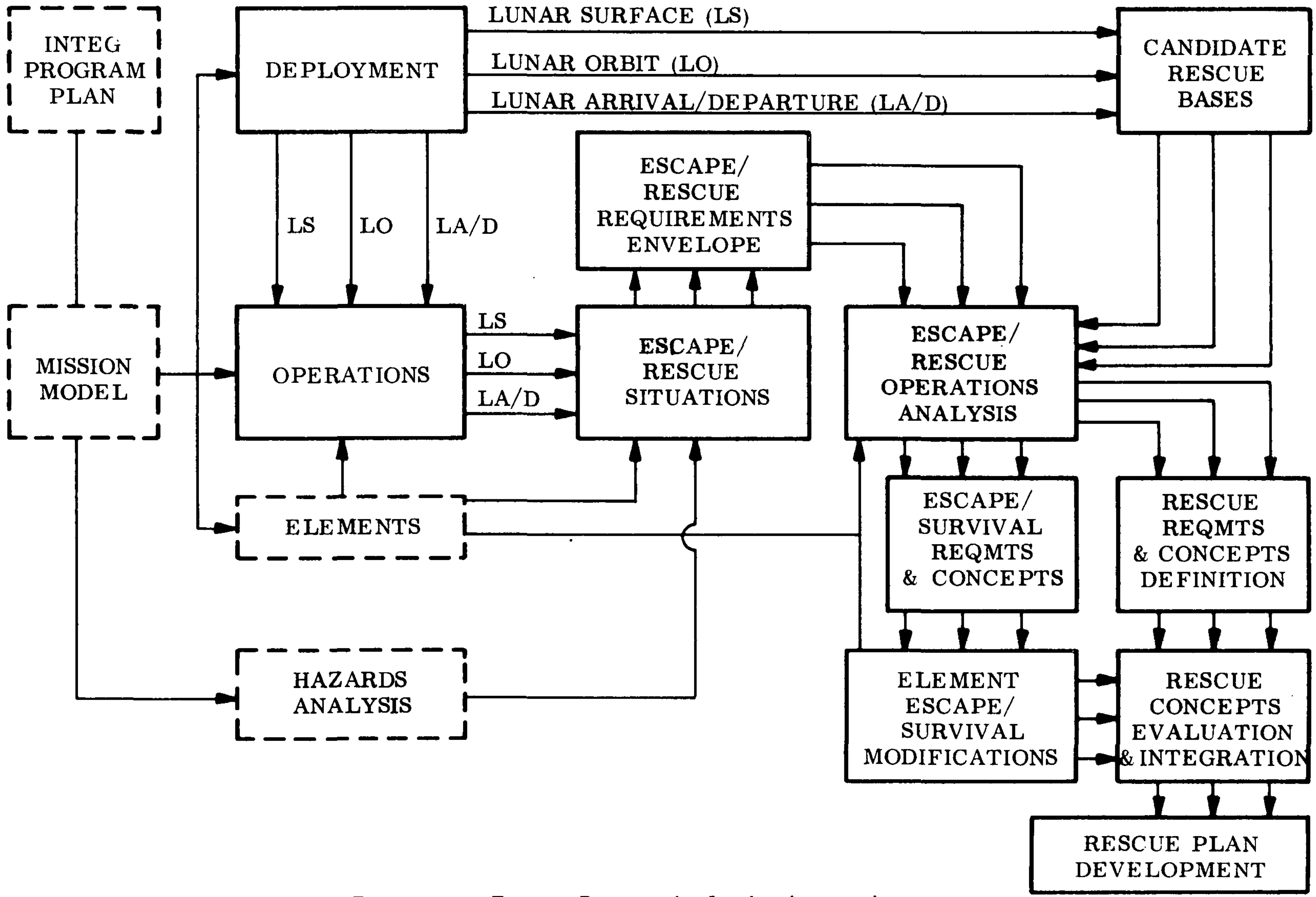

Fig. 4 Escape Rescue Analysis Approach

Section 5
BASIC DATA GENERATED AND SIGNIFICANT RESULTS

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.

ESCAPE/RESCUE PLAN

The advanced hardware elements considered for routine operations appear feasible for escape and rescue use in all stiuations 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 hardware elements in a manner that makes them available for excape/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 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 save haven. The reaction times for escape are usually much shorter than for rescue - in many cases, minutes or hours vs days.

The key program impact items involving deployment and basic capability are:

1. The tug must have the capability to return to Earth orbit from lunar orbit, and must have a minimum ΔV capability of 15,000 ft/sec.

2. A minimum of three lander 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; and one operational/escape tug on the surface.

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

4. 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.

5. 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 a tug capability with the initial manning mission to escape to Earth orbit in the event of a failure of a Prime Transport Vehicle or orbiting lunar station.

To ensure crew survival and the ability to perform a rescue operation for the various emergency situations that may occur, the study results recommend additions, modifications, and restrictions in both design and operation of the various hardware elements considered. 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:

1. Vehicles accommodating 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.

2. A simple, lightweight emergency pressure garment that can be donned in five seconds or less should be developed. This garment should provide adequate mobility. 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.

3. An uprated backpack is needed with a minimum metabolic capacity of 6,000 Btu and a battery lifetime of at least 12 hours. This provides for a 12-hour survival time for a man at rest.

4. Any compartment used for ferrying crews to and from the moon 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 ΔV capability of 1,000 ft/sec is required to attain a safe lunar orbit.

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

Rescue Response Time

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. The following initial conditions are necessary if minimum rescue response time is demanded:

1. If a rescue capability from Earth vicinity is required, a rescue vehicle based on the surface can respond in the shortest time.

2. 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.

3. Rescue tugs must be able to land on the lunar surface under all conditions of lighting and sun elevation. 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 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:

1. Return to the Earth vicinity from lunar orbit.
2. Descend to the lunar surface and return to an orbital lunar station (with no plane changes).
3. 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.
4. Ascend from the lunar surface, execute a 90-degree plane change, rendezvous, and dock with an orbiting lunar station.
5. 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 either refuel or 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 Requirements

Equipment required for escape, survival, and rescue includes:

1. Space tugs with 15,000 ft/sec ΔV capability, 14-day life support capability, landing legs and equipment, two pressurized compartments, manual control capability, and operable in a space suit.

2. An orbiting lunar station with two or more pressurized compartments and capability to support all crewmen in the lunar area for 14 days in an emergency.

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

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

5. A propellant depot in lunar orbit.

6. EVA rovers with 3-man nominal capacity, 16 nm range, and surface speed of 3 to 4 knots. The rover should be capable of carrying and supporting 4 men in an emergency.

7. Cabin rovers with 4-man capacity, and surface speed of 5 knots.

8. Rescue astronaut maneuvering units (AMU's with 2-man capacity, 90-minute life support, and 400 ft/sec ΔV capability, (rescue AMU required only if AMU's are used for normal operations).

9. Pressure suits with backpack switching capability during EVA, and RF and visual locator beacons.

10. Life support backpacks with 6,000 Btu capability, 12-hour life support capability, buddy sharing provisions for all functions, and switching capability during EVA.

11. Emergency pressure garments with 5-second don time, emergency oxygen supply attached, and adequate mobility.

12. Oxygen masks with emergency oxygen supply.

13. Portable airlocks with weight low enough to be handled by two men, and size to accommodate an incapacitated man in a pressurized stretcher and a second man in a pressure suit with backpack.

14. Pressurized stretchers.

15. First aid kits.

16. Emergency communications equipment including rocket propelled radio beacons, tracking beacons, and 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.

Escape/Rescue/Survival 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 lander 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 for some energencies is capable of landing on the lunar surface.
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 prime transport vehicles in Earth orbit/lunar orbit area, with crew compartments attached when carrying personnel or 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 astronaut maneuvering unit (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.

HAZARDS ANALYSIS RESULTS

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. The safety technology development results are presented in Section 7 as recommendations. Suggestions for additional study are presented in Section 8.

Hazards Analysis results having major program impact are summarized in the following six 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, communications, and metabolic needs of an EVA astronaut through external plug-ins on the exterior of a vehicle, station, or base (this must be accomplished without undue risk of losing oxygen 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 a 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.

Cabin and Suit Atmospheric Pressures

Pressures in cabins and space suits should be made compatible in order to avoid 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 cargo on each (or three crewmen on one, one crewman on the other, and disposable cargo 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.

Section 6

STUDY LIMITATIONS

The study was concerned with a safety analysis of operations, events, environments, and interfaces within the limitations of presently considered advanced concepts and planning. No analysis of hardware was performed, since all of the equipment items are in the study and concept stage. The results are, therefore, general and intended to influence future hardware design efforts and mission planning in the direction of incorporating increased safety. The analysis was confined to activities on the lunar surface and in lunar orbit.

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

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

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

Section 7

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 in a vacuum 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 small and medium-sized 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 meteoroids 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 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.

Section 8
SUGGESTED ADDITIONAL EFFORT

It is 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 probably 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.

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