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SAFETY AND RESCUE

STUDY CONTRACT NAS9-10969

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LUNAR MISSION SAFETY AND RESCUE MIDTERM PRESENTATION NOVEMBER 1970

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FOREWORD

This brochure presents a midterm progress summary of the "Lunar Mission Safety and Rescue" study being performed for the Manned Spacecraft Center, National Aeronautics and Space Administration, Houston, Texas, Under Contract NAS9-10969.

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SUMMARY

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STUDY OBJECTIVES

Within the limitations of the present concepts and planning of the Advanced Lunar Missions, the study will establish the essential guidelines for the enhancement of safety in advanced lunar missions.

STUDY OBJECTIVES

- ESTABLISH SAFETY GUIDELINES FOR ADVANCED LUNAR MISSIONS
- IDENTIFY RESCUE MISSION REQUIREMENTS
- ESTABLISH ESCAPE AND SURVIVABILITY REQUIREMENTS
- DEVELOP RESCUE CONCEPTS AND A RESCUE PLAN

STUDY CONSTRAINTS

This study is limited to a safety analysis of significant hazards that personnel may encounter on the lunar surface and during lunar orbital operations. From this analysis will result the determination of the necessary safety requirements to obviate these hazards, including preferential mission modes and preventive, remedial, emergency survival, escape, and rescue techniques and requirements, which need to be incorporated into the integrated program plan.

STUDY CONSTRAINTS

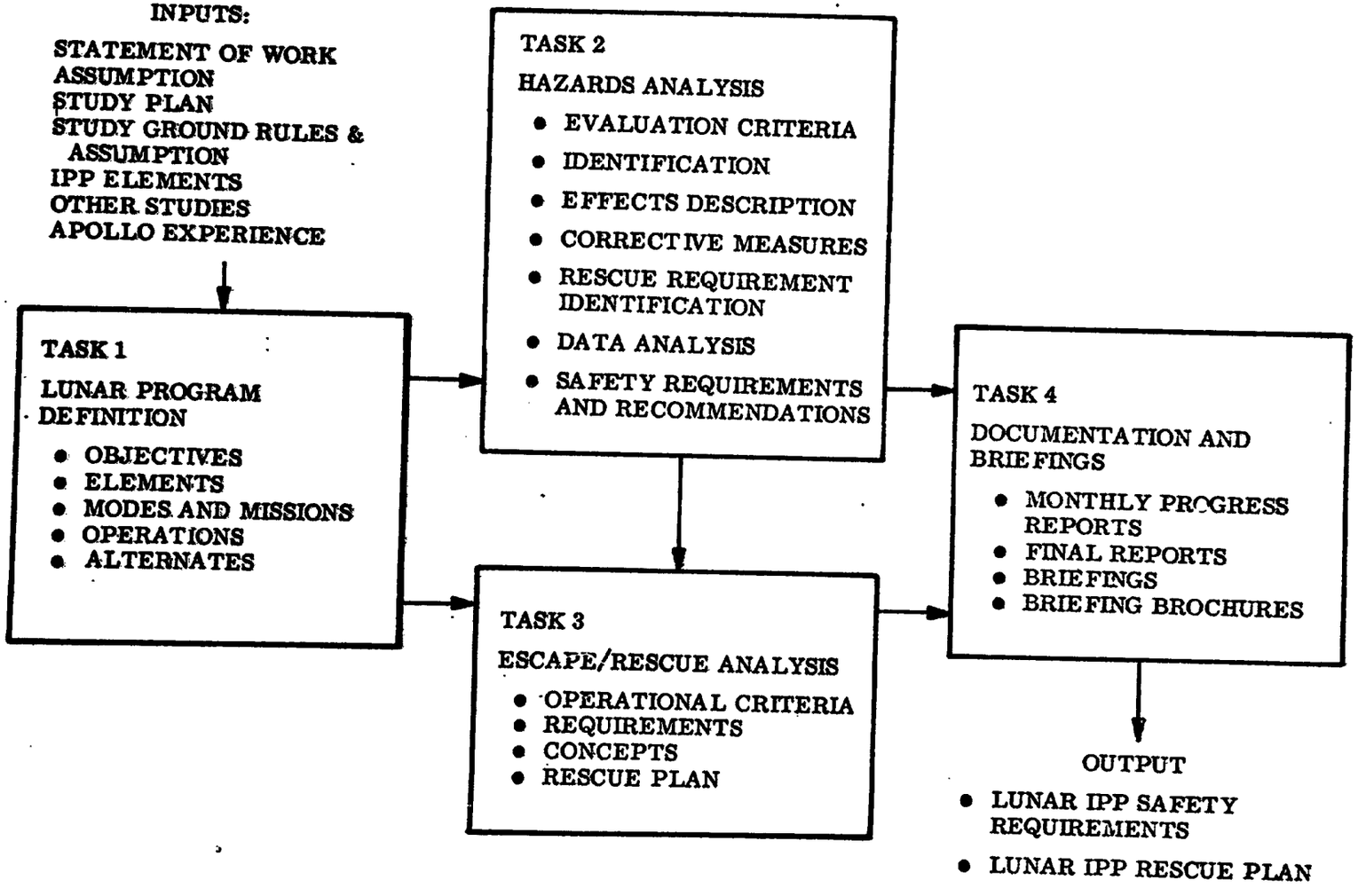
- ANALYSES CONSTRAINED TO LUNAR SPHERE OF INFLUENCE
- ANALYZE OPERATIONS AND INTERFACES OF MAJOR IPP ELEMENTS
- ASSUME DESIGN AND ROUTINE INTERNAL OPERATIONS OF MAJOR IPP ELEMENTS ARE OPTIMIZED AND NO HAZARDS ANALYSES REQUIRED
- NO CLASSICAL RELIABILITY OR PROBABILITY ANALYSES TO BE PERFORMED
- PREVIOUS STUDY EFFORTS ARE NOT TO BE DUPLICATED
- PLANNED IPP ELEMENTS ARE TO BE USED FOR RESCUE WHERE POSSIBLE
- STUDY RESULTS ARE TO BE KEPT GENERAL ENOUGH THAT THE GUIDELINES AND PLAN WILL BE VALID THOUGH IPP ELEMENTS AND OPERATIONS CHANGE

SUMMARY OF STUDY APPROACH

The study is divided into two major and two minor tasks. These are:

Task 1 (minor)	–	Definition of a representative Advanced Lunar Program exercising all reasonable elements of Advanced Lunar missions that could result in hazards to man. Lunar Integrated Program Plan models, Project Definition Documents, and studies of IPP elements are used as a basis.
Task 2 (major)	–	Hazards analyses leading to safety requirements and recommendations, rescue mission requirements, and safety technology development recommendations.
Task 3 (major)	–	Escape/rescue analysis leading to escape/rescue concepts and a lunar mission rescue plan.
Task 4 (minor	–	Documentation and briefings presenting the program and results of the study.

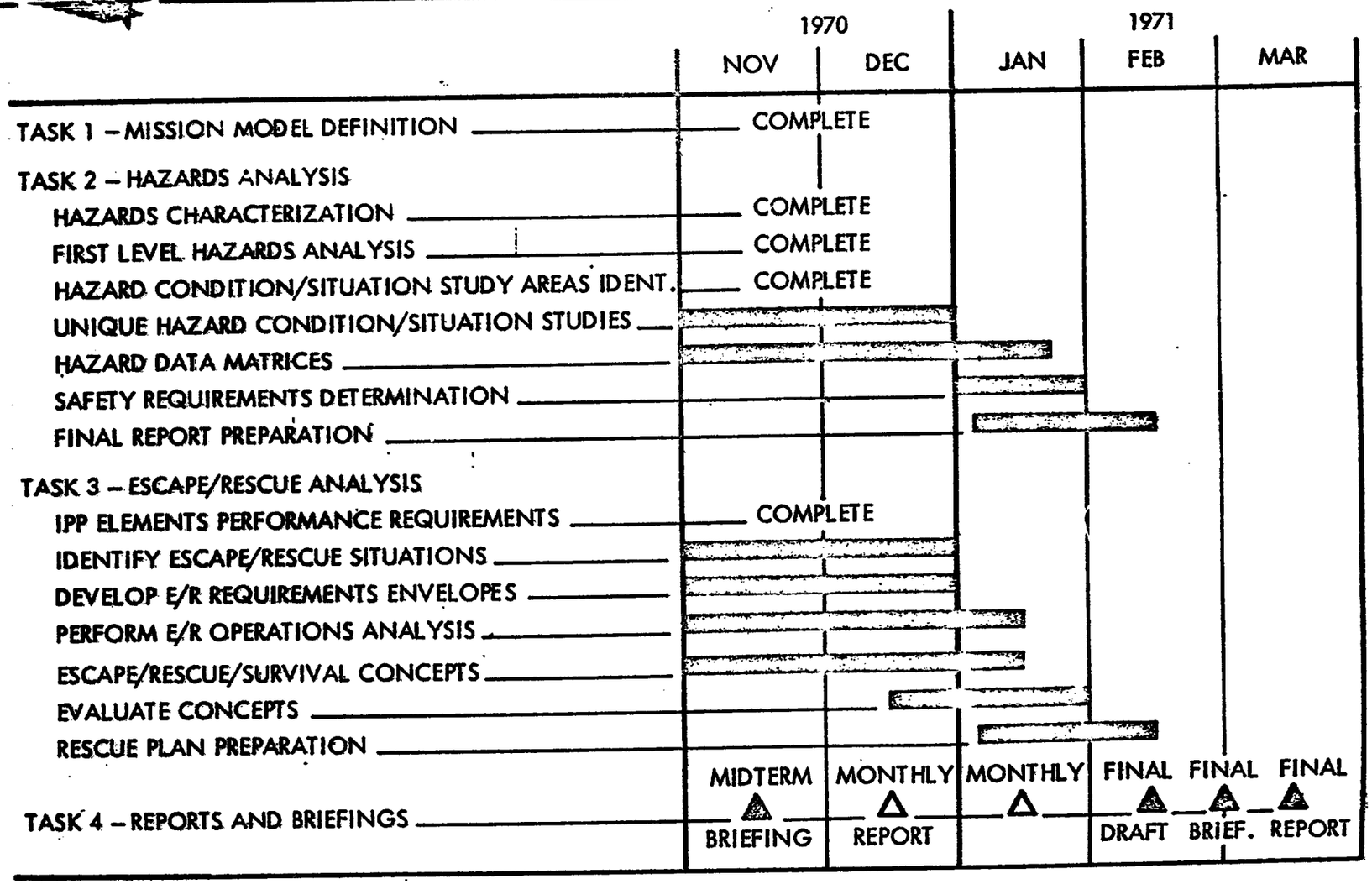
SUMMARY OF STUDY APPROACH



STUDY SCHEDULE

The study contract start date was June 15, 1970 and the scheduled completion date is March 15, 1971. Task 1 is complete except for final documentation.

STUDY SCHEDULE



MISSION MODEL

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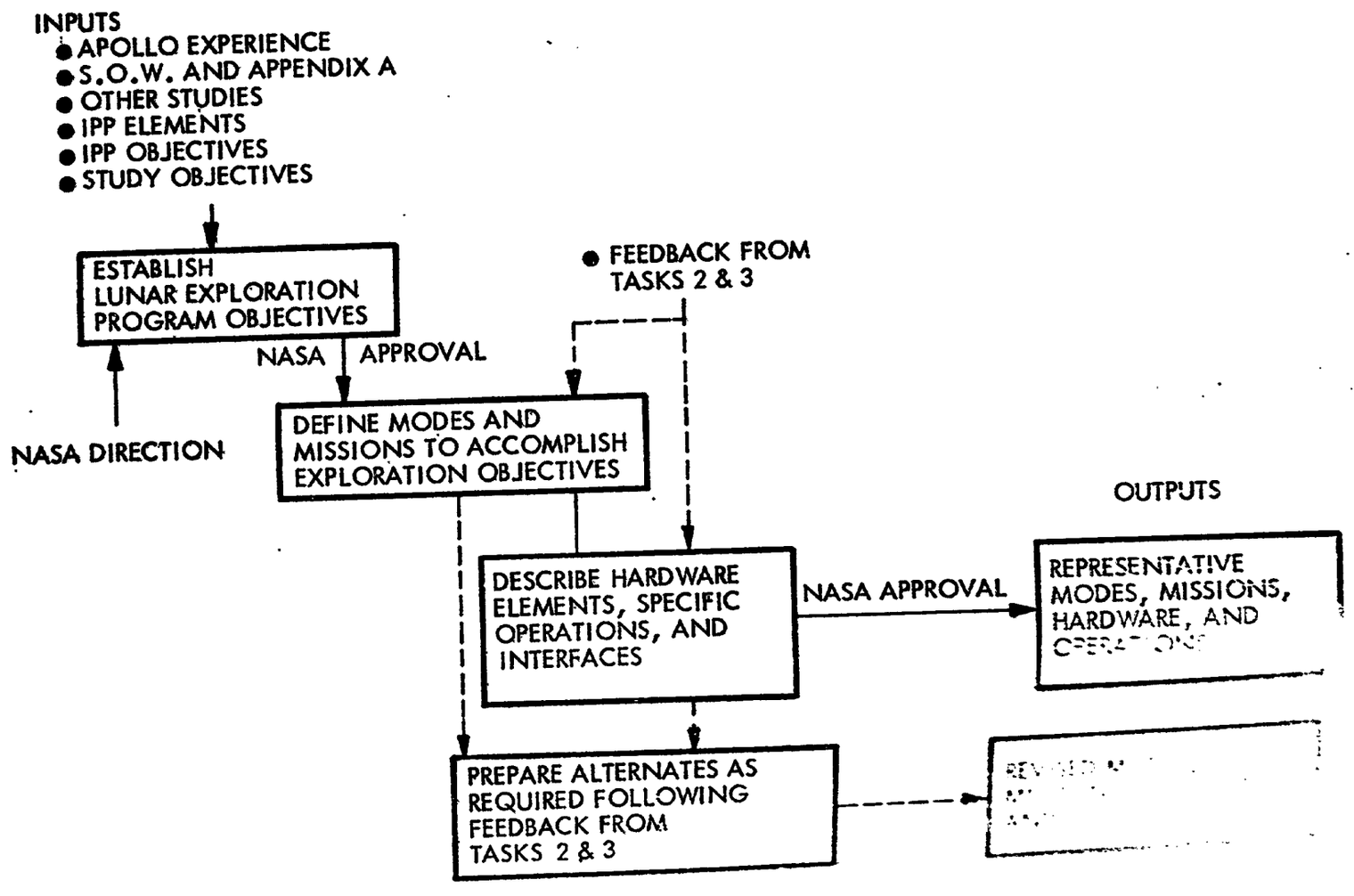
TASK 1 – MISSION MODEL DEFINITION

The mission model definition task defines a representative lunar exploration program for engineering development and scientific exploration, based on lunar integrated program plan elements and operations. This plan is used as a point of departure in Tasks 2 and 3 in the search for ways to enhance safety.

TASK-I MISSION MODEL DEFINITION



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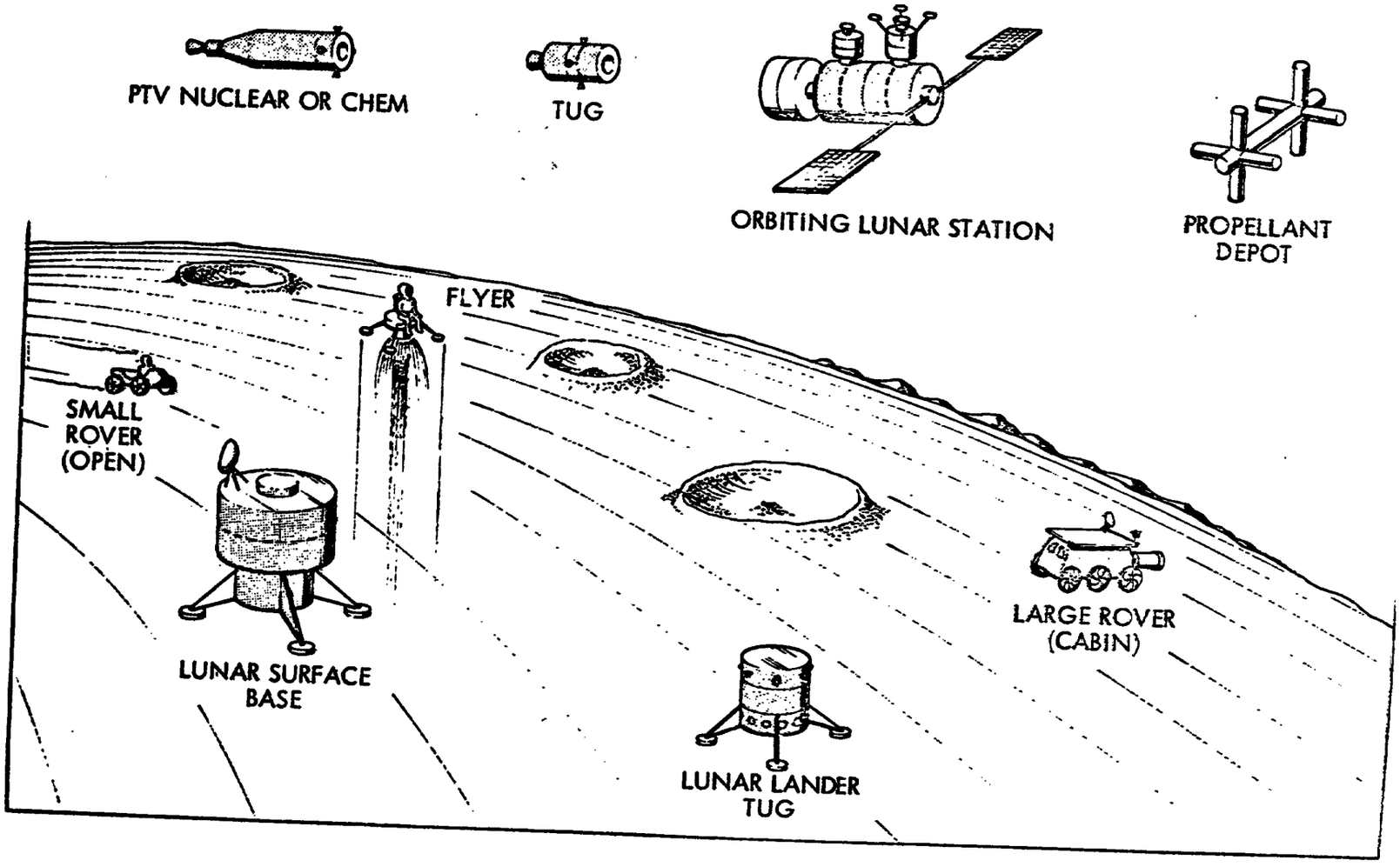
EQUIPMENT ELEMENTS AND USAGE

- 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 Satellites (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 cannisters, etc.)

EQUIPMENT ELEMENTS AND USAGE



LUNAR MISSION OPERATIONS

Lunar mission operations in orbit and on the surface are listed on the chart. Hazards associated with these operations are examined in the study.

LUNAR MISSION OPERATIONS

EARTH-MOON SHUTTLE OPERATIONS	ORBITAL OPERATIONS	SURFACE OPERATIONS
TRANSPORT PAYLOAD	RENDEZVOUS & DOCKING	SCIENCE
LUNAR ORBIT INSERTION	SCIENCE	MAINTENANCE
TRANS EARTH INJECTION	MAINTENANCE	TECHNOLOGY & ENGINEERING
RENDEZVOUS & DOCKING	TECHNOLOGY & ENGINEERING	DEPLOYMENT
STATION KEEPING	OPERATIONS BASE	ROVING
CONTINGENCY OPERATIONS	TUG REFUELING	FLYING
	EVA	WALKING
	ORBIT KEEPING & TRANSFER	RESUPPLY
	SATELLITE PLACE & SERVICE	RESCUE
	RESUPPLY	CONTINGENCY OPERATIONS
	RESCUE	
	CONTINGENCY OPERATIONS	

ALTERNATE OPERATIONS AND ELEMENTS

The basic mission model contains a set of equipment elements and mission operations. In the study these operations and elements are varied in the search for the resulting effects on safety and in recognition of the fluid state of future mission planning.

EXAMPLES OF ALTERNATE OPERATIONS AND ELEMENTS

- NUCLEAR VS CHEMICAL SHUTTLE
- SPACE TUGS VARYING IN PROPELLANT CAPACITY AND DIAMETER
- SMALL, OPEN ROVING VEHICLES VS LARGE, CABIN-TYPE ROVERS
- HIGH TRAFFIC RATE VS LOW TRAFFIC RATE
- ORBITING LUNAR STATION VS NO OLS

SOURCES OF MISSION MODEL DATA

Mission model data are derived from current NASA planning documents, current and past studies, and current project description documents.

SOURCES OF MISSION MODEL DATA

- SOURCES OF LUNAR EXPLORATION PROGRAM OBJECTIVES

  HIGH BUDGET TRAFFIC MODEL INTEGRATED PROGRAM PLAN (IPP)
  LOW BUDGET TRAFFIC MODEL IPP (ALTERNATE)
  PROJECT DESCRIPTION DOCUMENTS (PDD's)

- SOURCES OF LUNAR EXPLORATION EQUIPMENT DEFINITIONS

  PROJECT DESCRIPTION DOCUMENTS (PDD's)
  CURRENT FUNDED STUDIES
  PAST FUNDED STUDIES

HAZARDS ANALYSIS

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TASK 2 – HAZARDS ANALYSIS OBJECTIVES

The objectives of the hazards analysis task are to: determine how safety can be enhanced on the next generation of lunar exploration missions; determine the areas in which concentrated safety efforts should provide the greatest safety return; show how hazards can be effectively controlled; determine preferential mission modes; identify conditions and situations requiring rescue.

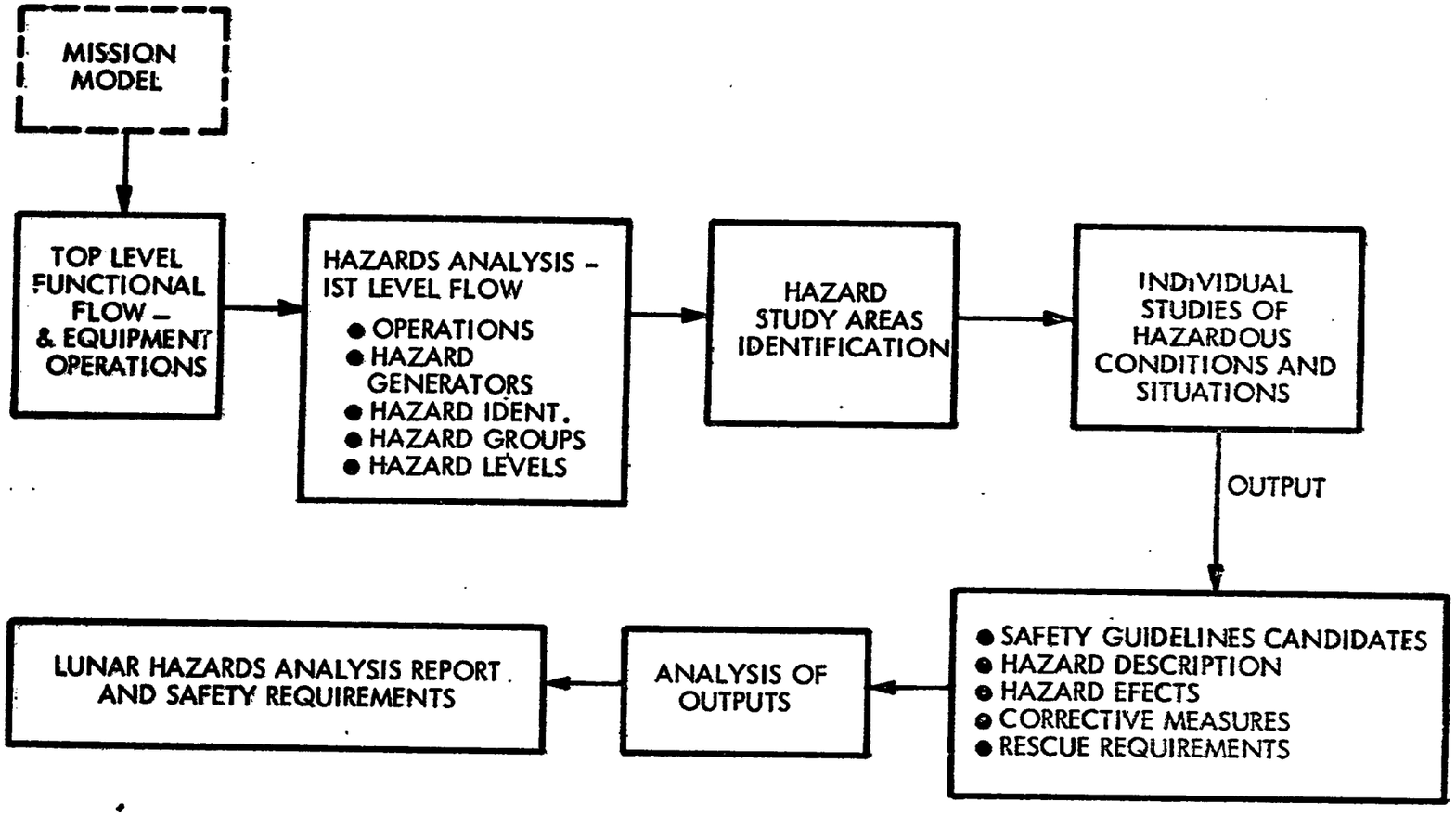
TASK 2 — HAZARDS ANALYSIS OBJECTIVES

- IDENTIFY POTENTIAL HAZARDS
  LUNAR ORBITAL AND SURFACE OPERATIONS
  CREW ACTIVITIES, FUNCTIONS AND ENVIRONMENTS
- DETERMINE HAZARDS EFFECTS
  CREW SAFETY IMPACT – DESCRIPTIVE
  CATEGORIZE HAZARD LEVELS
- CORRECTIVE MEASURES DEVELOPMENT
  HAZARDS DETECTION
  PREVENTIVE AND REMEDIAL CONCEPTS
- IDENTIFY RESCUE REQUIREMENTS
  SITUATIONS REQUIRING RESCUE
  SURVIVAL TIME LINE APPRAISAL
- ESTABLISH GUIDELINES FOR SAFETY ENHANCEMENT
  PROGRAMS HAZARDS CHARACTERIZATION
  HAZARDS CONTROL CONSIDERATIONS
  SAFETY TECHNOLOGY DEVELOPMENT RECOMMENDATIONS

HAZARDS ANALYSIS METHODOLOGY

Working from the task objectives and the defined mission model, the top level functions and operations of lunar exploration elements are described. This is expanded in a first level flow chart to identify potentially hazardous conditions and situations requiring study. A list of hazardous conditions and situations selected for further study is compiled, and the studies carried out. From the individual studies, rescue requirements are identified and candidates for safety guidelines proposed. When the individual studies are complete, a study of the guidelines candidates is made to assess compatibility and feasibility and firm up recommendations to be included in the final report.

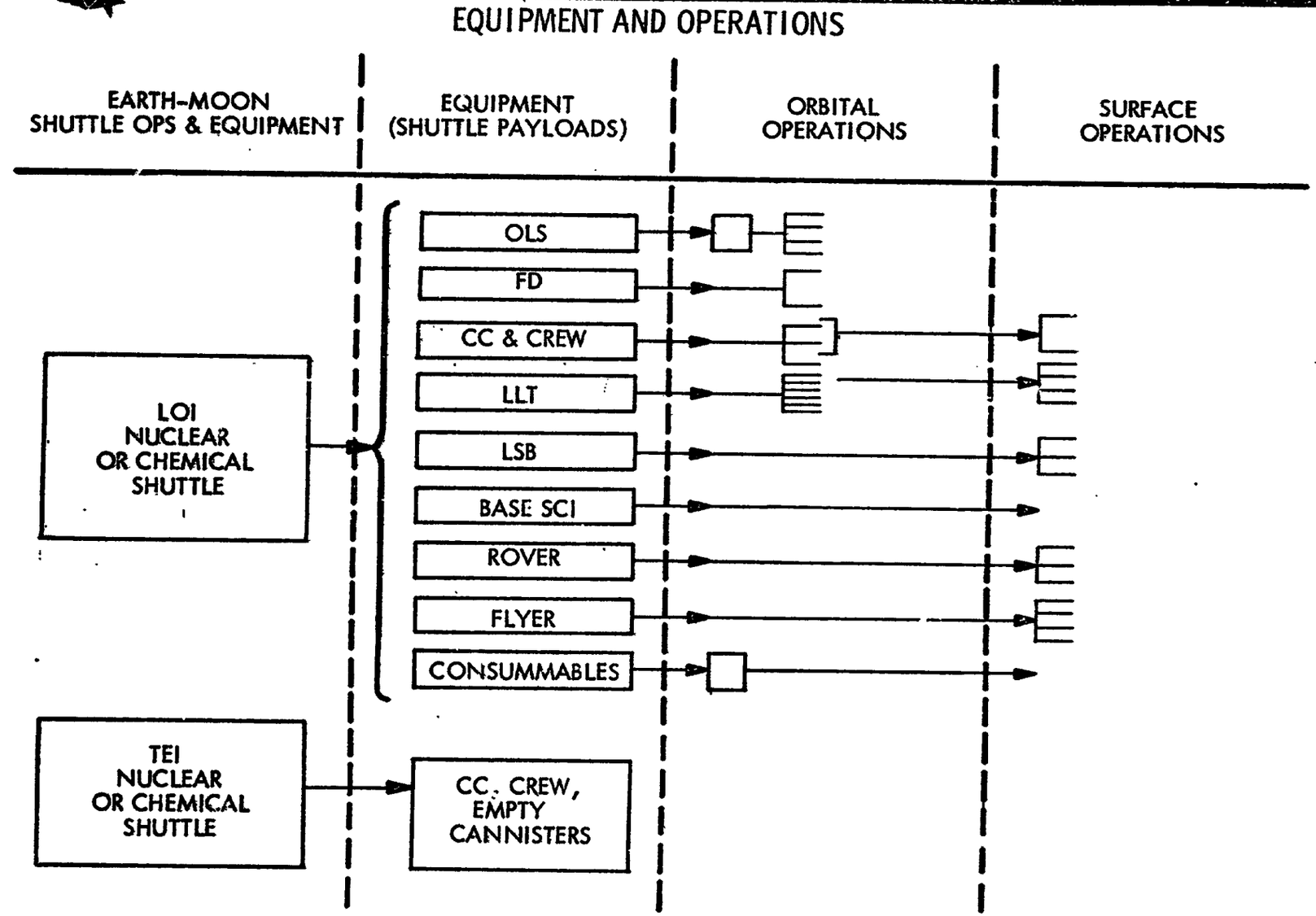
HAZARD ANALYSIS METHODOLOGY



TOP LEVEL FUNCTIONAL FLOW

A top level functional flow chart is prepared to display and link all major items of lunar exploration equipment and all major operations that take place with that equipment.

TOP LEVEL FUNCTIONAL FLOW



LUNAR MISSION PROGRAM MODEL – FIRST LEVEL HAZARDS ASSESSMENT (EXAMPLE)

Each series of major operations in the Lunar Mission Program model is displayed in flow diagram form as illustrated on the chart. A first level hazards assessment is then made of each event to identify hazard generators, the hazards that may result, potential effects of those hazards, and categorization by hazard groups and hazard level range.

The hazardous conditions or situations exposed here are compiled and earmarked for further analysis in individual Hazard Area Studies.

LUNAR MISSION PROGRAM MODEL
- FIRST LEVEL HAZARDS ASSESSMENT (EXAMPLE)

LOGISTIC OPERATION – 1.3: PRIME TRANSPORT VEHICLE DELIVERY OF REPLACEMENT CREW AND SUPPLIES (PTV/MPL)

(Subsequent Manned Missions)

PTV: Chemical or Nuclear Shuttle Vehicles
MPL: Any Payload Containing Crew Personnel

	1.3.2	1.3.3	1.3.4	1.3.5	1.3.6	1.3.7	1.3.8
Event	PTV/MPL LOI for Lunar Polar Orbit	Orbit Coast Tracking and Target Position Phasing	Separate MPL from PTV	Acquire and Secure Return MPL to PTV	Reorient PTV and Acquire OLS – PTV Separation Distance	PTV Ignition for 3-Burn LOD	PTV/MPL Trans-Earth Injection
Hazards Generator	Unable to Accomplish Successful LOI	Unable to Rendezvous to Target Position	Unable to Separate MPL from PTV – or Partial Separation	Unable to Dock and Secure Return MPL	Unable to Reorient and Reposition PTV/MPL (Ref.: 1.26)	Unable to Successfully Execute LOD PTV W/MPL	Unable to Successfully Execute TEI PTV W/MPL
Operational Hazards	Potential Loss of PTV/MPL	Excessive Transfer Distance to OLS	Requires OLS-Tug Assistance with Crew EVA – Hazardous activity	OLS Over-staff Condition – and Return Cargo Pile-Up	Uncooperative Vehicle in Lunar Orbit	Disabled PTV W/MPL in Non-Circular Lunar Orbit	Disabled PTV W/MPL in Selenocentric or Geocentric Orbit
Potential Effects	Escape/Rescue Req'd Potential loss of crew via tumbling vehicle or unreachable orbit	Potential Mission Delay	MPL – Temporary Entrapment. – Transfer of Crew May be Required	Potential Discontinuity in Critical Mission Logistics Availability	Potential Collision and/or Radiation Exposure to Crew in OLS	Rescue Req'd Potential Collision and/or Radiation Exposure Threat to Crew in OLS	Rescue Required PTV on Potential Lunar/Earth Impact Trajectory or in Very Long Period Orbit
Applicable Hazards Groups	7, 12	8, 7, 12	12, 7, 6	12, 7	8, 4, 10, 12, 11	12, 4, 7, 10, 1, 6	12, 7
Hazard Level Range	A to C	C to D	B to C	D	A to C	A to C	A to C

Hazard Groups:

1. Explosion/Implosion
2. Fire
3. Pressure Excursions
4. Collision
5. Contamination
6. Injury/Illness
7. Personnel Isolation
8. Motion/Accelerations
9. Human Errors
10. Hostile Environment
11. Radiological Hazards
12. System or Subsystem Malfunction

Hazard Levels:

A. Safety Catastrophic
B. Safety Critical
C. Safety Marginal
D. Safety Negligible

FIRST LEVEL HAZARDS ASSESSMENT – LOGISTICS OPERATION 1.3.2

The previous page presents an example of the flow diagram approach to a first level hazards assessment. One operational step in the example sequence, Logistic Operation 1.3.2, is reproduced here and will be used to illustrate the process used in analyzing a specific hazardous situation or condition.

FIRST LEVEL HAZARDS ASSESSMENT
— LOGISTICS OPERATION — 1.3.2

Prime Transport Vehicle Delivery of Replacement Crew and Supplies

EVENT	PTV/MANNED PAYLOAD (MPL) LOI FOR LUNAR POLAR ORBIT
HAZARD GENERATOR	UNABLE TO ACCOMPLISH SUCCESSFUL LOI
OPERATIONAL HAZARD	POTENTIAL LOSS OF PTV/MPL
POTENTIAL EFFECTS	RESCUE REQ'D LOSS OF CREW IN AN UNREACHABLE ORBIT
APPLICABLE HAZARDS GROUPS	12 7 8
HAZARD LEVEL RANGE	A TO C

MAJOR HAZARDOUS CONDITIONS/SITUATIONS – AREAS IDENTIFIED FOR INDIVIDUAL STUDIES

Approximately seventy individual areas for study of hazardous conditions or situations have been identified. Each study area may contain several variables such as manned vs unmanned system, chemical vs nuclear power.

MAJOR HAZARDOUS CONDITIONS/SITUATIONS AREAS IDENTIFIED FOR INDIVIDUAL STUDIES

1.0 PRIME TRANSPORT VEHICLE (PTV) IN UNCONTROLLED TRAJECTORY

STUDY AREA 1.1 PTV FAILS TO ACHIEVE LUNAR ORBIT INSERTION (LOI)

MANNED OR UNMANNED CHEMICAL SYSTEM
INITIAL MANNING OF OLS, OR SUBSEQUENT OPERATIONS

1.2 PTV FAILS TO ACHIEVE LOI

MANNED OR UNMANNED NUCLEAR SYSTEM
INITIAL MANNING OF OLS, OR SUBSEQUENT OPERATIONS

1.3 PTV FAILS TO ACHIEVE TRANS EARTH INJECTION (TEI)

MANNED OR UNMANNED CHEMICAL SYSTEM
INITIAL MANNING OF OLS, OR SUBSEQUENT OPERATIONS

1.4 PTV FAILS TO ACHIEVE TEI

MANNED OR UNMANNED NUCLEAR SYSTEM
INITIAL MANNING OF OLS, OR SUBSEQUENT OPERATIONS

2.0 PTV UNABLE TO RENDEZVOUS WITH ORBITING LUNAR STATION (OLS)

2.1 PTV MANNED OR UNMANNED, CHEMICAL OR NUCLEAR

OLS MANNED OR UNMANNED

29.0 SPECIAL PROBLEMS

29.1 LIGHTING – NATURAL AND ARTIFICIAL

29.2 COMMUNICATIONS

29.3 ----

(APPROX. 70 STUDY AREAS IDENTIFIED)

HAZARD AREA STUDY FORMAT

The individual studies of hazardous operations and conditions are performed and documented using the format shown on the chart. The space devoted to documenting each study, and the means for showing tradeoffs and corrective measures concepts is varied to suit the need.

HAZARD AREA STUDY FORMAT

- STUDY TITLE
- INTRODUCTION
- ASSUMPTIONS
- IDENTIFICATION OF THE MAJOR HAZARDS
- ANALYSIS OF THE IDENTIFIED HAZARDS
    - DESCRIPTION OF THE HAZARD
    - EFFECTS OF THE HAZARD
    - DESCRIPTION OF ALTERNATE CORRECTIVE MEASURES
    - ESCAPE/RESCUE REQUIREMENTS
- SUMMARY OF SAFETY GUIDELINES CANDIDATES
- DATA SOURCE REFERENCES

THE SITUATION TO BE ANALYZED – EXAMPLE 1, STUDY AREA 1-1
(PTV fails to achieve Lunar orbit insertion)

The first step in a Hazard Area Study is a statement of the assumptions and the basic situation to be analyzed. The chart summarizes these items for the example chosen.

THE SITUATION TO BE ANALYSED
— EXAMPLE 1, STUDY AREA 1.1

1. ORBITING LUNAR STATION (OLS) IS MANNED AND ACTIVE

2. CHEMICALLY POWERED PRIME TRANSPORT VEHICLE (PTV) IS APPROACHING THE MOON WITH A REPLACEMENT CREW PLUS CARGO

3. THE CREW IS IN A CREW COMPARTMENT WITH NO PROPULSION CAPABILITY

4. PTV IS IN-PLANE WITH THE OLS AND AT SUPER ORBITAL VELOCITY

5. THE PTV FAILS TO ACHIEVE LUNAR ORBIT INSERTION

THE HAZARD GENERATOR AND HAZARDS – EXAMPLE 1, STUDY AREA 1.1

The second step in a Hazard Area Study is the identification of the hazard generator, possible sources of the hazard generator, and the major hazards that might result. The Hazard Groups and range of Hazard Levels are also identified.

THE HAZARD GENERATOR AND HAZARDS
— EXAMPLE 1, STUDY AREA 1.1

HAZARD GENERATOR

1. THE PRIME TRANSPORT VEHICLE FAILS TO ACHIVE LUNAR ORBIT DUE TO ONE OF THE FOLLOWING CAUSES:
   - A. GUIDANCE FAILURE
   - B. ATTITUDE CONTROL FAILURE
   - C. PROPULSION FAILURE

HAZARDS GENERATED

1. THE POTENTIAL HAZARDOUS CONDITIONS ARE:
   - A. PERSONNEL ON AN UNCONTROLLED ESCAPE TRAJECTORY
   - B. PTV TUMBLING

HAZARD GROUPS ARE: PERSONNEL ISOLATION, MOTION/ACCELERATIONS, AND SYSTEM/SUBSYSTEM FAILURE

HAZARD LEVEL RANGE IS: SAFETY CATASTROPHIC TO SAFETY MARGINAL

CORRECTIVE MEASURES – EXAMPLE 1, STUDY AREA 1.1

During analyses of the identified hazards, trade studies are made of alternate corrective measures to assess relative safety, relative cost, and relative impact on the planned normal activities on and about the moon.

The corrective measures of interest in this example are presented in subsequent charts entitled Candidate Safety Guidelines.

CORRECTIVE MEASURES — EXAMPLE 1, AREA 1.1

PREVENTIVE MEASURES

PREVENTIVE MEASURES ARE FUNCTIONS OF PTV DESIGN, BACK-UP SUBSYSTEMS PROVIDED, AND CAPABILITY PROVIDED THE CREW COMPARTMENT TO SEPARATE AND BE SELF-SUSTAINING WITH PROPULSION, ATTITUDE CONTROL, COMMUNICATION, LIFE SUPPORT, ETC., TO ACHIEVE ORBIT OR AWAIT RESCUE

REMEDIAL MEASURES

REMEDIAL MEASURES INCLUDE PROVISION OF THE CAPABILITY TO ESCAPE, SURVIVE, AND ACHIEVE ORBIT INDEPENDENTLY OR BE RESCUED, AND THE PROVISION OF A RESCUE VEHICLE

ESCAPE/RESCUE REQUIREMENTS – EXAMPLE 1, STUDY AREA 1.1

The possible need for escape or rescue is identified for each study area. Escape/Rescue requirements are examined under the Escape/Rescue Analysis task to determine energy requirements, operations requirements, practicality of rescue for the situation described, and rescue concepts. This information is analyzed together with the results of the Corrective Measures study to arrive at alternate Candidate Safety Guidelines.

ESCAPE/RESCUE REQUIREMENTS — EXAMPLE 1, STUDY AREA 1.1

ESCAPE/RESCUE REQUIREMENTS ARE:

1. A CREW COMPARTMENT (CC) WITH THE CAPABILITY TO SEPARATE FROM THE PTV, STABILIZE, COMMUNICATE, AND AWAIT RESCUE

2. A RESCUE VEHICLE WITH A ΔV CAPABILITY OF 14,000 FT/SEC STANDING BY AT THE OLS

ALTERNATE

A. A CC WITH THE CAPABILITY OF ITEM 1 ABOVE, PLUS 1000 FT/SEC ΔV CAPABILITY TO ACHIEVE AN ELLIPTICAL ORBIT, AND A RESCUE VEHICLE WITH A ΔV CAPABILITY OF 4,400 FT/SEC STANDING BY AT THE OLS

OR B. A CC WITH THE CAPABILITY OF ITEM 1 ABOVE, PLUS 3000 FT/SEC ΔV CAPABILITY IN ORDER TO PROCEED TO THE OLS WITHOUT PHYSICAL RESCUE ASSISTANCE.

CANDIDATE SAFETY GUIDELINES

At the conclusion of each hazard area study, candidate safety guidelines are written based on the condition or situation analyzed. It is recognized that demands from other situations, and practical considerations such as impact on program cost and schedule, may preclude a proposed guideline. For this reason, alternate guidelines are shown and these are considered in the analyses performed following completion of the hazard areas study writeups.

This chart, and the two following, give samples of candidate safety guidelines and alternates for the situation where a chemically powered manned prime transport vehicle fails to achieve lunar orbit insertion. The orbiting lunar station is assumed to be manned.

The first example requires a modest ΔV capability on board the crew compartment to place it in an elliptical orbit, plus a rescue vehicle with a relatively modest ΔV capability standing by at the OLS.

The weight for propulsion system plus propellant to provide a ΔV of 1000 ft/sec to a 10,000 lb crew compartment and 3,300 lb instrumentation unit is between 1500 and 2000 lb, depending on propellants assumed.

CANDIDATE SAFETY GUIDELINES (EXAMPLE)

A. EACH CREW COMPARTMENT MUST HAVE THE CAPABILITY TO SEPARATE FROM A DISABLED PTV, PROVIDE A ΔV OF 1,000 FT/SEC, AND MAINTAIN ATTITUDE, COMMUNICATIONS, AND LIFE SUPPORT WHILE AWAITING RESCUE.

B. DURING EACH OPERATIONAL CREW ARRIVAL AND DEPARTURE AT THE MOON A RESCUE VEHICLE, MANNED AND READY, AND WITH A ΔV CAPABILITY OF AT LEAST 4,400 FT/SEC, MUST BE STANDING BY AT THE ORBITING LUNAR STATION.

C. DURING EACH CREW ARRIVAL OR DEPARTURE AT THE MOON, OPERATIONS IN ORBIT AND ON THE SURFACE WILL BE RESTRICTED TO THOSE WITH LOW RISK OF GENERATING A RESCUE REQUIREMENT.

1ST ALTERNATE CANDIDATE SAFETY GUIDELINES (EXAMPLES)

This alternate places a minimum requirement on the crew compartment but demands fast reaction and high ΔV capability in the rescue vehicle to intercept the disabled crew on an escape trajectory. The rescue vehicle is expected to have this capability through meeting orbit-to-surface rescue requirements. The risk associated with sending a rescue crew to escape velocity to aid a crew already on an escape trajectory must be considered against the weight penalty of the basic candidate guideline.

1st ALTERNATE CANDIDATE SAFETY GUIDELINES (EXAMPLE)

LOCKHEED

A. EACH CREW COMPARTMENT MUST HAVE THE CAPABILITY TO SEPARATE FROM A DISABLED PTV, MOVE A SAFE DISTANCE AWAY, AND PROVIDE COARSE ATTITUDE CONTROL, COMMUNICATIONS, AND LIFE SUPPORT WHILE AWAITING RESCUE.

B. DURING EACH OPERATIONAL CREW ARRIVAL AND DEPARTURE AT THE MOON A RESCUE VEHICLE, MANNED AND READY, MUST BE ON STANDBY AT THE OLS TO INTERCEPT ANY PTV THAT FAILS TO ACHIEVE LOI OR LOD. THIS RESCUE VEHICLE MUST HAVE A ΔV CAPABILITY OF 14,000 FT/SEC.

C. DURING EACH CREW ARRIVAL OR DEPARTURE AT THE MOON, OPERATIONS IN ORBIT AND ON THE SURFACE WILL BE RESTRICTED TO THOSE WITH LOW RISK OF GENERATING A RESCUE REQUIREMENT.

2ND ALTERNATE CANDIDATE SAFETY GUIDELINES (EXAMPLE)

This alternate circumvents the need for rescue by providing capability for the crew compartment to proceed to the orbiting lunar station without physical assistance. Assuming that propulsion is added to provide a ΔV of 3,000 ft/sec to a 10,000 lb crew compartment and 3,300 lb instrumentation unit, the propulsion weight penalty would be between 4,500 and 6,000 lb depending on propellants assumed.

2nd ALTERNATF CANDIDATE SAFETY GUIDELINES (EXAMPLE)

LOCKHEED

A. EACH CREW COMPARTMENT MUST HAVE THE CAPABILITY TO SEPARATE FROM A DISABLED PTV AND PROVIDE ALL NECESSARY LIFE SUPPORT FUNCTIONS WHILE CONTINUING ON TO RENDEZVOUS AND DOCK WITH THE OLS. THIS REQUIRES A ΔV CAPABILITY OF 3,000 FT/SEC.

HAZARDS DATA MATRIX STRUCTURE

The hazards data matrices presented in the matrix structure chart are in reality summary tables arranged to present the available data in a useful format. The logic utilized in each format is structured to develop guideline information regarding the impact of potential hazardous conditions and situations involving man, machines, and environment upon a planned program.

1. HAZARDS DATA MATRIX – I
   - TABULATION OF HAZARDS DATA BY PROGRAM ELEMENT FOR SEQUENTIAL MISSION EVENTS AND ACTIVITIES

2. HAZARDS DATA MATRIX – II
   - TABULATION OF HAZARDS DATA ABSTRACTED FROM MATRIX – I AND ARRANGED BY:
     - HAZARDS UNIQUE TO PROGRAM ELEMENTS
     - HAZARDS UNIQUE TO MISSION EVENTS
     - HAZARDS UNIQUE TO MISSION ACTIVITIES

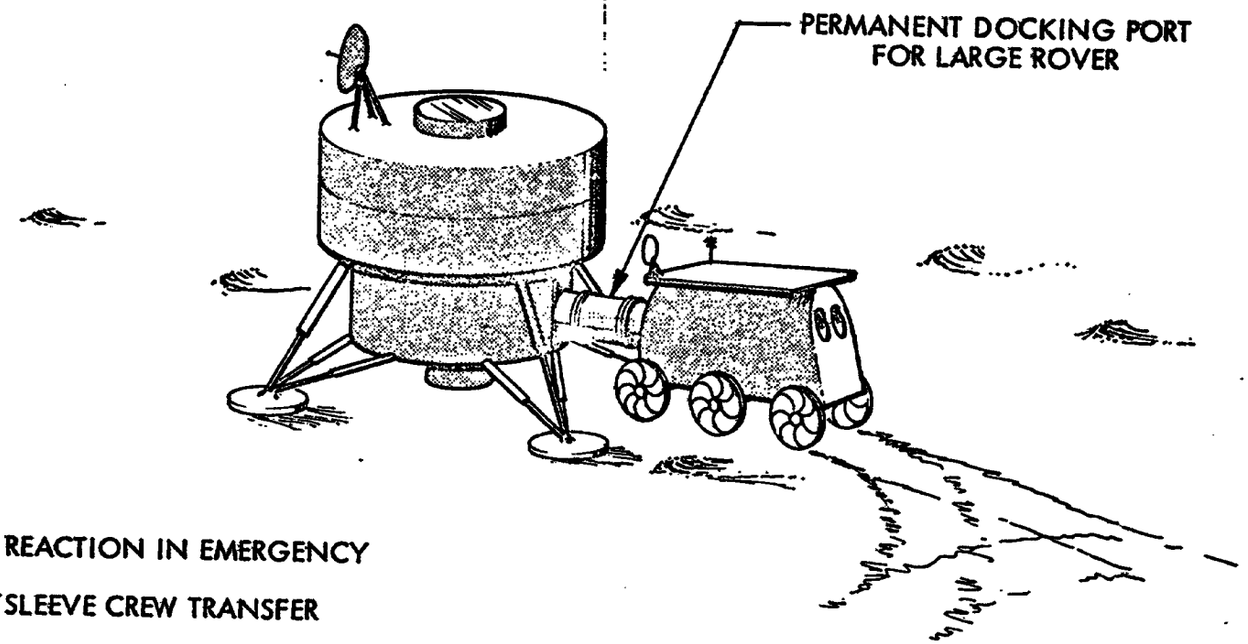
3. HAZARDS DATA MATRIX – III
   - TABULATION OF HAZARDS DATA ABSTRACTED FROM MATRIX – I AND ARRANGED BY:
     - ORBITAL OPERATIONS AND ACTIVITIES
     - SURFACE OPERATIONS AND ACTIVITIES
     - ORBITAL AND SURFACE INTERFACE HAZARDS

4. PROGRAM HAZARDS DATA MATRIX
   - TABULATION OF DATA ABSTRACTED FROM MATRICES – I, II, AND III, ARRANGED BY SEVERITY OF IMPACT UPON THE ADVANCED LUNAR EXPLORATION PROGRAM. THE DATA IS TO BE PRESENTED IN ORDER OF DECREASING SEVERITY FOR:
     - PROGRAM ELEMENTS
     - PROGRAM OPERATIONS
     - PROGRAM ACTIVITIES

LUNAR SURFACE BASE/ROVER INTERFACE SAFETY EFFECTS

The chart is presented to illustrate interface features that have been examined in the effort to improve operational safety.

LSB ROVER INTERFACE SAFETY EFFECTS



- FAST REACTION IN EMERGENCY
- SHIRTSLEEVE CREW TRANSFER
- AVOIDS AIRLOCK HAZARDS
- PROVIDES ALTERNATE EMERGENCY SHELTER

LUNAR SURFACE BASE – SITE LAYOUT SAFETY EFFECTS

The physical layout of a lunar surface base can contribute to safety effects. The chart illustrates safety tradeoffs for single, multiple dispersed, and multiple clustered lunar surface shelters.

LSB — SITE LAYOUT SAFETY EFFECTS

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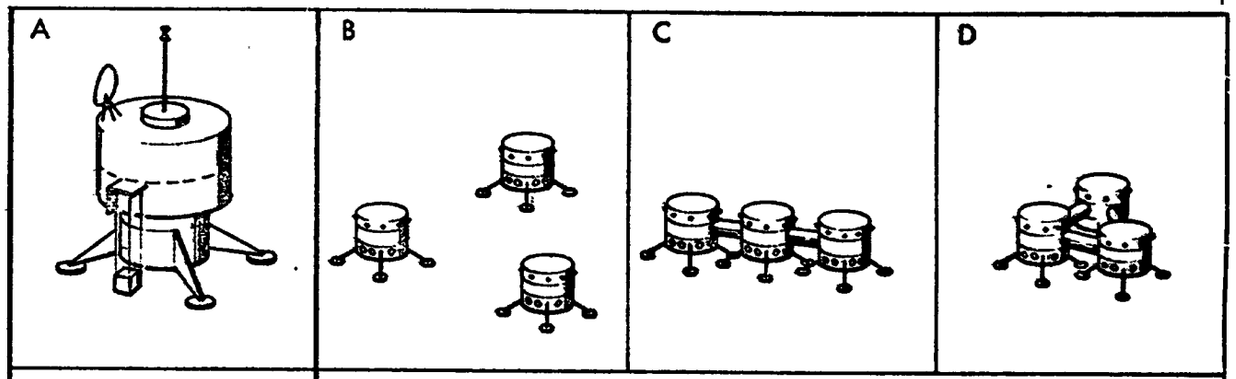

	SINGLE SHELTER	MULTIPLE SHELTERS		
		DISPERSED AS LANDED	CLUSTERED IN-LINE	CLUSTERED CIRCLE
EXPLOSION	COULD BE CATASTROPHIC TO ENTIRE CREW & BASE	COULD BE CATASTROPHIC TO ONE SHELTER ONLY	COULD BE CATASTROPHIC TO ALL BUT LESS LIKELY	SAME AS C BUT SOMEWHAT MORE HAZARDOUS
FIRE	DITTO – HOWEVER ENTIRE CREW AVAILABLE TO TAKE ACTION	DITTO – BUT CREWS UNABLE TO PROVIDE FAST RESPONSE	DITTO – HOWEVER ENTIRE CREW COULD HELP. BULKHEADS TO PREVENT SPREAD.	DITTO
CONTAMINATION	LARGE QUANTITIES OF CONTAMINANTS NECESSARY TO SPOIL ATMOSPHERE & EASIER TO DETECT	FASTER PROBLEM THAN IN A BUT CREW COULD USE OTHER SHELTERS	SAME AS B BUT CREW CAN TRANSFER FASTER TO AID IN ISOLATING PROBLEM SHELTER	CONTAMINATION BETWEEN SHELTERS MORE DIFFICULT TO ISOLATE

TRANSPORTATION & ASSEMBLY PROBLEMS

TASK 3 ESCAPE/RESCUE ANALYSIS

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ESCAPE/RESCUE TASK SCOPE

The escape/rescue analysis task is being directed at all hardware and operational situations associated with the advanced lunar mission. The chart lists types of hardware that may be used in each of three operational areas: surface, orbit, and arrival/departure.

ESCAPE/RESCUE TASK SCOPE

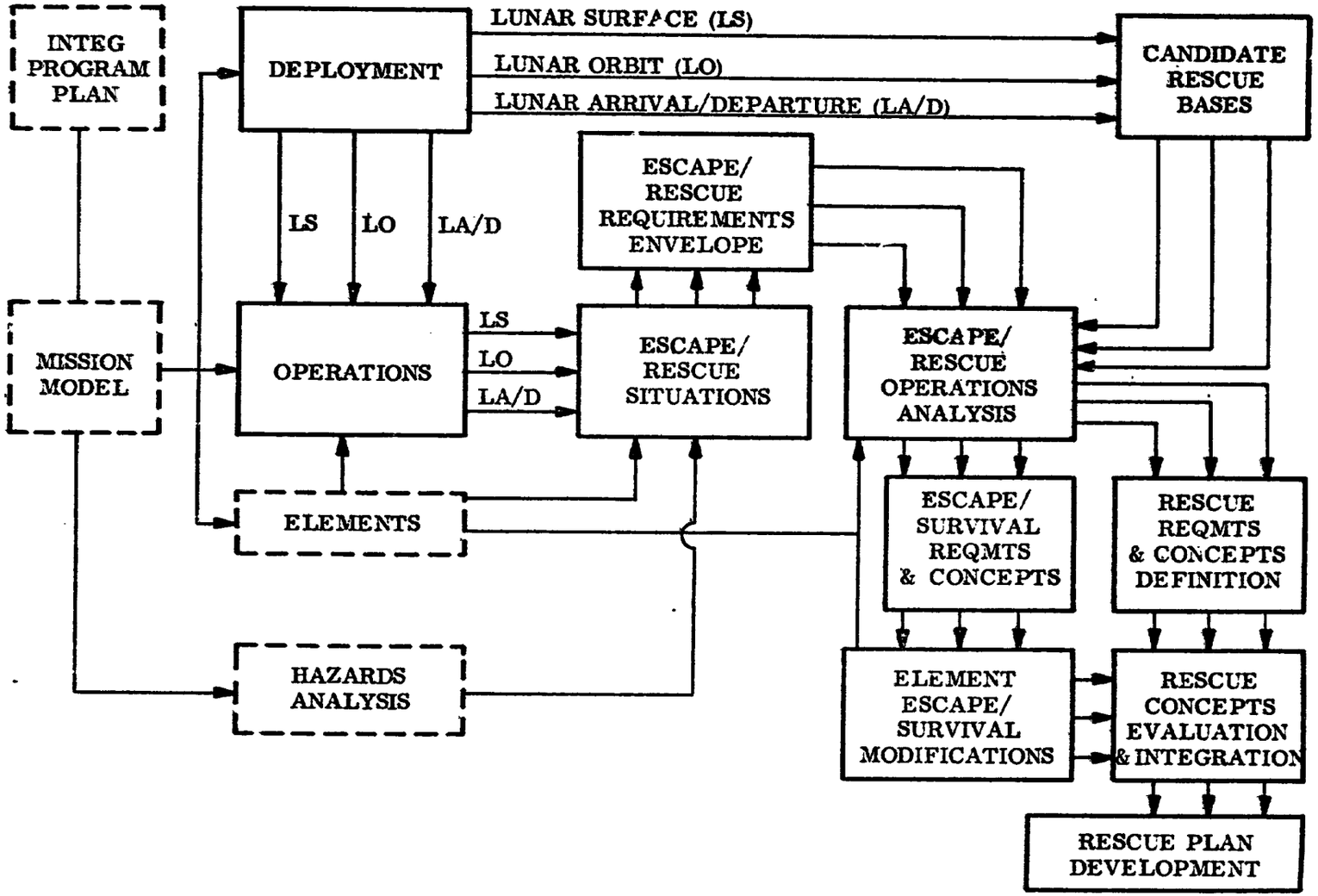
LUNAR SURFACE	LUNAR ORBIT	LUNAR ARRIVAL & DEPARTURE
• SURFACE BASE	• SHUTTLE	• REUSABLE NUCLEAR SHUTTLE
• LUNAR LANDER TUG	• TUG	• CHEMICAL PROPULSION SHUTTLE
• SURFACE ROVER	• FUEL DEPOT	
• FLYER	• ORBITING LUNAR STATION	

ESCAPE/RESCUE ANALYSIS TASK APPROACH

The baseline for the escape/rescue analysis task approach is composed of the various hardware elements involved in the advanced lunar program, their deployment in the lunar area, and their operational utility. For analysis purposes the task is separated into three parts based upon hardware element deployment, lunar surface, lunar orbit, and lunar arrival/departure.

Escape/rescue situations are developed based on both planned operations with the various IPP hardware elements and on inputs from the hazards analysis task. A requirements envelope is then established, expressed in terms of operational and performance limits and constraints. Candidate rescue and escape/survival requirements and concepts are then defined, based on an operations analysis and trade-off evaluation. The rescue plan will include all escape/rescue guidelines and concepts, and will specify the required modifications and additions of IPP hardware elements and operations. The rationale supporting these results will also be included.

ESCAPE/RESCUE ANALYSIS TASK APPROACH

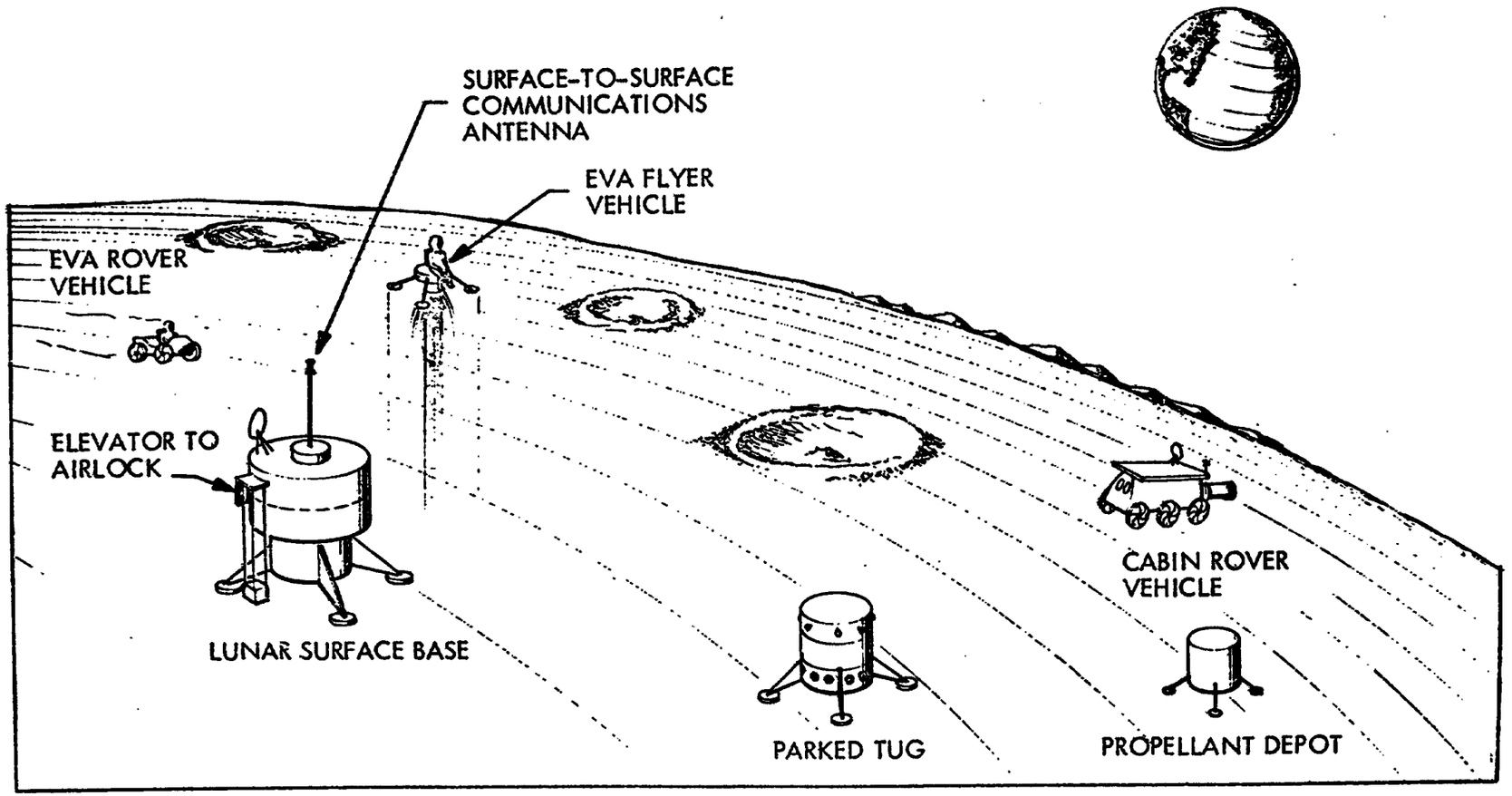


LUNAR SURFACE BASE

This chart depicts the Lunar Surface Base (LSB) and supporting key items of equipment that could be deployed. The tug landing area will be at least 1-1/4 nm from the LSB to preclude damage due to lunar surface material being scattered by the rocket blast effect of a landing or departing tug, or shrapnel damage due to a tug explosion.

The height of the surface-to-surface communications antenna depends on the desired operating range in the vicinity of the LSB. For an antenna height of 50 feet and a tug height of 75 feet the tug-to-surface communications range would be approximately 6 nm.

LUNAR SURFACE BASE



RESPONSE TIME OF RESCUE PLANS

This chart presents the factors influencing the required response time for various rescue situations. Note that rescue of a crew stranded in the Lunar Surface Base can be performed by a surface crew in about one-half the time required for orbital rescue.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

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RESPONSE TIMES OF RESCUE PLANS (HOURS)

	RESCUE FROM LUNAR ORBIT		RESCUE BY SURFACE CREW VIA PARKED TUG	
	NO BACKSIDE COMMUNICATIONS RELAY	WITH BACKSIDE COMMUNICATIONS RELAY	RESCUE CREW ON EVA ROVER TRAVERSE	RESCUE CREW IN PARKED TUG
MAXIMUM CREW TO BE RESCUED	6	6	4	8
• CONTACT DELAY TIME	1.0	–	–	–
• DECISION TIME	0.25	0.25	0.25	0.25
RESCUE INITIATION TIME INTERVAL	1.25	0.25	0.25	0.25
• DESCENT/LANDING TIME	3.25	3.25	–	–
• DEBARCATION OF RESCUE CREW	0.25	0.25	–	0.25
• UNLOAD ROVER VEHICLE	0.75	0.75	–	0.75
• TRIP TIME TO BASE	0.25	0.25	1.6	0.25
• ENTRY INTO BASE	0.25	0.25	0.25	0.25
ARRIVAL TIME INTERVAL	5.0	5.0	1.85	1.5
REMOVAL TIME INTERVAL				
2 MAN ROVER VEHICLE	3.5	3.5	2.25	4.50
5 MAN ROVER VEHICLE	1.5	1.5	1.25	1.25
TOTAL TIME INTERVAL				
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

LUNAR SURFACE MOBILITY VEHICLES

There are two classes of mobility vehicles; the EVA and pressurized cabin types. The ranges of the former are limited mainly by the capacities of the portable life support systems. The pressurized cabin vehicles may go on extended traverses, using EVA for the actual exploration by the crew at various stopping points. From a rescue point of view the most important characteristics of the vehicles are the maximum ranges and speeds of the vehicles, the number of men they carry, and the life support time-to-go. The mobility vehicles may break down on a traverse, and the crew must be rescued. The vehicles can also serve as rescue vehicles if necessary.

LUNAR SURFACE MOBILITY VEHICLES

CLASS OF VEHICLE	NAME	CREW	NOMINAL TRAVERSE TIME	RANGE (NM)	VELOCITY (KNOTS)
EVA	APOLLO ROVER VEHICLE 4 WHEEL	2	PLSS LIFE	16	3-1/2
	DUAL MODE ROVER VEHICLE 6 WHEEL	2	PLSS LIFE	16 MANNED 540 UNMANNED	4
	LUNAR FLYER VEHICLE	1	PLSS LIFE	10	180
	UPRATED LUNAR FLYER VEHICLE	2	PLSS LIFE	30	180
	GROUND EFFECTS MACHINE	1	PLSS LIFE	22	14
PRESSURIZED CABIN	SMALL CABIN ROVER	2	14 DAYS	270	5.4
	LARGE CABIN ROVER	2	24 DAYS	400	5.4

EVA TRAVERSE RESCUE SITUATIONS

The rescue situations shown here are for the mobility vehicles described on the previous chart. The terrain limits represent the operational constraints for the particular vehicle. The rover position uncertainty is based on the nominal velocity capability of the rover and assumes that the malfunction occurred just before a planned 5-minute interval reporting time. The flyers could experience a malfunction at any point along their flight path and could overshoot a planned landing site by 4500 feet if the malfunction occurred just prior to landing. The ground effects vehicle could also malfunction at any point along its planned traverse path.

EVA TRAVERSE RESCUE SITUATIONS

VEHICLE	CREW	TERRAIN LIMITS	POSITION UNCERTAINTY
ROVER	2	SMOOTH, GENTLE SLOPES	1700 FT X 4000 FT (5 MINUTE REPORTING PERIOD)
FLYER	1	ELEVATED LOCATIONS, SEVERE SLOPES	0-5 NM ALONG TRAVERSE PATH 4500 FT OVERSHOOT OF LANDING SITE
UPRATED FLYER	2	ELEVATED LOCATIONS, SEVERE SLOPES	0-15 NM ALONG TRAVERSE PATH 4500 FT OVERSHOOT OF LANDING SITE
GROUND EFFECTS MACHINE	1	SMOOTH TO ROUGH, GENTLE SLOPES	0-1.4 NM ALONG TRAVERSE PATH

CABIN ROVER TRAVERSE RESCUE SITUATIONS

The accidents and malfunctions that a cabin-type rover vehicle can sustain are characterized, for escape/rescue purposes, by the condition of its mobility subsystems and the integrity of the pressurized, shirtsleeve compartment. If this compartment should be damaged and inoperable, the crew must survive on their PLSS units. If this compartment is intact, the crew can survive a minimum of seven days by powering down all non-essential vehicle subsystems. If the communication subsystem is out, the crew must then decide on their own whether to drive on to the planned end of mission site, return to their base, or await rescue.

A vehicle position uncertainty of no more than three miles is based on a planned reporting period of 30 minutes. If driveback is attempted without communications capability this position uncertainty will become quite large.

CABIN ROVER TRAVERSE RESCUE SITUATIONS

	VEHICLE IS MOBILE	VEHICLE IS IMMOBILE
PRESSURIZED COMPARTMENT UNDAMAGED	COMMUNICATIONS FAILURE SURVIVAL TIME ≥ 7 DAYS DRIVEBACK POSSIBLE	VEHICLE DAMAGED/ CRITICAL SUBSYSTEM FAILURE SURVIVAL TIME ≥ 7 DAYS NO DRIVEBACK
PRESSURIZED COMPARTMENT FAILURE	SKIN PUNCTURE SURVIVAL TIME LIMITED TO PLSS DRIVEBACK LIMITED	VEHICLE TIPS OVER SURVIVAL TIME LIMITED TO PLSS NO DRIVEBACK

LUNAR TRAVERSE ESCAPE/RESCUE

This chart presents a matrix of candidate escape/rescue approaches for various traverse-type situations. For example, walk back to the base from the emergency site is a feasible concept for a stranded EVA-type rover vehicle or flyer. Note that a survival kit drop from orbit could extend the survival time for situations for traverse crews stranded a considerable distance from their base and depending on their PLSS units for life support.

LUNAR TRAVERSE ESCAPE/RESCUE APPROACHES

	EVA TRAVERSES				CABIN ROVER TRAVERSES	
	ROVER VEHICLE	FLYER	UPRATED FLYER	GROUND EFFECTS MACHINE	VEHICLE IMMOBILE	PRESSURE COMPARTMENT STRUCTURAL FAILURE
WALKBACK	X	X				
ROVER VEHICLE FROM BASE	X	X				
CARRY EMERGENCY LESS					X	X
LESS FROM BASE		X	X	X		
TUG BALLISTIC HOP			X	X	X	X
LUNAR LANDER TUG FROM ORBIT			X	X	X	X
CARRY EMERGENCY LEAP					X	X
SURVIVAL KIT DROP + LLT FROM ORBIT						X
SURVIVAL KIT DROP + SURFACE RESCUE			X	X		

ESCAPE/RESCUE SITUATIONS

Four orbital escape/rescue situations were selected for this presentation:

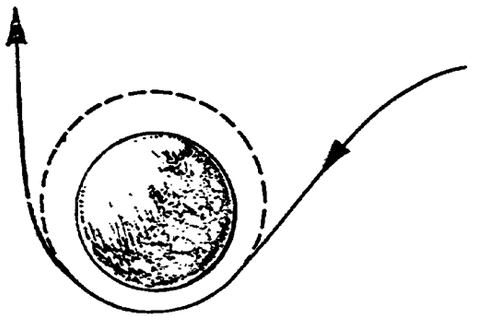
(1) Prime transport vehicle injection into lunar orbit and rendezvous with the orbiting lunar station. Included here is the case in which injection does not occur and the transport vehicle is on a lunar escape trajectory.

(2) Initial manning and activation of the orbiting lunar station.

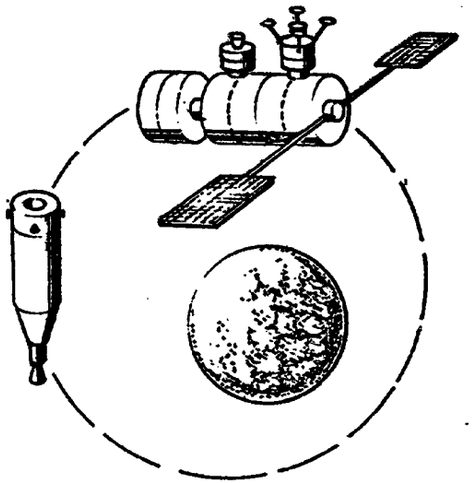
(3) EVA activities associated with normal orbiting lunar station activities.

(4) Fuel depot support of the orbiting lunar station.

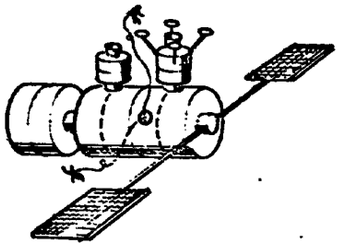
ESCAPE/RESCUE SITUATIONS



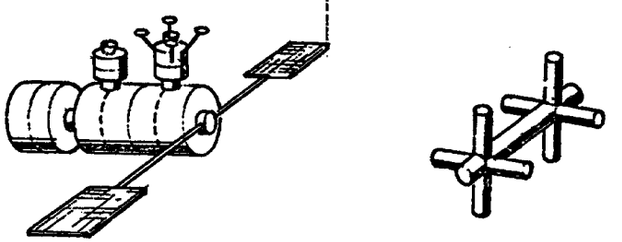
INJECTION/RENDEZVOUS



INITIAL MANNING & ACTIVATION



EVA ACTIVITIES



FUEL DEPOT

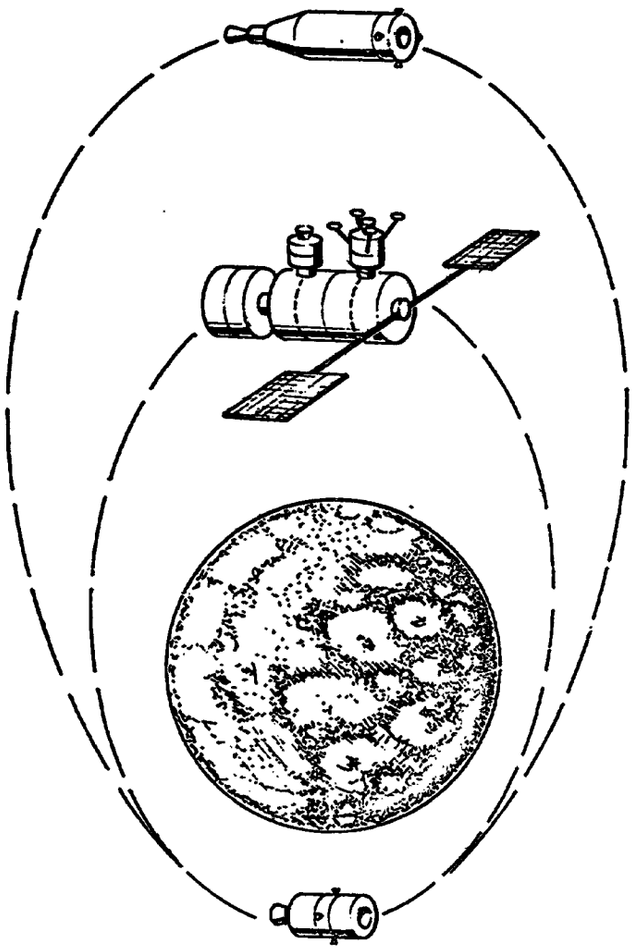
ELLIPTICAL ORBIT ESCAPE/RESCUE

Failure of the prime transport vehicle to inject as planned into lunar orbit would result in the vehicle being in a elliptical orbit as depicted on the chart. The Δ velocity requirements needed for a tug to separate from the orbiting lunar station, transfer to the stranded vehicle orbit, rendezvous, dock, pick-up the crew and then return to the station are also presented. These velocity needs are for a stranded vehicle in a worst-case 36 hour period elliptical orbit.

Two escape/rescue situations are possible: (1) the logistics cargo includes a manned and fueled tug, and (2) the crew is in a crew compartment with no tug. In the first case there is a choice between escape and rescue. In the second case the crew must be rescued.

Regardless of the choice, it is desirable to recover both the crew and the logistics cargo in order to minimize the impact on the planned lunar program. The critical situation could be for a maximum cargo payload and a crew in a crew compartment. For this case the rescue tug would separate from the station, intercept and dock with the crew compartment, separate the cargo and crew, and return both to the station. Even for this extreme payload weight the available tug velocity capability is 5570 ft/sec, well over the required 4400 ft/sec.

ELLIPTICAL ORBIT ESCAPE/RESCUE



EVENT	Δ VELOCITY FT/SEC
1. SEPARATE FROM OLS & PHASE	150
2. ORBIT TRANSFER	1950
3. RENDEZVOUS & DOCK	150
4. SEPARATE	50
5. CIRCULARIZE	1950
6. RENDEZVOUS & DOCK	150
TOTAL	4400
AVAILABLE	5570

LUNAR ARRIVAL ESCAPE/RESCUE SITUATIONS

INITIAL MANNING

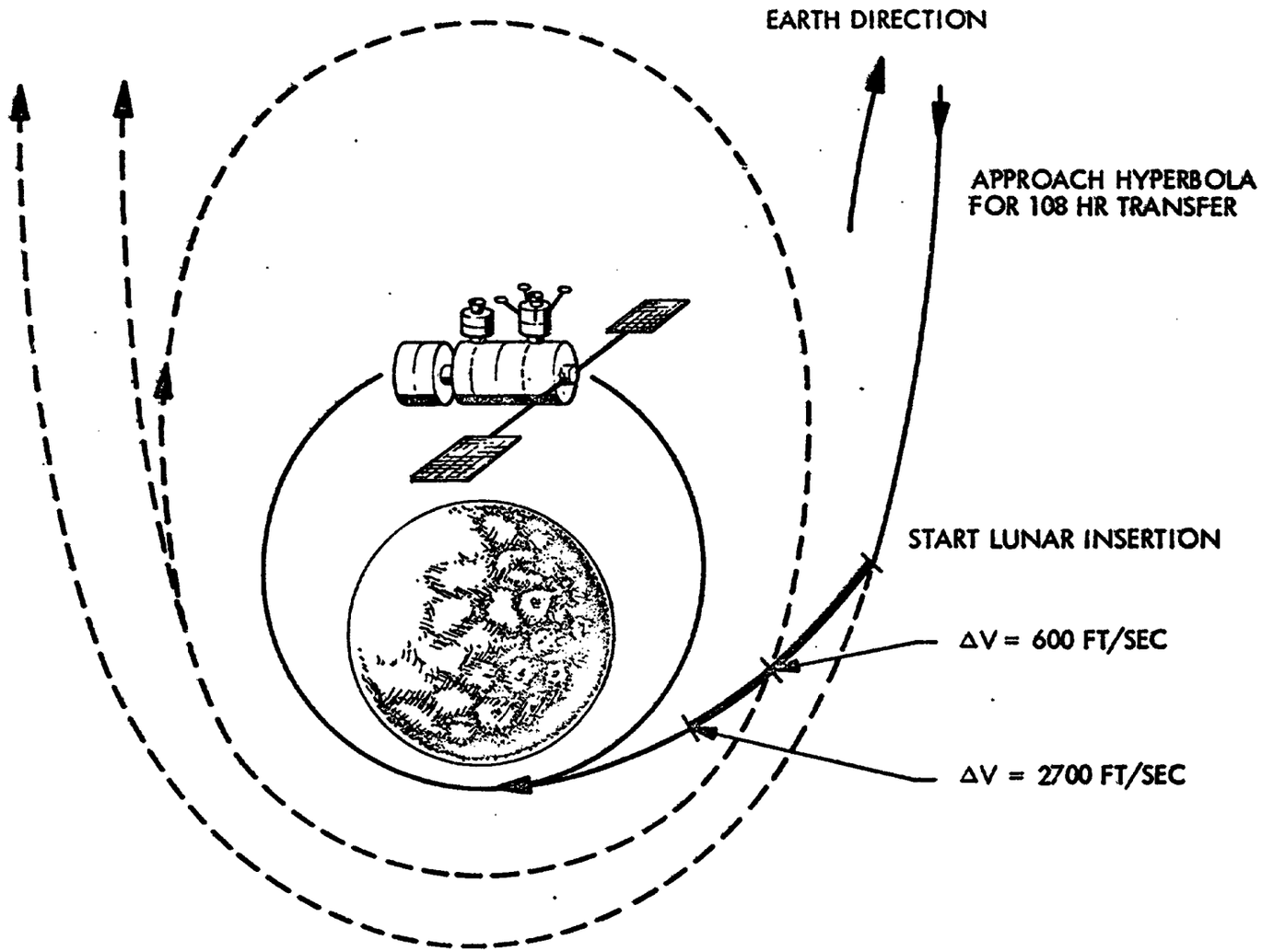
For the first manned flight, the crew will be in a fully fueled tug capable of returning to earth orbit if the nuclear shuttle fails to inject into lunar orbit. Similarly, the second crew will be transported in a fully fueled tug capable of earth return. The second crew will have the option of either returning to earth or rendezvousing with the manned OLS in the event escape is necessary. Either option will require minimum plane change because the basic shuttle trajectories are planned to be coplanar.

ROUTINE CREW ROTATION

The present nuclear shuttle/crew capsule combination planned for the logistics flights provides no escape capability. Consequently, outside rescue must be provided from either the OLS or the earth in the event of lunar injection failure.

Lunar injection failure could be the result of no burn or partial burn resulting in either a hyperbolic escape trajectory or an elliptical lunar orbit depending on the total ΔV imparted. The possibility of lunar impact due to short burn can be avoided by proper design of the arrival trajectory and insertion burn. The critical ΔV between a capture ellipse and an escape hyperbola is in the order of 600 ft/sec for 108 hour flight time. The case of zero burn would put the shuttle back on the lunar departure trajectory at maximum velocity thereby requiring maximum ΔV for the tug to catch up and rendezvous with the stranded crew.

LUNAR ARRIVAL ESCAPE/RESCUE TRAJECTORIES



STUDY OUTPUT

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PROJECTED STUDY OUTPUT

- SAFETY REQUIREMENTS FOR ADVANCED LUNAR MISSIONS
- RESCUE PLAN FOR ADVANCED LUNAR MISSIONS
- RECOMMENDATIONS FOR FURTHER INVESTIGATION

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POTENTIAL APPLICATIONS OF STUDY RESULTS TO APOLLO/SKYLAB

There are several potential areas of application of the Lunar Mission Safety and Rescue Study results to the existing Apollo and Skylab programs. The accompanying chart indicates several areas of commonality between the study and the two programs. Within these areas the study results could form a baseline for application to the Apollo and Skylab programs in order to: (1) identify hazards and escape/rescue situations; (2) determine realistic candidate solutions; (3) establish recommended approaches; and (4) identify penalties associated with their implementation.

POTENTIAL APPLICATION OF STUDY RESULTS TO APOLLO/SKYLAB

LUNAR MISSION SAFETY & RESCUE APPLICATION AREA	APOLLO		SKYLAB		
	ORBIT	SURFACE	MANNING & ACTIVATION	ORBIT	EVA
LUNAR ARRIVAL/DEPARTURE	X				
RENDEZVOUS & DOCKING	X		X		
OLS ORBIT OPERATIONS	X			X	
EVA ACTIVITIES					X
LOGISTICS VEHICLE OPN'S				X	
LUNAR LANDING & ASCENT	X				
SURFACE EVA & TRAVERSES		X			
EARTH BASED RESCUE	X	X	X	X	

HAZARDS ANALYSIS

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TASK 2 – HAZARDS ANALYSIS OBJECTIVES

The objectives of the hazards analysis task are to: determine how safety can be enhanced on the next generation of lunar exploration missions; determine the areas in which concentrated safety efforts should provide the greatest safety return; show how hazards can be effectively controlled; determine preferential mission modes; identify conditions and situations requiring rescue.

TASK 2 — HAZARDS ANALYSIS OBJECTIVES

- IDENTIFY POTENTIAL HAZARDS
  LUNAR ORBITAL AND SURFACE OPERATIONS
  CREW ACTIVITIES, FUNCTIONS AND ENVIRONMENTS
- DETERMINE HAZARDS EFFECTS
  CREW SAFETY IMPACT – DESCRIPTIVE
  CATEGORIZE HAZARD LEVELS
- CORRECTIVE MEASURES DEVELOPMENT
  HAZARDS DETECTION
  PREVENTIVE AND REMEDIAL CONCEPTS
- IDENTIFY RESCUE REQUIREMENTS
  SITUATIONS REQUIRING RESCUE
  SURVIVAL TIME LINE APPRAISAL
- ESTABLISH GUIDELINES FOR SAFETY ENHANCEMENT
  PROGRAMS HAZARDS CHARACTERIZATION
  HAZARDS CONTROL CONSIDERATIONS
  SAFETY TECHNOLOGY DEVELOPMENT RECOMMENDATIONS

HAZARDS ANALYSIS – THE ANALYTICAL APPROACH

The analytical approach employed in the hazards analysis task systematically examines the operations and equipment elements contained in the lunar exploration program model. The approach taken requires a thorough understanding of the model lunar program definition, its mission elements, operational modes, and the programmed element events and personnel activities. The approach is designed to yield quantitative information for the development of guidelines for program safety enhancement.

HAZARD ANALYSIS — THE ANALYTICAL APPROACH

LOCKHEED

FROM: THE ADVANCED LUNAR EXPLORATION PROGRAM MODEL – FOR ANY GIVEN MISSION SEQUENTIAL FUNCTION EVENT OR ACTIVITY

FIND: THE SIGNIFICANT FUNCTION FAILURES AND NATURAL CONDITIONS WHICH GENERATE, OR PRESENT, HAZARDOUS SITUATIONS OR CONDITIONS

DETERMINE: THE SIGNIFICANT DIRECT OR DERIVATIVE EFFECTS WHICH POSE A THREAT TO MAN OR THE SYSTEMS UPON WHICH MAN IS DEPENDENT

DEVELOP: PLAUSIBLE AND FEASIBLE CORRECTIVE MEASURES WHICH ARE EITHER:

- PREVENTIVE – TO ELIMINATE THE FUNCTION FAILURE OR MITIGATE THE NATURAL CONDITION
- REMEDIAL – FOR THE MITIGATION OR ELIMINATION OF THE CONSEQUENCES/EFFECTS ASSOCIATED WITH THE FUNCTION FAILURE OR NATURAL CONDITION

IDENTIFY: FOR THE HAZARDOUS SITUATION OR CONDITION:

- THE PRINCIPAL HAZARDS TO MAN
- THE PRINCIPAL EFFECTS UPON MAN
- THE APPLICABLE CORRECTIVE MEASURES
- THE RESCUE/ESCAPE REQUIREMENTS

DERIVE: THE SAFETY GUIDELINES AND REQUIREMENTS PERMITTING OPTIMAL SAFETY ENHANCEMENT IN THE PLANNED DEVELOPMENT OF ELEMENT SYSTEMS FOR ADVANCED LUNAR EXPLORATION OPERATIONS

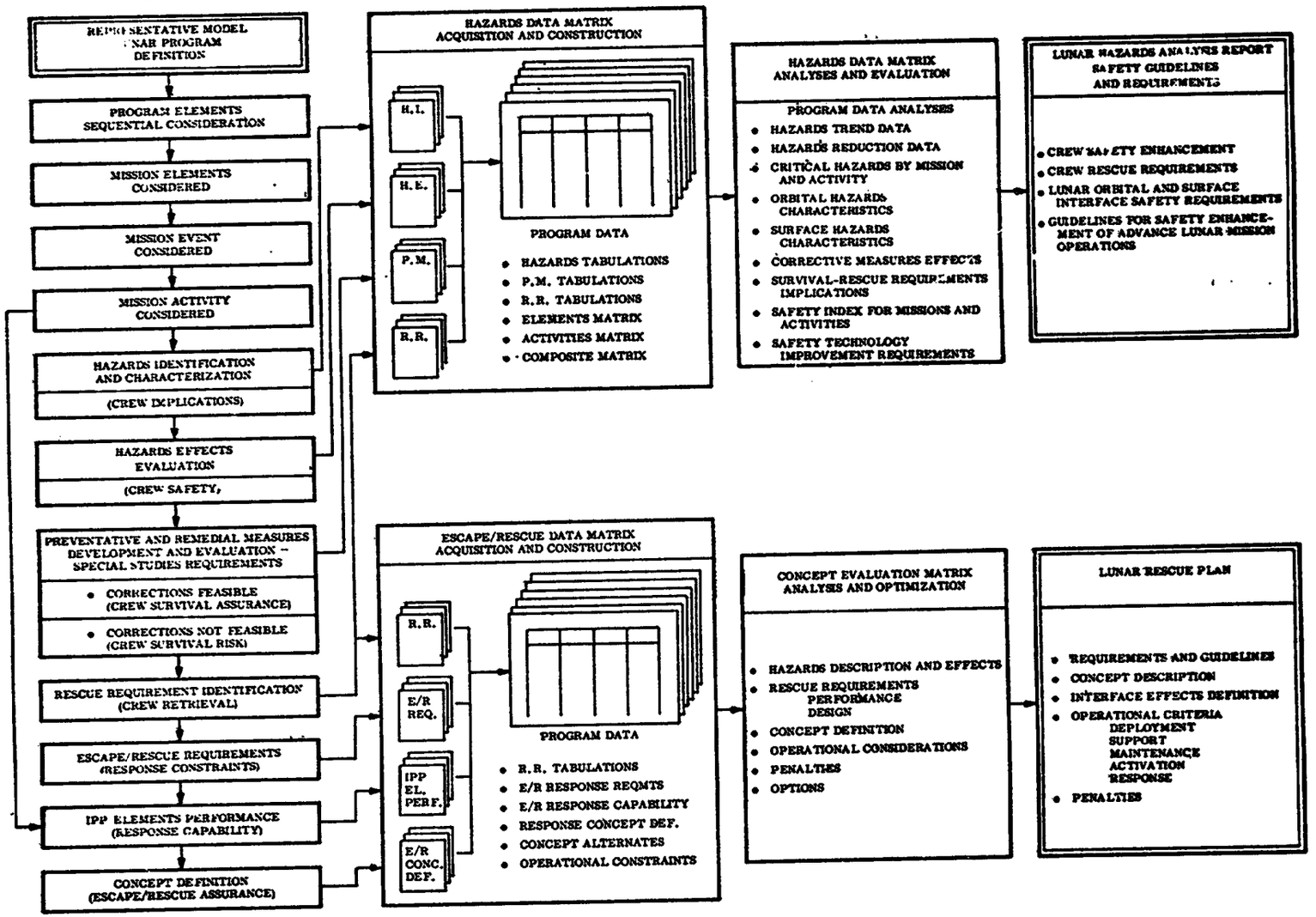
THE ANALYTICAL PROCEDURAL SEQUENCE

The chart shows the sequence of analyses for the integrated study effort, proceeding from the definition of a representative lunar exploration program through hazards analyses and escape/rescue analyses to safety guidelines and a rescue plan.

The hazards analysis will explore the programmed events and associated personnel activities in an ordered serial sequence to accomplish the following:

- Hazards identification and characterization
- Hazards effects determination and categorization
- Evaluation of corrective or countermeasure techniques applicable to the reduction of the defined hazards
- Necessary rescue and/or escape requirements generated for the events and activities considered.

THE ANALYTICAL PROCEDURAL SEQUENCE



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HAZARDS CHARACTERIZATION

HAZARD DEFINITION

The definition for "HAZARD" is from MSCM-1702, "System Safety Program Requirements for Space Flight Contractors," NASA-MSC, and is specified for use in this study.

HAZARD

LOCKHEED

DEFINITION:

THE PRESENCE OF A POTENTIAL RISK SITUATION, CREATED BY

- AN UNSAFE ACT OR CONDITION
- ENVIRONMENT OR NATURAL PHENOMENON
- PERSONNEL ERROR
- DESIGN CHARACTERISTICS
- TIME CRITICAL NORMAL OR EMERGENCY OPERATION
- PROCEDURE DEFICIENCIES
- SUBSYSTEM MALFUNCTION

WHICH WILL CAUSE SYSTEM OR PERSONNEL LOSS.

THE HAZARD LEVELS

"Hazard Levels," as defined in MSCM-1702 "System Safety Program Requirements for Space Flight Contractors" NASA/MSC-Houston, and as used in the study are:

a. Safety Catastrophic – Condition(s) such that environment, personnel error, design characteristics, procedural deficiencies, or subsystem malfunction will cause system or personnel loss.

b. Safety Critical – Condition(s) . . . malfunction must be counteracted by urgent crew action (no time available for ground/flight crew analysis) to prevent system or personnel loss.

c. Safety Marginal – Condition(s) . . . malfunction can be counteracted or controlled with time available for ground/flight crew analysis to prevent system and/or personnel loss.

d. Safety Negligible – Condition(s) such that personnel error, design characteristics, procedural deficiencies, or subsystem failure will not result in system or personnel loss.

THE HAZARD LEVELS

A. SAFETY CATASTROPHIC

B. SAFETY CRITICAL

C. SAFETY MARGINAL

D. SAFETY NEGLIGIBLE

THE HAZARD GROUP DEFINITIONS

1. EXPLOSION/IMPLOSION

The sudden and violent disruption of vehicle, shelter, haven or contiguous equipment component integrity.

2. FIRE

Slow or rapid combustion of vehicular, habitat, or suit materials capable of sustained burning once ignited.

3. PRESSURE EXCURSIONS

Any non-violent decompression/over-pressure event occurring in vehicle, habitat or suit, outside of established pressure limits.

4. COLLISION

Impact with natural or man-made objects whether originating from internal (vehicle, shelter) or external sources.

5. CONTAMINATION

The presence of an elemental or structured substance, or biological organism, whether toxic or non-toxic, which exceeds specified permissible concentration limits for the surface, fluid or media under consideration.

6. INJURY/ILLNESS

Condition in which the health and well-being of the crew or a crew member is impaired or destroyed, due to organic damage or degradation or to biological invasion.

7. PERSONNEL ISOLATION

Condition or situation wherein a barrier exists between a crewman and his haven of safety.

8. MOTION/ACCELERATIONS

Situations induced by the movement of personnel, or of space or surface vehicles, whether planned or unplanned.

9. HUMAN ERROR

Accidental or unintentional departure from established plans or procedures. Impaired awareness of, or misjudgment regarding a situation and a course of action required.

10. HOSTILE ENVIRONMENT

Exposure to environmental conditions which may be inherently destructive to human life.

11. RADIOLOGICAL HAZARDS

(a) Natural Sources: External electromagnetic radiation, cosmic radiation, solar flares, & by-products of Stellar nuclear reactions.

(b) Man-Made Sources: Energy radiating equipments, of all types emitting penetrating rays, beams and particles.

12. SYSTEM OR SUBSYSTEM MALFUNCTION

The malfunction of system, subsystem, or equipment item, the functional capability of which is critical to the execution of a local or remote operation or activity.

THE HAZARD GROUPS

1. EXPLOSION/IMPLOSION
2. FIRE
3. PRESSURE EXCURSION
4. COLLISION
5. CONTAMINATION
6. INJURY/ILLNESS
7. PERSONNEL ISOLATION
8. MOTION/ACCELERATIONS
9. HUMAN ERROR
10. HOSTILE ENVIRONMENT
11. RADIOLOGICAL HAZARDS
12. SYSTEM OR SUBSYSTEM MALFUNCTION

LUNAR EXPLORATION PROGRAM MODEL

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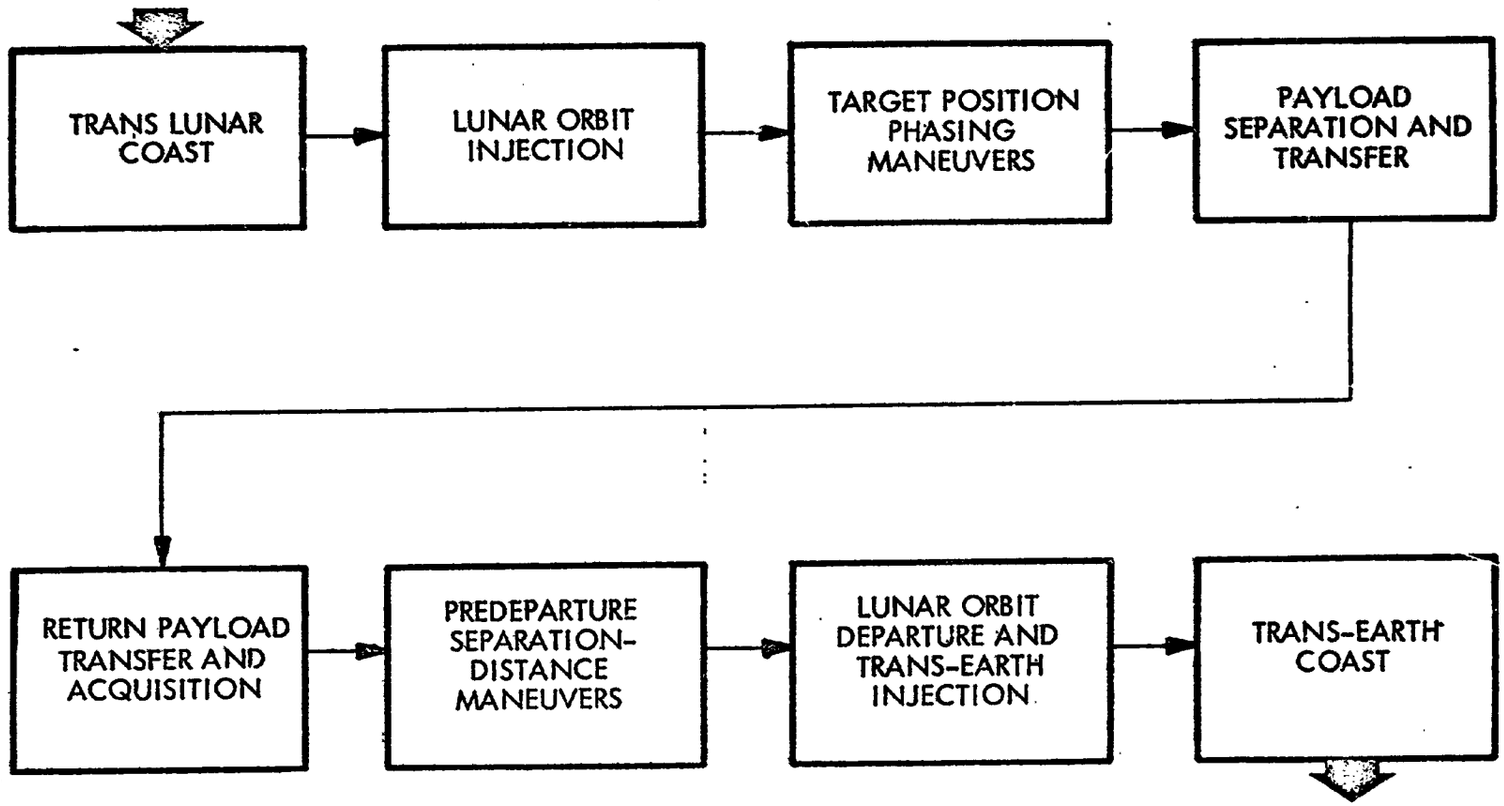
LUNAR PROGRAM MODEL – TYPICAL LOGISTICS MISSION

The chart illustrates the significant events sequence applicable to the lunar shuttle logistics missions for either unmanned or manned payloads. Each event embodies critical operations or activities basic to the successful accomplishment of the mission. The sequence, therefore, is a basic consideration in the ordering of the hazards analysis data.

TYPICAL LOGISTICS MISSION

LOCKHEED

SIGNIFICANT EVENTS SEQUENCE



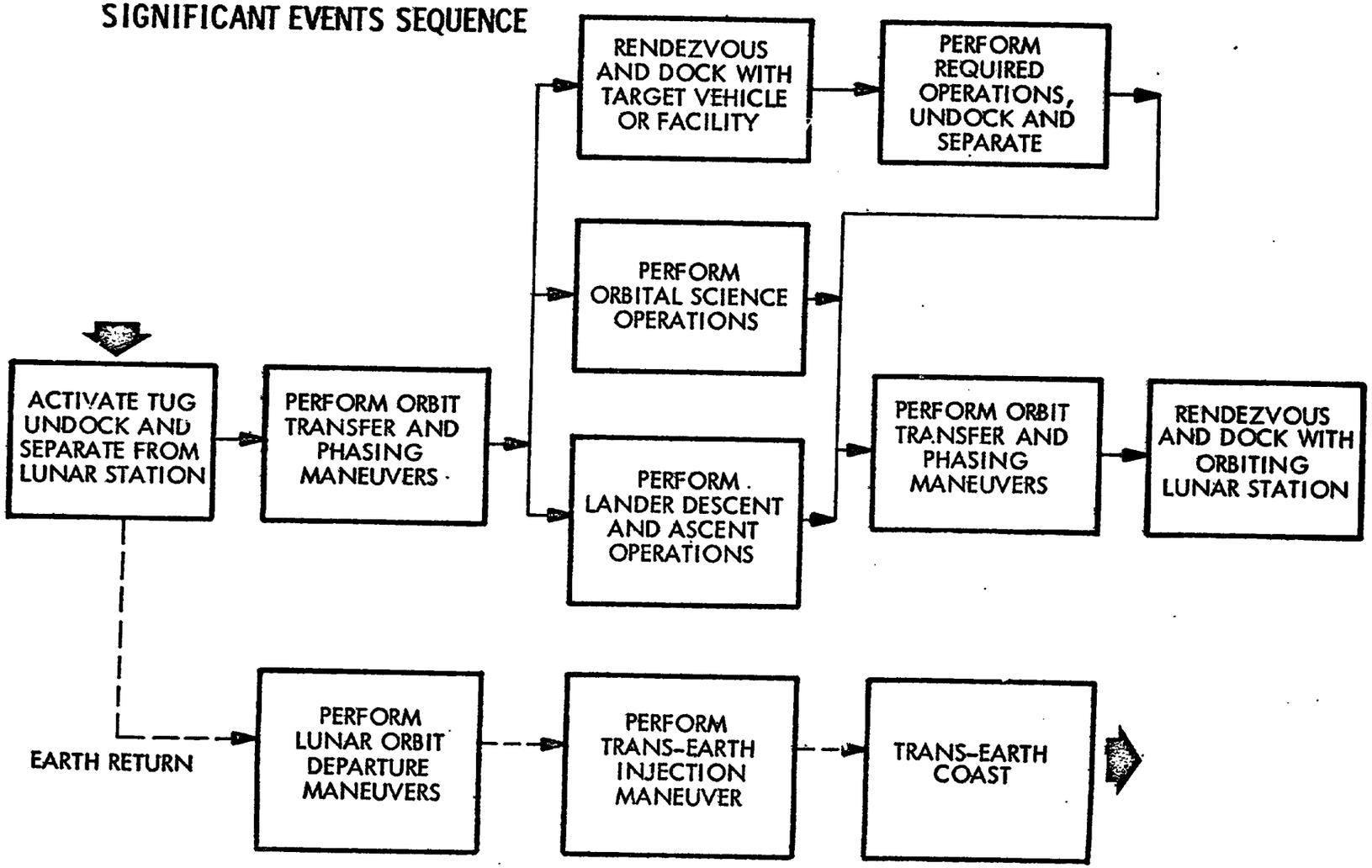
LUNAR PROGRAM MODEL – TYPICAL ORBITAL OPERATIONS

The typical orbital operations sequence presented in the chart is a somewhat simplified representation of the orbital activities considered in the program model. Practically, the orbital operations sequence can involve upwards to twenty or thirty separate events and activities, as in the case of the breakdown and distribution of a large mixed-cargo payload delivered by the lunar shuttle. A good many of the events would be repetitive maneuvers to different locations for the deposition of a payload segment.

TYPICAL ORBITAL OPERATIONS

LOCKHEED

SIGNIFICANT EVENTS SEQUENCE

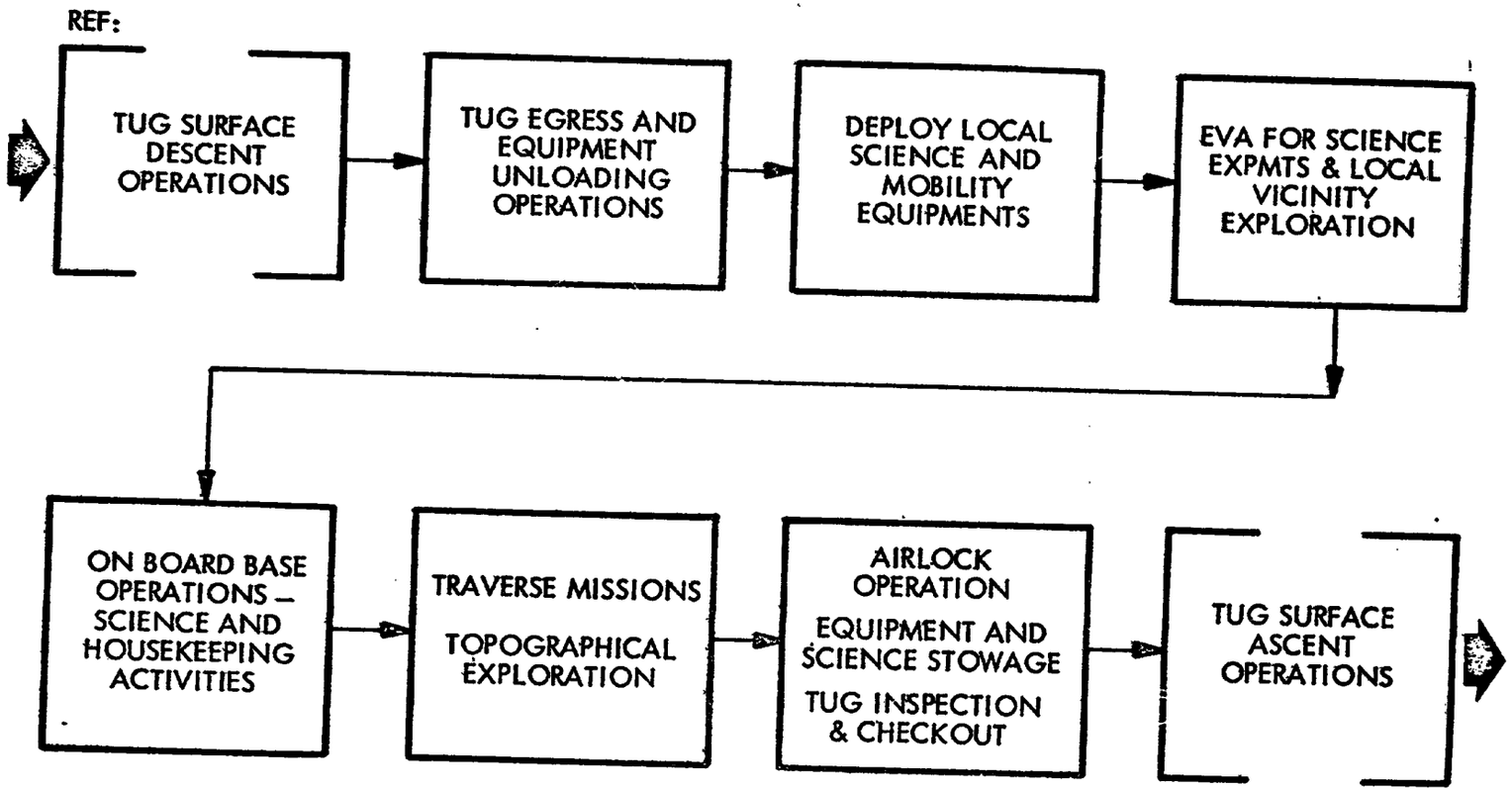


LUNAR PROGRAM MODEL – TYPICAL SURFACE LANDER OPERATIONS

The tug lander, in addition to providing transportation to and from the lunar surface, must also provide shelter, life support, laboratory and science support, and function as a temporary surface base. The chart presents the typical operations sequence of significant events for a lander exploration operation.

TYPICAL SURFACE OPERATIONS

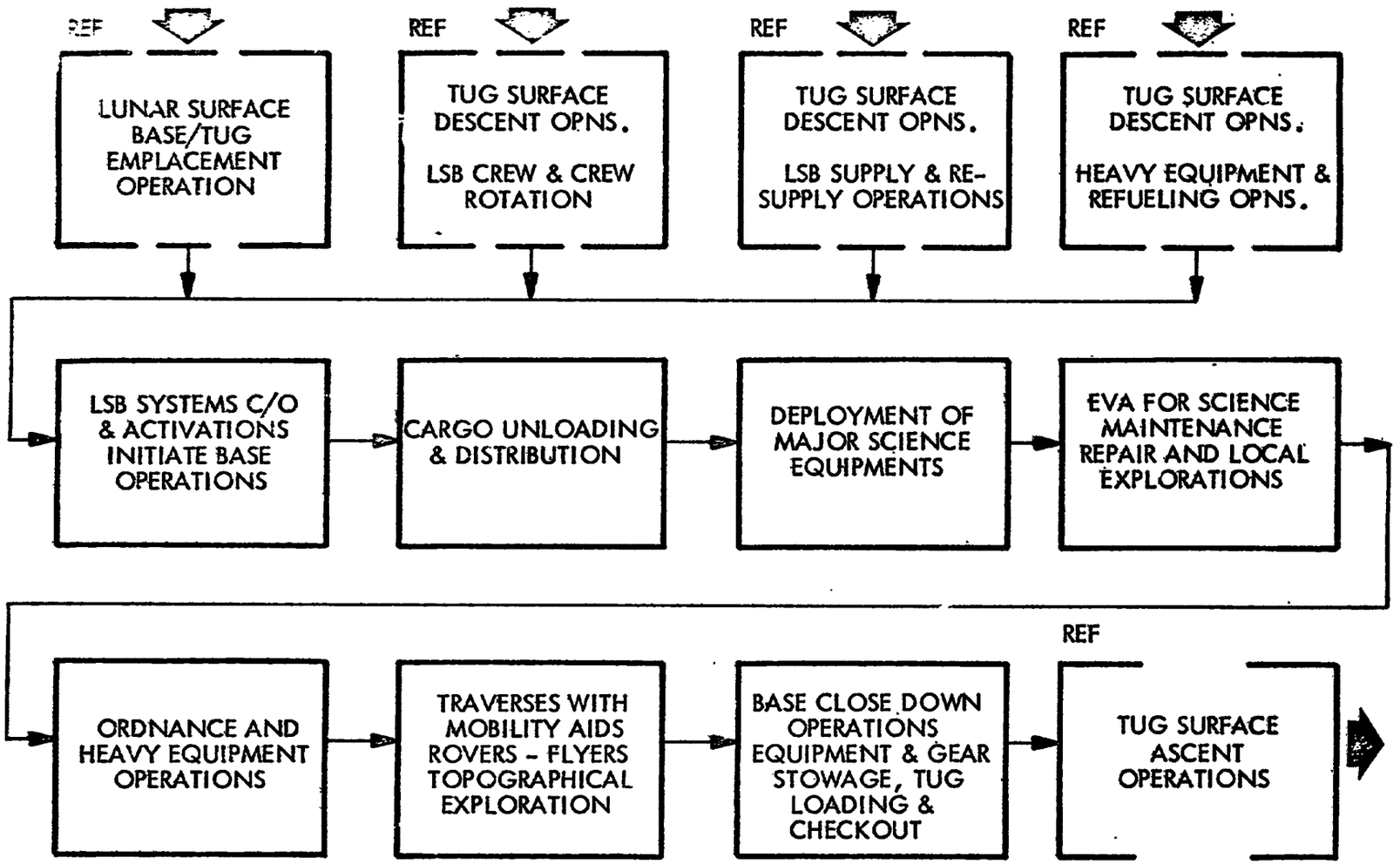
SIGNIFICANT EVENTS SEQUENCE



LUNAR PROGRAM MODEL – TYPICAL SURFACE BASE OPERATIONS

The emplacement and activation of the Lunar Surface Base requires that the tug vehicles perform personnel, cargo, and resupply delivery missions in addition to providing shelter and standby escape and rescue capability. The significant activities associated with surface base operations are illustrated in the chart on the next page. For clarity, it is to be assumed that the tug surface descent operations imply a return ascent to the orbiting lunar station.

TYPICAL SURFACE BASE OPERATIONS



HAZARDS ANALYSIS METHODOLOGY AND EXAMPLES

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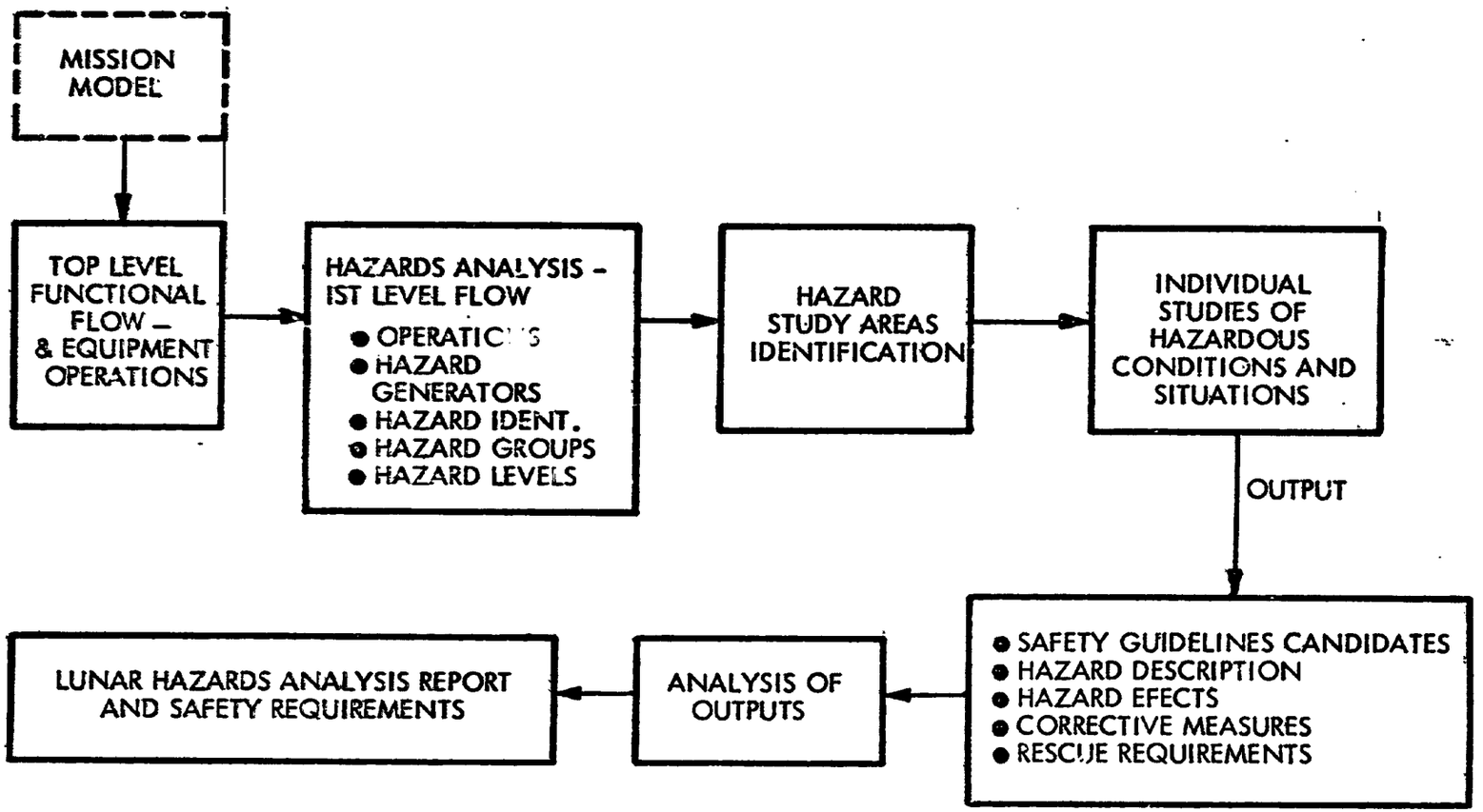
HAZARDS ANALYSIS METHODOLOGY

Working from the task objectives and the defined mission model, the top level functions and operations of lunar exploration elements are described. This is expanded in a first level flow chart to identify potentially hazardous conditions and situations requiring study. A list of hazardous conditions and situations selected for further study is compiled, and the studies carried out. From the individual studies, rescue requirements are identified and candidates for safety guidelines proposed. When the individual studies are complete, a study of the guidelines candidates is made to assess compatibility and feasibility and firm up recommendations to be included in the final report.

HAZARD ANALYSIS METHODOLOGY



FIRST LEVEL HAZARDS ASSESSMENT – ORBITAL OPERATIONS – 2.2
TUG ORBITAL OPERATIONS, LOGISTIC CARGO HANDLING (TYPICAL)

From events based on a mission model, equipment elements and alternates, as described earlier, malfunctions, failures, or errors are postulated which comprise hazard generators. These present the hazard from which potential effects are ascertained. Applicable hazard groups and hazard level range are identified. The Hazard Groups and Hazard Levels are defined in an earlier chart.

FIRST LEVEL HAZARDS ASSESSMENT — ORBITAL OPERATION 2.2.10

Tug Orbital Operations, Logistics Cargo Handling (Typical)

EVENT	PERFORM ORBIT TRANSFER/PHASING MANEUVERS, RENDEZVOUS & DOCK RETURN PAYLOAD (RPL) TO PTV		
HAZARD GENERATOR	LOSS OF TUG PROPULSION OR MANEUVERING CAPABILITY	(OR) PHASING MANEUVER ERRORS	(OR) DOCKING MANEUVER ERRORS
OPERATIONAL HAZARD	STRANDED CREW IN DISABLED TUG	POTENTIAL RADIATION EXPOSURE TO CREW IF PTV IS NUCLEAR VEHICLE	POTENTIAL COLLISION DAMAGE TO PTV OR RPL OR TUG OR DOCKING STRUCTURES
POTENTIAL EFFECTS	RESCUE REQ'D RETRIEVAL OF STRANDED CREW, TUG, AND PAYLOAD IS REQUIRED	CREW RADIATION EXPOSURE MAY EXCEED ALLOWABLE DOSE LIMITS FOR MISSION DUTY PERIOD BY LARGE MARGIN	EXTENT OF DAMAGE MAY REQUIRE EXTERNAL ASSISTANCE OR RESCUE; SALVAGE OR REPAIR MAY REQUIRE EVA
APPLICABLE HAZARDS GROUPS	12 7 8	9 11 6	9 4 1 2 12 10 7
HAZARD LEVEL RANGE	B TO C	B TO C	A TO C

FIRST LEVEL HAZARDS ASSESSMENT – ORBITAL OPERATIONS 2.3
TUG ASCENT OPERATIONS (TYPICAL)

An example of the first level hazards assessment for tug ascent operations is shown.

Note the pronounced effect that timing of a failure may have upon the resulting hazard, hazard groups, and hazard levels.

FIRST LEVEL HAZARDS ASSESSMENT
— ORBITAL OPERATION 2.3.7.1

LOCKHEED

Tug Ascent Operations (Typical)

EVENT	CHECKOUT AND ACTIVATE TUG SYSTEMS, LAUNCH FROM SURFACE	
HAZARD GENERATOR	DEGRADED PROPULSION CAPABILITY, UNABLE TO LIFT OFF FROM SURFACE	OR — PROPULSION CAPABILITY DEGRADES DURING LIFTOFF ALT. = 10 TO 50 FEET
OPERATIONAL HAZARD	STRANDED CREW IN DISABLED TUG ON LUNAR SURFACE	SURFACE IMPACT OF TUG VEHICLE IN NEAR FREE-FALL CONDITION
POTENTIAL EFFECTS	RESCUE REQ'D NON-CRITICAL RETRIEVAL OF CREW IN 24TH DAY OF 28 DAY SURFACE MISSION. TUG REPAIR	RESCUE REQ'D PHYSICAL DAMAGE TO VEHICLE AND CREW. SURVIVOR SEARCH AND EXTRACTION MAY BE REQUIRED
APPLICABLE HAZARDS GROUPS	12 7	12 4 1 2 6 7 10
HAZARD LEVEL RANGE	C TO D	A TO B

FIRST LEVEL HAZARDS ASSESSMENT – SURFACE OPERATIONS – 3.3
LONG TRAVERSES (TYPICAL)

Hazards associated with long traverses on the lunar surface are analyzed through the same steps as those of other operations.

Here the effects of different kinds of malfunctions, failures or environmental problems during traverses are indicated.

FIRST LEVEL HAZARDS ASSESSMENT — SURFACE OPERATIONS 3.3.4

LOCKHEED

Long Traverses (Typical)

EVENT	DRIVE (PERIODIC STOPS) FOR SCIENCE EXPERIMENTS		
HAZARD GENERATOR	SUBSYSTEM MALFUNCTION MOBILITY SYS	(OR) REDUCED VISIBILITY	(OR) BACK PACK FAILURE DURING EVA
OPERATIONAL HAZARD	REDUCED OR LOSS MOBILITY	COLLISION WITH TERRAIN	REDUCED OR LOSS OF OXYGEN
POTENTIAL EFFECTS	INABILITY TO DRIVE TO SAFE HAVEN	ISOLATION INJURY	TEMPORARY ISOLATION LOSS OF CREW
APPLICABLE HAZARDS GROUPS	6 7 8 12	6 7 8 9	6 7 12
HAZARD LEVEL RANGE	B TO C	A TO C	A TO C

MAJOR HAZARDOUS CONDITIONS/SITUATIONS – AREAS IDENTIFIED FOR INDIVIDUAL STUDIES

Approximately seventy individual areas for study of hazardous conditions or situations have been identified. Each study area may contain several variables such as manned vs unmanned system, chemical vs nuclear power.

MAJOR HAZARDOUS CONDITIONS/SITUATIONS
AREAS IDENTIFIED FOR INDIVIDUAL STUDIES

1.0 PRIME TRANSPORT VEHICLE (PTV) IN UNCONTROLLED TRAJECTORY

STUDY AREA 1.1 PT / FAILS TO ACHIEVE LUNAR ORBIT INSERTION (LOI)

MANNED OR UNMANNED CHEMICAL SYSTEM
INITIAL MANNING OF OLS, OR SUBSEQUENT OPERATIONS

1.2 PTV FAILS TO ACHIEVE LOI

MANNED OR UNMANNED NUCLEAR SYSTEM
INITIAL MANNING OF OLS, OR SUBSEQUENT OPERATIONS

1.3 PTV FAILS TO ACHIEVE TRANS EARTH INJECTION (TEI)

MANNED OR UNMANNED CHEMICAL SYSTEM
INITIAL MANNING OF OLS, OR SUBSEQUENT OPERATIONS

1.4 PTV FAILS TO ACHIEVE TEI

MANNED OR UNMANNED NUCLEAR SYSTEM
INITIAL MANNING OF OLS, OR SUBSEQUENT OPERATIONS

2.0 PTV UNABLE TO RENDEZVOUS WITH ORBITING LUNAR STATION (OLS)

2.1 PTV MANNED OR UNMANNED, CHEMICAL OR NUCLEAR

OLS MANNED OR UNMANNED

29.0 SPECIAL PROBLEMS

29.1 LIGHTING – NATURAL AND ARTIFICIAL

29.2 COMMUNICATIONS

29.3 ----

(APPROX. 70 STUDY AREAS IDENTIFIED)

HAZARD STUDY EXAMPLE 2, STUDY AREA 3.1

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HAZARDS ANALYSIS STUDY AREA 3.1 – THE UNCOOPERATIVE OR DISABLED PRIME TRANSPORT VEHICLE IN LUNAR ORBIT

PTV DELIVERY OF THE UNMANNED ORBITING LUNAR STATION

This situation is unique in that the PTV and payload are dispatched to lunar orbit in an unmanned remote-operating mode. All maneuvers and activities are to be executed remotely including return of the PTV to earth orbit. The singularity of the situation is the fact that any major function failure which results in vehicle stranding in lunar orbit can only be remedied via a subsequent manned mission.

The significant PTV function failures (i.e., failure of PTV to respond to internally programmed or externally transmitted commands, or system failures which inhibit execution of commanded vehicle operations) can occur in either the operational 60 nm. circular polar orbit or in some segment of a planned lunar departure sequence resulting in an elliptical orbit of some dimension.

DETAILED HAZARDS ANALYSIS (TYPICAL) — STUDY AREA 3.1

LOCKHEED

STUDY TITLE: UNCOOPERATIVE OR DISABLED PRIME TRANSPORT VEHICLE IN LUNAR ORBIT

INTRODUCTION: THE MAJOR OPERATION WHICH CAN INVOLVE AN UNCOOPERATIVE OR DISABLED PTV IN LUNAR ORBIT ARE IDENTIFIED AS FOLLOWS:

- FIRST PTV DELIVERY OF AN UNMANNED PAYLOAD, SPECIFICALLY THE ORBITING LUNAR STATION.
- SUBSEQUENT PTV DELIVERIES OF MANNED AND UNMANNED PAYLOADS.
- VARIATIONS OF THE ABOVE SITUATIONS WHICH DERIVE FROM THE PTV BEING EITHER A CHEMICAL OR NUCLEAR PROPULSION SYSTEM.

ASSUMPTIONS — THE POSTULATED FUNCTION FAILURES:

- PTV FUNCTIONAL FAILURE PREVENTS VEHICLE FROM EXECUTING PAYLOAD VICINITY DEPARTURE MANEUVERS AND RENDERS VEHICLE TOTALLY UNCOOPERATIVE IN OPERATIONAL ORBIT.
- PTV SUCCESSFULLY EXECUTES FIRST BURN OF 3-BURN LUNAR ORBIT DEPARTURE SEQUENCE BUT FAILS TO EXECUTE SUBSEQUENT MANEUVERS. RESULTANT ELLIPTICAL ORBIT PERIGEE IS 60 NM.

HAZARDS DESCRIPTION – STUDY AREA 3.1

The major hazard in either assumed situation is the uncooperative or disabled PTV in lunar orbit. The hazard and its consequences are largely residual in nature and have the following implications:

PTV in operational orbit:

- Potential PTV and OLS collision resulting in damage or destruction, due chiefly to PTV venting-induced rates and/or motions.
- Potential future navigational and OLS access obstacle presented by large uncooperative vehicle in operational lunar orbit.
- Potential radiological hazard to future manned mission (nuclear only).

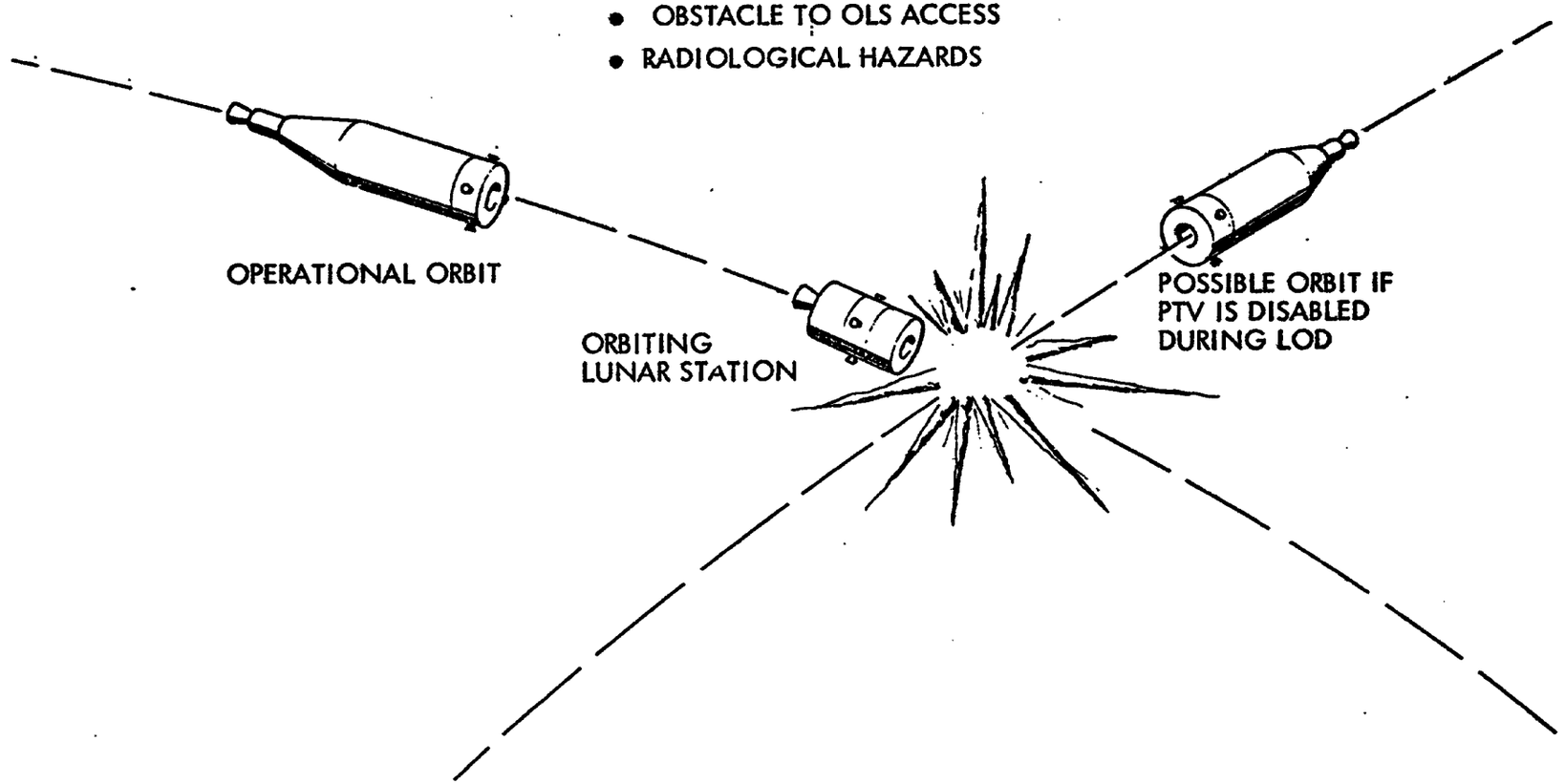
PTV in departure orbit:

- Potential for PTV and OLS collision at some future time since orbit altitudes coincide at elliptical orbit perigee.
- Potential navigational hazard to subsequent lunar orbit mission activities both in the operational orbit and lunar orbit departure.

HAZARDS DESCRIPTION — STUDY AREA 3.1

HAZARD POTENTIALS:

- PTV AND OLS COLLISION
- NAVIGATION HAZARD
- OBSTACLE TO OLS ACCESS
- RADIOLOGICAL HAZARDS



HAZARDS EFFECTS – STUDY AREA 3.1

The major effects of the hazards deriving from an uncooperative or disabled PTV in lunar orbit are as follows:

For non-collision situations – as given in chart.

For collision situations – the consequences resulting from a collision of the unmanned OLS with a disabled PTV in the operational orbit, where both vehicles have very closely the same orbital energy, are not likely to be totally catastrophic in nature. However, a collision at coincident orbits would be catastrophic. The residual effects in either case are:

- Necessity for a potentially hazardous inspection and damage survey mission to ascertain future OLS and PTV usability and/or salvage potential.
- Should the PTV be a nuclear vehicle which has suffered severe structural damage, a mission requirement will then exist for the remote capture of the wreckage for disposal purposes in order to remove the ultimate possibility of nuclear engine lunar impact.

HAZARDS EFFECTS — STUDY AREA 3.1

- LOSS OF PTV FOR LOGISTIC MISSION UTILIZATION – SERIOUS DELAY IN OVERALL MISSION PROGRAM SCHEDULE IF LOSS IS PERMANENT.
- REQUIRES MODIFICATION OF SUBSEQUENT MANNED MISSION TO INCLUDE THE CAPTURE AND REGAINING CONTROL OF DISABLED PTV TO PERMIT UNRESTRICTED ACCESS TO OLS.
- MAY REQUIRE SPECIAL LOW-PAYLOAD MISSION OF SECOND PTV TO RETURN DISABLED PTV TO EARTH ORBIT FOR MAJOR SYSTEM REPAIR.

CORRECTIVE MEASURES – STUDY AREA 3.1

The preventive and remedial measures applicable to the postulated PTV functional failures are as follows:

Preventive measures – The PTV system design must include sufficient system redundancy and back-up mode operational capability to provide for contingency operation during all foreseeable critical mission maneuvers. It must not be possible for the PTV to become, in itself, an obstacle or hazard directly in the path of mission accomplishment.

Remedial measures – The PTV functional failures postulated permit no immediate remedial measures, since there would be no means of locally implementing such measures. However, delayed remedy of the postulated situations is possible in the subsequent manned mission which follows the OLS emplacement mission.

CORRECTIVE MEASURES — STUDY AREA 3.1

PREVENTIVE MEASURES:

- CRITICAL SYSTEMS DESIGNED TO FAIL-OPERATIONAL
- INCORPORATE INDEPENDENT ENGINE OPERATIONAL CAPABILITY FOR CHEMICAL PTV
- PROVIDE FOR NERVA ENGINE CONTINGENCY OPERATION CAPABILITY IN NUCLEAR PTV

REMEDIAL MEASURES:

- NONE AVAILABLE – UNMANNED SITUATION.

SAFETY GUIDELINES CANDIDATES – STUDY AREA 3.1

The safety guideline recommendations derivable from the postulated PTV function failure considered, are as follows:

- Propulsion Capability

  Chemical PTV – A back-up propulsion mode contingency capability shall exist in the vehicle, such that it is not possible for the PTV to be rendered totally disabled.

  Nuclear PTV – The nuclear engine shall be capable of contingency operation at a reduced thrust level sufficient to permit the placement of vehicle into a safe lunar orbit.

- Guidance and Control Capability

  Chemical or Nuclear PTV – The remote-mode of PTV operation shall incorporate two independent G & C systems. The programmable primary system shall fail operational to a direct command mode after which it shall fail-safe. The independent secondary G & C system shall utilize direct command links.

SAFETY GUIDELINE CANDIDATES — STUDY AREA 3.1

- PROPULSION SYSTEM CONTINGENCY OPERATION CAPABILITY IS REQUIRED FOR BOTH THE CHEMICAL AND THE NUCLEAR SHUTTLE VEHICLES.
- THE GUIDANCE AND CONTROL SYSTEMS FOR BOTH VEHICLES SHALL INCORPORATE AN INDEPENDENT EMERGENCY G&C SUBSYSTEM.
- ALL OTHER CRITICAL SYSTEMS MUST FAIL-OPERATIONAL FOR THE FIRST FAILURE IN EITHER VEHICLE.

HAZARDS DATA MATRICES

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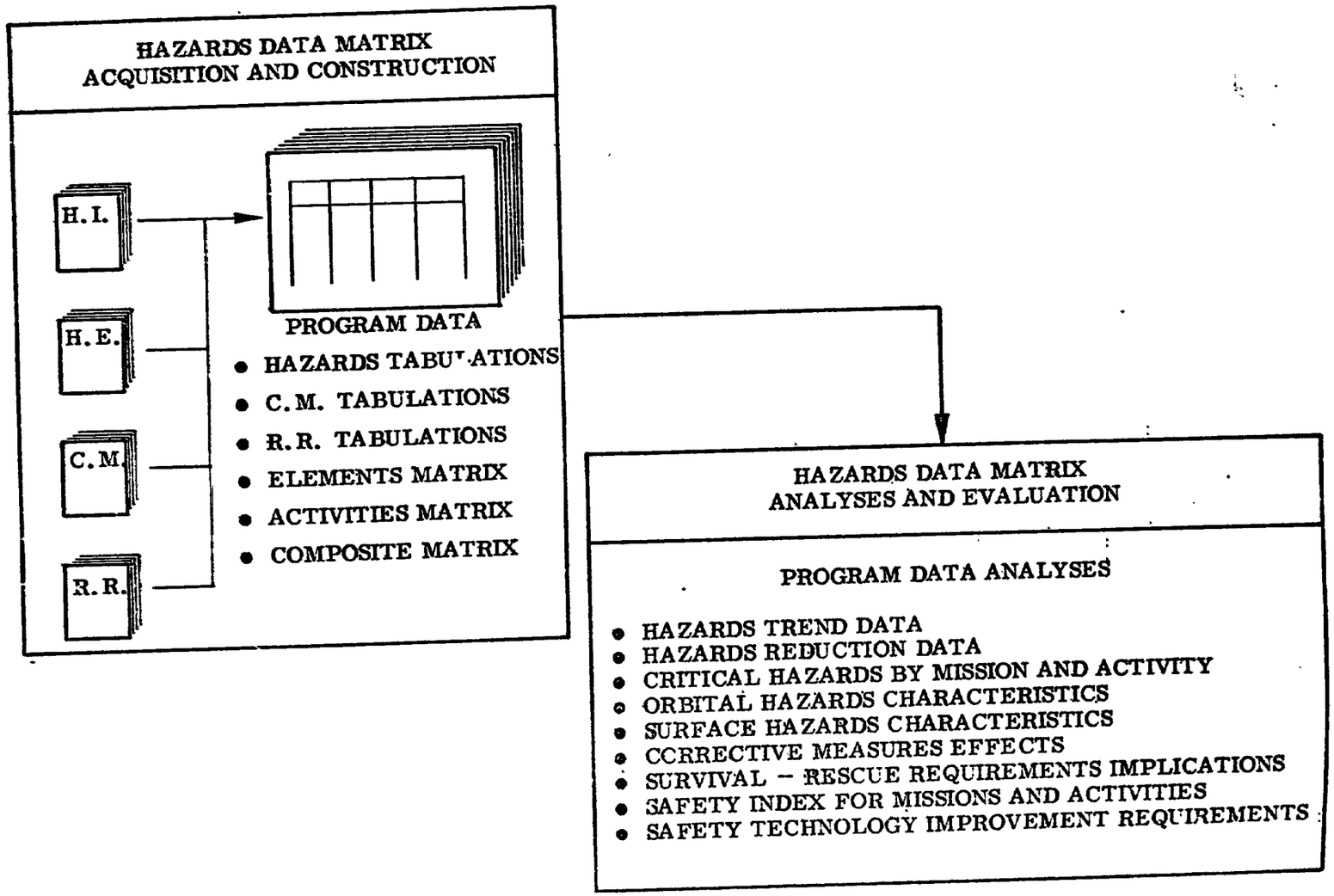
DATA ACQUISITION AND ANALYSIS

Pertinent data generated in the analytical studies are documented in the hazards data matrices, utilizing a set of formatted data tabulation sheets. Data reduction to matrix format provides an orderly method for mission and program element and activity comparison and evaluation. From the element and activity data matrices, a program formatted matrix is evolved to present the study information developed for the derivation and establishment of Advanced Lunar Program Safety Guidelines.

DATA ACQUISITION AND ANALYSIS



MATRIX FOR HAZARD SITUATION ASSESSMENT

The spectrum of operations and activities performed by the program elements may be reduced to matrix form. This matrix then serves as a checklist on the coverage of the significant events and activities considered in the hazards analysis and hazards data matrices. Many of the operations and activities occur repeatedly in missions involving the various program elements.

MATRIX FOR HAZARD SITUATION ASSESSMENT

OPERATION OR ACTIVITY \ ELEMENT	PTV	OLS	TUG	CM	OFD	LSSM	LRV	LFV	LSB
ORBITAL INSERTION AND DEPARTURE (LOI, LOD, TEI, STATIONKEEPING)	●	●	●		●				
RENDEZVOUS, DOCKING, AND SEPARATION	●	●	●	●	●				
ORBIT TRANSFER AND PHASING	●		●	●					
PAYLOAD TRANSFER AND CARGO HANDLING	●	●	●	●		●	●	●	●
FUEL DEPOT AND REFUELING OPERATIONS	●		●	●	●				
EVA AND IVA OPERATIONS		●	●	●		●	●	●	●
OLS ACTIVATION	●	●	●	●					
DESCENT TO LUNAR SURFACE			●	●					
ASCENT FROM LUNAR SURFACE			●	●					
LUNAR SURFACE OPERATIONS			●	●		●	●	●	●
LSB EMPLACEMENT		●	●		●				●
SURFACE BASE OPERATIONS			●	●	●	●	●	●	●
EQUIPMENT DEPLOYMENT		●	●			●	●	●	●
SURFACE EXPLORATION			●	●		●	●	●	●
SURFACE SCIENCE			●	●		●	●	●	●

PTV – PRIMARY TRANSPORT VEHICLE
OLS – ORBITING LUNAR STATION
CM – CREW MODULE
OFD – ORBITING FUEL DEPOT

LSSM – MEDIUM SIZE ROVER
LRV – CABIN ROVER
LFV – LUNAR FLYER
LSB – LUNAR SURFACE BASE

HAZARDS DATA MATRIX STRUCTURE

The hazards data matrices presented in the matrix structure chart are in reality summary tables arranged to present the available data in a useful format. The logic utilized in each format is structured to develop guideline information regarding the impact of potential hazardous conditions and situations involving man, machines, and environment upon a planned program.

HAZARDS DATA MATRIX STRUCTURE

1. HAZARDS DATA MATRIX – I
   - TABULATION OF HAZARDS DATA BY PROGRAM ELEMENT FOR SEQUENTIAL MISSION EVENTS AND ACTIVITIES
2. HAZARDS DATA MATRIX – II
   - TABULATION OF HAZARDS DATA ABSTRACTED FROM MATRIX – I AND ARRANGED BY:
     - HAZARDS UNIQUE TO PROGRAM ELEMENTS
     - HAZARDS UNIQUE TO MISSION EVENTS
     - HAZARDS UNIQUE TO MISSION ACTIVITIES
3. HAZARDS DATA MATRIX – III
   - TABULATION OF HAZARDS DATA ABSTRACTED FROM MATRIX – I AND ARRANGED BY:
     - ORBITAL OPERATIONS AND ACTIVITIES
     - SURFACE OPERATIONS AND ACTIVITIES
     - ORBITAL AND SURFACE INTERFACE HAZARDS
4. PROGRAM HAZARDS DATA MATRIX
   - TABULATION OF DATA ABSTRACTED FROM MATRICES – I, II, AND III, ARRANGED BY SEVERITY OF IMPACT UPON THE ADVANCED LUNAR EXPLORATION PROGRAM. THE DATA IS TO BE PRESENTED IN ORDER OF DECREASING SEVERITY FOR:
     - PROGRAM ELEMENTS
     - PROGRAM OPERATIONS
     - PROGRAM ACTIVITIES

THE HAZARDS DATA MATRIX-I FORMAT IS ILLUSTRATED IN PARTIALLY COMPLETED FORM IN THE NEXT THREE PAGES. A COMPLETED SET OF THE MATRIX-I SHEETS WILL INCLUDE ALL DEFINED PROGRAM ELEMENTS AND ALL SIGNIFICANT OPERATIONAL EVENTS AND ACTIVITIES SPECIFIED IN THE REFERENCE MISSION MODEL.

HAZARD DATA MATRIX – I (EXAMPLE, PART I)

ELEMENT: PRIMARY TRANSPORT VEHICLE (PTV) *E* - CHEMICAL OR NUCLEAR SHUTTLE

OPERATIONAL EVENT	FUNCTION FAILURE	OPERATIONAL HAZARD
LUNAR ORBIT INSERTION:		
A. 1st unmanned mission; *E*	1. Loss of main propulsion 2. Loss of guidance and control 3. Loss of vehicle electrical power	A. Loss of primary transport vehicle and payload
B. 1st manned mission: *E*	1. Loss of main propulsion 2. Loss of guidance and control 3. Loss of vehicle electrical power	B. Potential loss of primary transport vehicle and manned payload
C. Subsequent manned missions *E*	1. Loss of main propulsion 2. Loss of guidance and control 3. Loss of vehicle electrical power	C. Potential loss of primary transport vehicle and manned payload

HAZARD DATA MATRIX —I (FORMAT)

ELEMENT: _____

OPERATIONAL EVENT	FUNCTION FAILURE	OPERATIONAL HAZARD

HAZARDS EFFECTS	HAZARD LEVEL	ACTION REQUIRED	CORRECTIVE MEASURES

SAFETY GUIDELINE CONSIDERATIONS	REFERENCE DOCUMENTATION

HAZARD DATA MATRIX – I (EXAMPLE, PART 2)

ELEMENT: PRIMARY TRANSPORT VEHICLE (PTV)

Hazards Effects	Hazard Level	Action Required	Corrective Measures
A. Heliocentric, selenocentric or geocentric orbit insertion is possible. Potential for earth or lunar surface impact exists.	A	None possible	A. Preventive – alternate contingency modes of operation for critical vehicle functions A. Remedial – no immediate remedial measures available. Delayed remedy possible thru chase and capture by earth orbit based vehicle
B. Stranded crew on tug stack payload aboard disabled PTV. Orbit insertion potential as "A" above.	B TO A	Escape required	B. Preventive – as in A. Preventive – given above B. Remedial – crew escape possible by having tugs activated and powered up prior to LOI. Requires emergency separation and orbit transfer to lunar orbit or earth return orbit
C. Stranded crew in crew module on cargo stack aboard disabled PTV. Orbit insertion potential as given in "A" above. NOTE: Crew module has no propulsion capability.	B TO A	Rescue required	C. Preventive – as in A. Preventive – given above C. Remedial – crew and crew module must be rescued via OLS based tug vehicle chase and capture required. Requires OLS based tug to be in rapid-response configuration at time of PTV scheduled arrival

HAZARD DATA MATRIX – I (EXAMPLE, PART 3)

ELEMENT: PRIMARY TRANSPORT VEHICLE (PTV)

	SAFETY GUIDELINE CONSIDERATIONS	REFERENCE DOCUMENTATION
	PROPULSION CAPABILITY	LMS & R – Lunar orbital missions 1, 2 and 4 MSC-IPP reference schedule-high budget base-LOS traffic schematic, 5/19/70 LMSC – Nuclear flight system definition study – final briefing, LMSC-A968323, May 19, 1970 LMSC & R Study – Analysis study area 1.1.
A. B. &C.	Chemical PTV – A back-up propulsion mode contingency capability shall exist in the vehicle, such that it is not possible for the PTV to be totally disabled.	
A. B. &C.	Nuclear PTV – The nuclear engine shall be capable of contingency operation at a reduced thrust level to permit the placement of vehicle into a safe lunar orbit.	
	G & C CAPABILITY	
A. B. &C.	Chemical or nuclear PTV – The remote-mode of PTV operation shall incorporate two independent G&C systems. The programmable primary system shall fail operational to a direct command mode after which it shall fail-safe. The independent secondary G&C system shall utilize direct command links and brute-force control techniques.	
	ELECTRICAL POWER REDUNDANCY	
A. B. &C.	Chemical or nuclear PTV – A basic requirement for the PTV power supply system is that it shall fail-operational, fail-safe to a battery bank.	
	MANNED PAYLOAD SAFETY	
C.	Crew module – In the event of PTV malfunction or loss of vehicle integrity, a payload crew module shall have the capability of leaving the PTV and performing an abort orbit achievement maneuver. This maneuver shall be defined as the minimum ΔV required to place the crew module in a non-impact lunar "await-rescue" orbit.	

HAZARDS ANALYSIS SUMMARY

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ANALYSES TO BE COMPLETED

- ORBITAL AND SURFACE STUDIES CURRENTLY UNDERWAY
- REVIEW OF ALTERNATE OPERATION MODES FOR ORBITAL AND SURFACE STUDIES
- REVIEW OF HAZARDS STUDIES VALIDITY FOR PROGRAM CONSTRAINTS, (I.E., NO OLS, SMALLER TUGS, ETC.).
- HAZARDS OF RESCUE OPERATIONS

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DATA MATRICES TO BE COMPLETED

- MATRIX-I — JUST STARTED
- MATRIX-II — EARLY JAN 1971
- MATRIX-III — EARLY JAN 1971
- PROGRAM MATRIX — LATE JAN 1971

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HAZARDS ANALYSIS STATUS SUMMARY

HAZARDS EVALUATION CRITERIA	COMPLETE
HAZARDS CHARACTERIZATION	COMPLETE
HAZARDS ANALYSIS METHODOLOGY	DEVELOPED
FIRST LEVEL HAZARDS ANALYSES	COMPLETE
HAZARD STUDY AREAS IDENTIFICATION	COMPLETE
DETAILED HAZARD AREA STUDIES	50% COMPLETE
HAZARD DATA MATRICES	WORK STARTED

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ESCAPE/RESCUE ANALYSIS

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ESCAPE/RESCUE TASK OBJECTIVES

The advanced lunar missions planned by NASA for the post Apollo period involve new hardware concepts, environmental exposures, and operational factors. In addition the flight personnel could include scientists and technicians as well as highly trained astronauts. The escape/rescue analysis task will produce a rescue plan that will identify the emergency survival equipment, escape/rescue vehicle concepts, and operational techniques needed to ensure the best chance for survival.

ESCAPE/RESCUE TASK OBJECTIVE

PRODUCE A REALISTIC RESCUE PLAN APPLICABLE TO ADVANCED LUNAR MISSIONS

ESCAPE/RESCUE TASK SCOPE

The escape/rescue analysis task is being directed at all hardware and operational situations associated with the advanced lunar mission. The chart lists types of hardware that may be used in each of three operational areas: surface, orbit, and arrival/departure.

ESCAPE/RESCUE TASK SCOPE

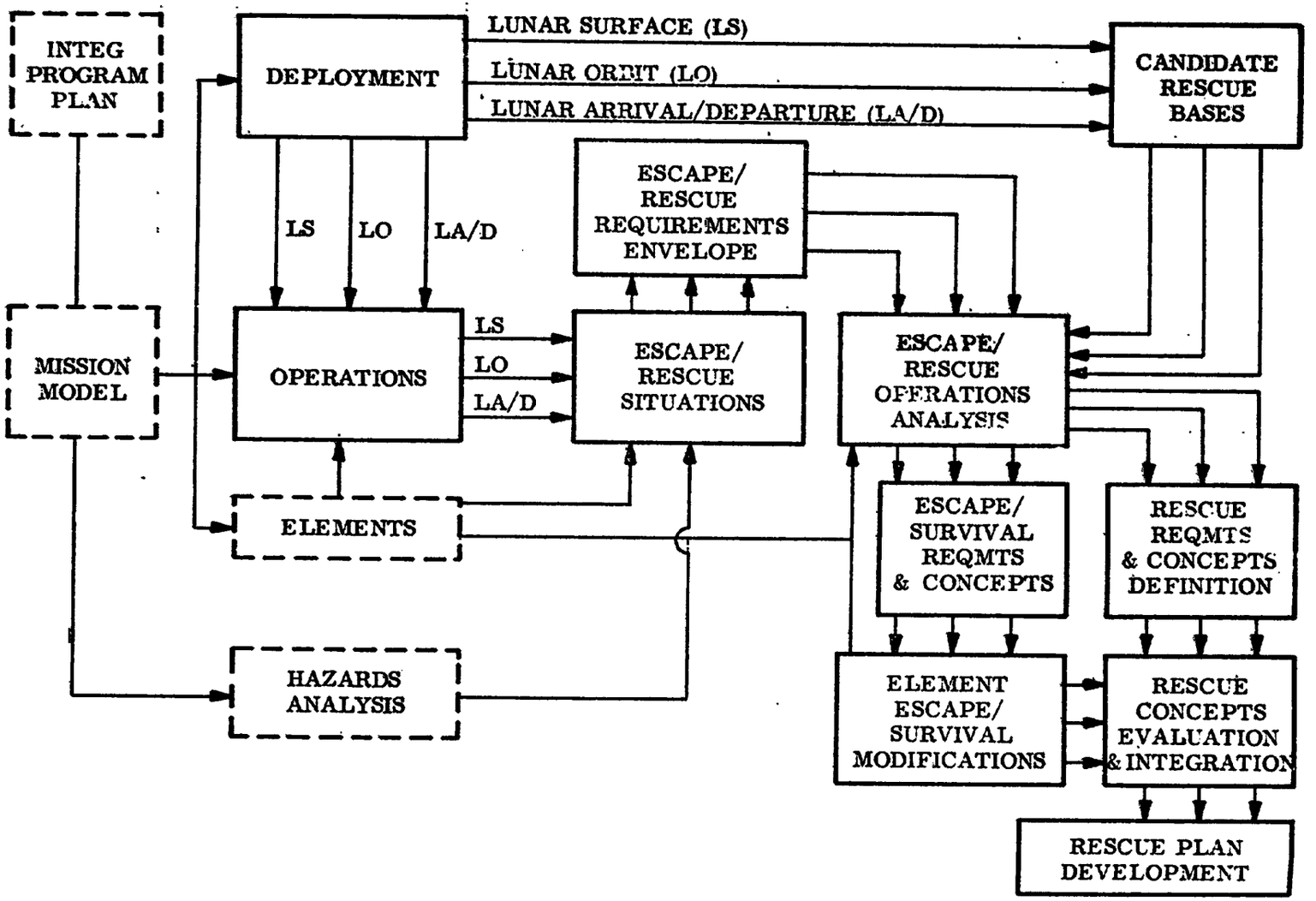
LUNAR SURFACE	LUNAR ORBIT	LUNAR ARRIVAL & DEPARTURE
• SURFACE BASE	• SHUTTLE	• REUSABLE NUCLEAR SHUTTLE
• LUNAR LANDER TUG	• TUG	• CHEMICAL PROPULSION SHUTTLE
• SURFACE ROVER	• FUEL DEPOT	
• FLYER	• ORBITING LUNAR STATION	

ESCAPE/RESCUE ANALYSIS TASK APPROACH

The baseline for the escape/rescue analysis task approach is composed of the various hardware elements involved in the advanced lunar program, their deployment in the lunar area, and their operational utility. For analysis purposes the task is separated into three parts based upon hardware element deployment, lunar surface, lunar orbit, and lunar arrival/departure.

Escape/rescue situations are developed based on both planned operations with the various IPP hardware elements and on inputs from the hazards analysis task. A requirements envelope is then established, expressed in terms of operational and performance limits and constraints. Candidate rescue and escape/survival requirements and concepts are then defined, based on an operations analysis and trade-off evaluation. The rescue plan will include all escape/rescue guidelines and concepts, and will specify the required modifications and additions of IPP hardware elements and operations. The rationale supporting these results will also be included.

ESCAPE/RESCUE ANALYSIS TASK APPROACH



ESCAPE/RESCUE DEFINITIONS AND GUIDELINES

Here are listed and defined some of the key escape/rescue analysis definitions and guidelines:

Survival time	The span of time that a crewman remains alive after an emergency has occurred.
Response time	The span of time between occurrence of an emergency and the escape or rescue of the stranded crew and their placement into a safe haven.
Escape	Departure from the emergency site using resources in the immediate vicinity with no outside assistance.
Rescue	Departure from the emergency site using resources and assistance from outside the emergency site.
Surface rescue	Rescue of personnel from an emergency site on the lunar surface.
Orbital rescue	Rescue of personnel from an orbital emergency site.
Safe haven	Either a temporary or permanent facility that provides life support and environmental control capability in a planned manner.

ESCAPE/RESCUE DEFINITIONS & GUIDELINES

- SURVIVAL TIME
- RESPONSE TIME
- ESCAPE
- RESCUE
- SURFACE RESCUE
- ORBITAL RESCUE
- SAFE HAVEN

LUNAR SURFACE ESCAPE/RESCUE

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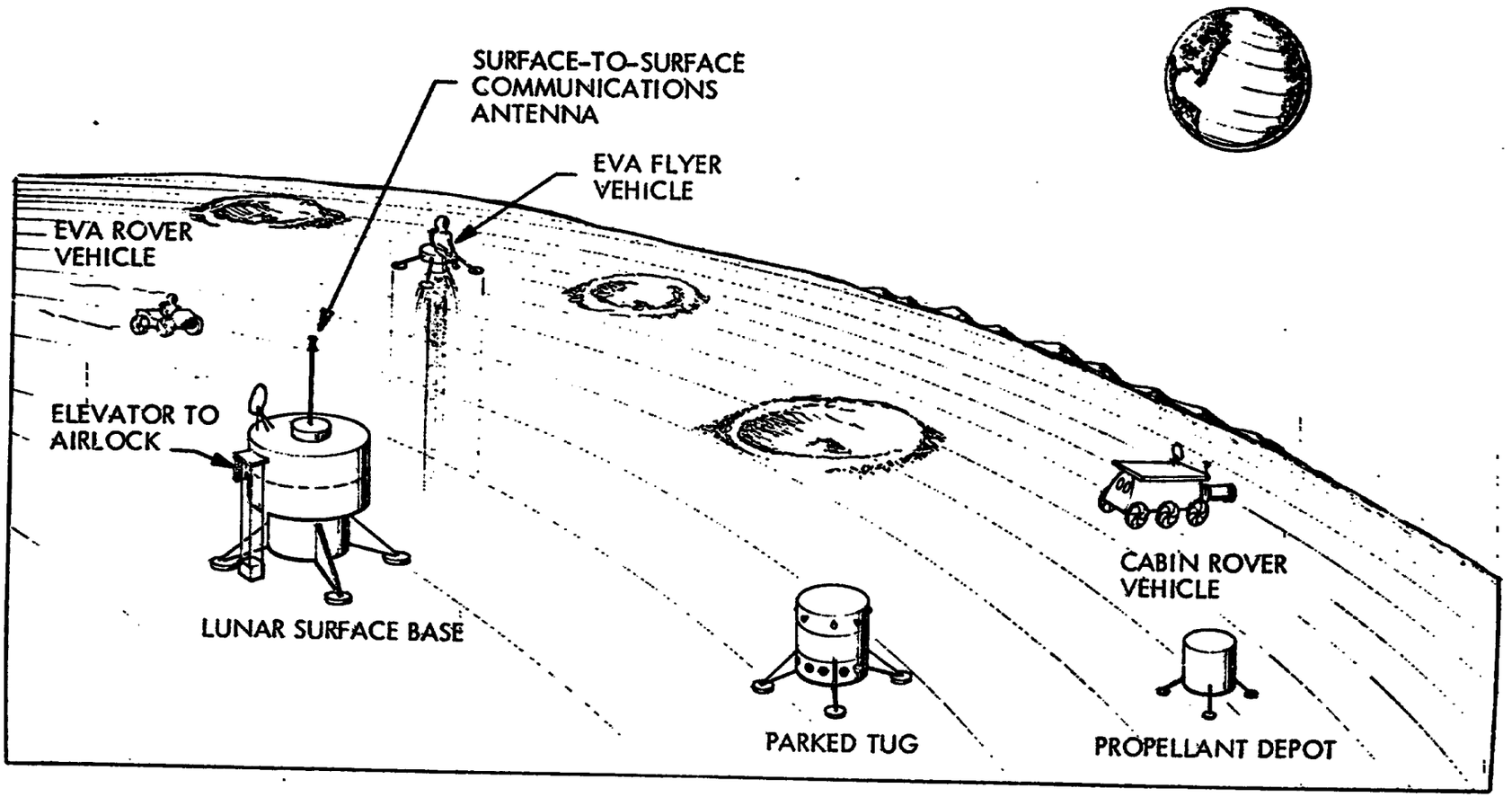
LUNAR SURFACE BASE

This chart depicts the Lunar Surface Base (LSB) and supporting key items of equipment that could be deployed. The tug landing area will be at least 1-1/4 nm from the LSB to preclude damage due to lunar surface material being scattered by the rocket blast effect of a landing or departing tug, or shrapnel damage due to a tug explosion.

The height of the surface-to-surface communications antenna depends on the desired operating range in the vicinity of the LSB. For an antenna height of 50 feet and a tug height of 75 feet the tug-to-surface communications range would be approximately 6 nm.

LUNAR SURFACE BASE



TYPICAL SITUATIONS IN VICINITY OF LSB

The spectrum of personnel distribution situations can be grouped into eight baseline cases. Note that in all cases but one, two or more crewmen are not in the LSB but are on traverse and/or in the tug.

TYPICAL SITUATIONS IN VICINITY OF LSB

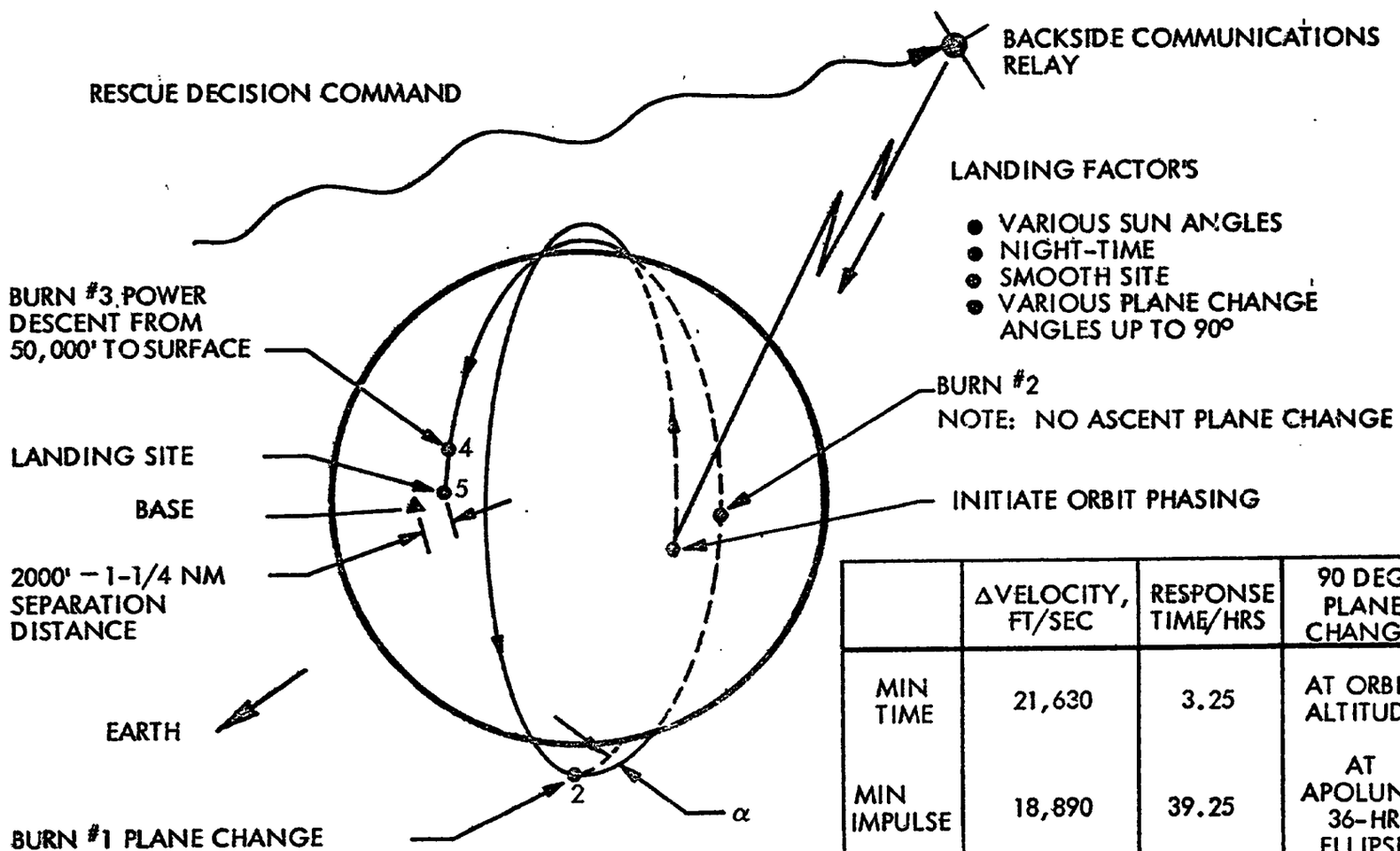
CASE NO.	DISTRIBUTION OF PERSONNEL ON			TOTAL NUMBER OF PERSONNEL	*NUMBER OF TUGS NEAR BASE	SITUATION
	BASE	TRAVERSE	TUG			
1	6	0	0	6	1	REST CYCLE
2	4	2	0	6	1	NORMAL WORKING DAY
3	2	4	0	6	1	SPECIAL PROJECTS WORKING DAY
4	6	2	4	12	2	UNLOADING SUPPLIES & EQUIPMENT
5	6	4	2	12	2	TRANSFERRING PERSONNEL & SUPPLIES
6	8	2	2	12	2	INITIAL CREW ROTATION & BRIEFINGS
7	4	2	6	12	2	FINAL CREW ROTATION
8	6	0	6	12	2	PREPARATION TO RETURN TO LOSS

*1 TUG ALWAYS AT POPULATED BASE

LSB ORBITAL RESCUE OPERATIONS

The sequence of events between receipt of the decision to rescue to touchdown at the Lunar Surface Base (LSB) is depicted here. The required plane change for a polar orbiting rescue tug could be as much as 90°. There are two general orbit rescue trajectory and consequent response time approaches: (1) minimum time for which the required plane change is made at the orbit altitude, and (2) minimum impulse which requires the tug to inject into a 36-hour period ellipse with the required plane change executed at apolune. The minimum impulse approach results in a potential saving of 2750 feet/second of impulse velocity for the 90° plane change case.

LSB ORBITAL RESCUE OPERATIONS



	ΔVELOCITY, FT/SEC	RESPONSE TIME/HRS	90 DEG PLANE CHANGE
MIN TIME	21,630	3.25	AT ORBIT ALTITUDE
MIN IMPULSE	18,890	39.25	AT APOLUNE 36-HR ELLIPSE

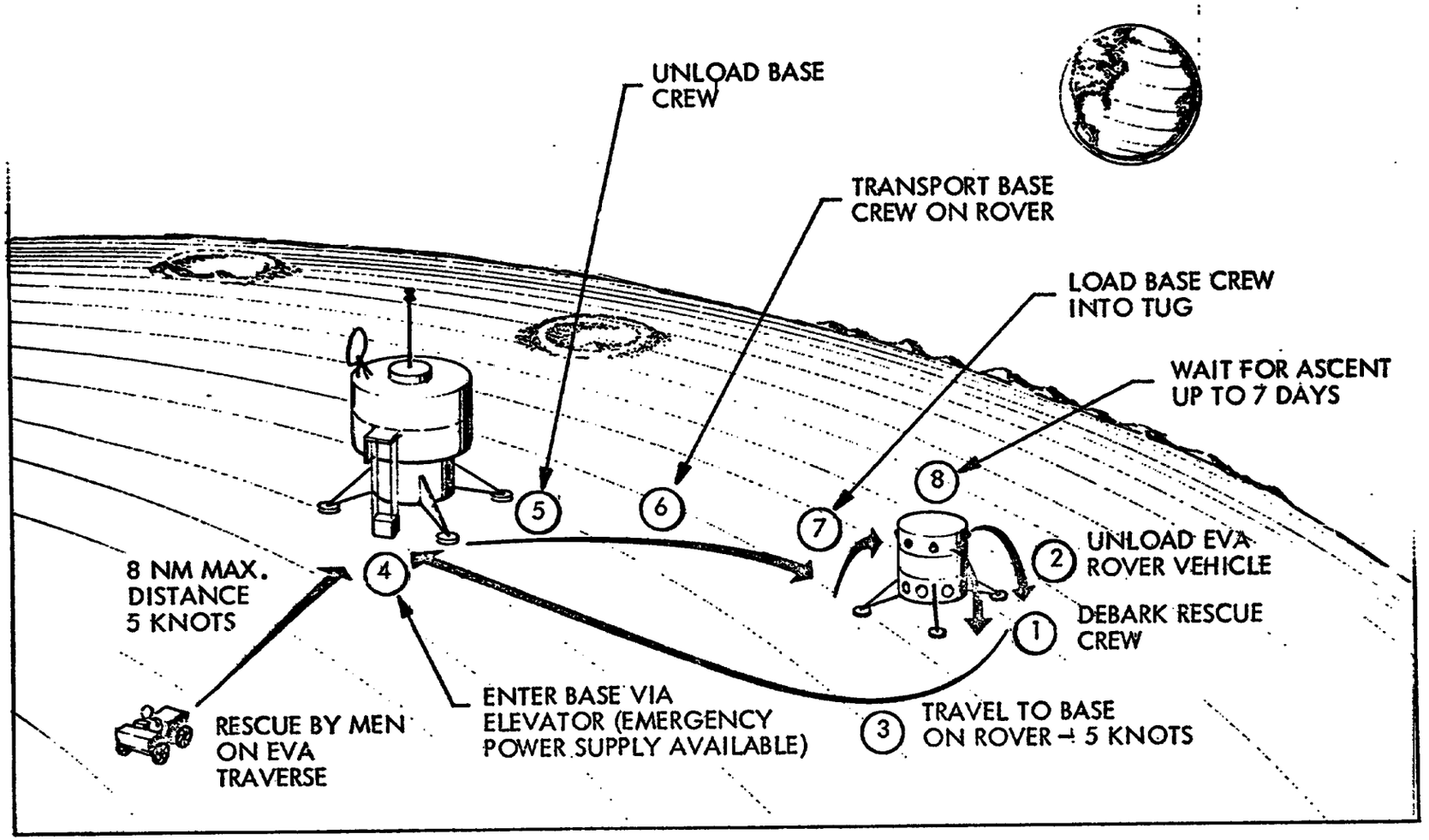
LSB SURFACE RESCUE OPERATIONS

Here the crew in the Lunar Surface Base (LSB) requires outside rescue assistance. Two alternate approaches seem promising:

(1) Two or more crewmen are present in the tug and can debark, ride a rover vehicle to the base, recover the stranded crew and return to the tug. The tug then waits up to seven days to take advantage of the approximate 0.5 deg/hour orbital rotation rate of the moon and thereby eliminate the required plane change. The tug then departs in phase with the orbiting OLS and completes rendezvous and docking maneuvers.

(2) A crew is on a traverse mission in the near vicinity of the LSB and can return to carry out the rescue mission. In this latter case the parked tug would again be used as a temporary safe haven until the tug could depart for a return to the OLS.

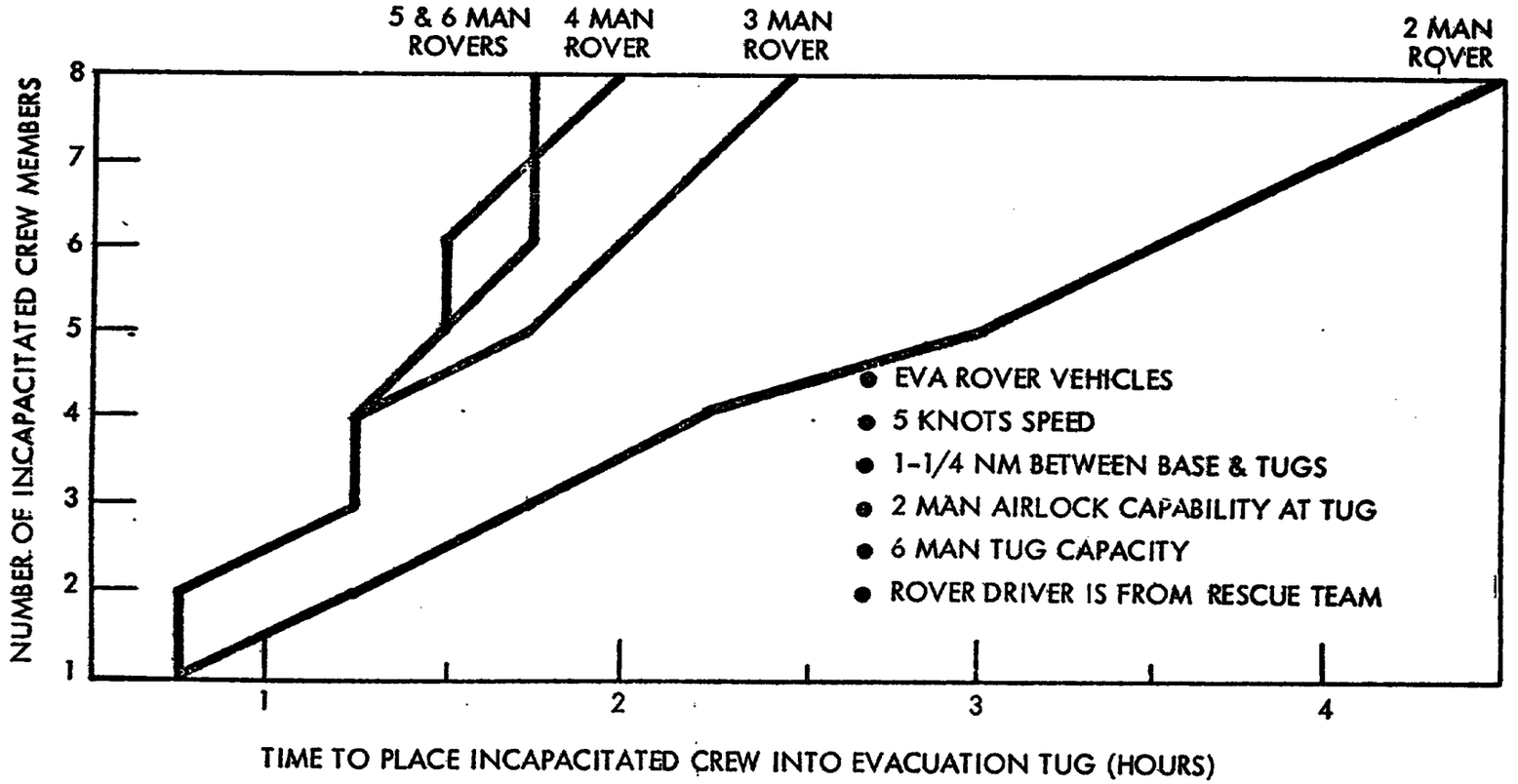
LSB SURFACE RESCUE OPERATIONS



EVACUATION CAPABILITIES – LUNAR SURFACE BASE TO PARKED TUG

One of the critical response time variables is the time span required to place the stranded crew members into the rescue tug. The time span needed for transporting the crew on rover vehicles with a range of crew-carrying capabilities is the major variable. This chart displays the required time span for various capacity rover vehicles and number of crewmen.

EVACUATION CAPABILITIES (LUNAR SURFACE BASE TO PARKED TUG(S)



RESPONSE TIME OF RESCUE PLANS

This chart presents the factors influencing the required response time for various rescue situations. Note that rescue of a crew stranded in the Lunar Surface Base can be performed by a surface crew in about one-half the time required for orbital rescue.

RESPONSE TIMES OF RESCUE PLANS (HOURS)

	RESCUE FROM LUNAR ORBIT		RESCUE BY SURFACE CREW VIA PARKED TUG	
	NO BACKSIDE COMMUNICATIONS RELAY	WITH BACKSIDE COMMUNICATIONS RELAY	RESCUE CREW ON EVA ROVER TRAVERSE	RESCUE CREW IN PARKED TUG
MAXIMUM CREW TO BE RESCUED	6	6	4	8
• CONTACT DELAY TIME	1.0	–	–	–
• DECISION TIME	0.25	0.25	0.25	0.25
RESCUE INITIATION TIME INTERVAL	1.25	0.25	0.25	0.25
• DESCENT/LANDING TIME	3.25	3.25	–	–
• DEBARCATION OF RESCUE CREW	0.25	0.25	–	0.25
• UNLOAD ROVER VEHICLE	0.75	0.75	–	0.75
• TRIP TIME TO BASE	0.25	0.25	1.6	0.25
• ENTRY INTO BASE	0.25	0.25	0.25	0.25
ARRIVAL TIME INTERVAL	5.0	5.0	1.85	1.5
REMOVAL TIME INTERVAL				
2 MAN ROVER VEHICLE	3.5	3.5	2.25	4.50
5 MAN ROVER VEHICLE	1.5	1.5	1.25	1.25
TOTAL TIME INTERVAL				
2 MAN ROVER VEHICLE	9.50	8.50	4.35	6.25
5 MAN ROVER VEHICLE	7.50	6.50	3.35	3.0

LUNAR TRAVERSE ESCAPE/RESCUE

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LUNAR SURFACE MOBILITY VEHICLES

There are two classes of mobility vehicles; the EVA and pressurized cabin types. The ranges of the former are limited mainly by the capacities of the portable life support systems. The pressurized cabin vehicles may go on extended traverses, using EVA for the actual exploration by the crew at various stopping points. From a rescue point of view the most important characteristics of the vehicles are the maximum ranges and speeds of the vehicles, the number of men they carry, and the life support time-to-go. The mobility vehicles may break down on a traverse, and the crew must be rescued. The vehicles can also serve as rescue vehicles if necessary.

LUNAR SURFACE MOBILITY VEHICLES

CLASS OF VEHICLE	NAME	CREW	NOMINAL TRAVERSE TIME	RANGE (NM)	VELOCITY (KNOTS)
EVA	APOLLO ROVER VEHICLE 4 WHEEL	2	PLSS LIFE	16	3-1/2
	DUAL MODE ROVER VEHICLE 6 WHEEL	2	PLSS LIFE	16 MANNED 540 UNMANNED	4
	LUNAR FLYER VEHICLE	1	PLSS LIFE	10	180
	UPRATED LUNAR FLYER VEHICLE	2	PLSS LIFE	30	180
	GROUND EFFECTS MACHINE	1	PLSS LIFE	22	14
PRESSURIZED CABIN	SMALL CABIN ROVER	2	14 DAYS	270	5.4
	LARGE CABIN ROVER	2	24 DAYS	400	5.4

EVA TRAVERSE RESCUE SITUATIONS

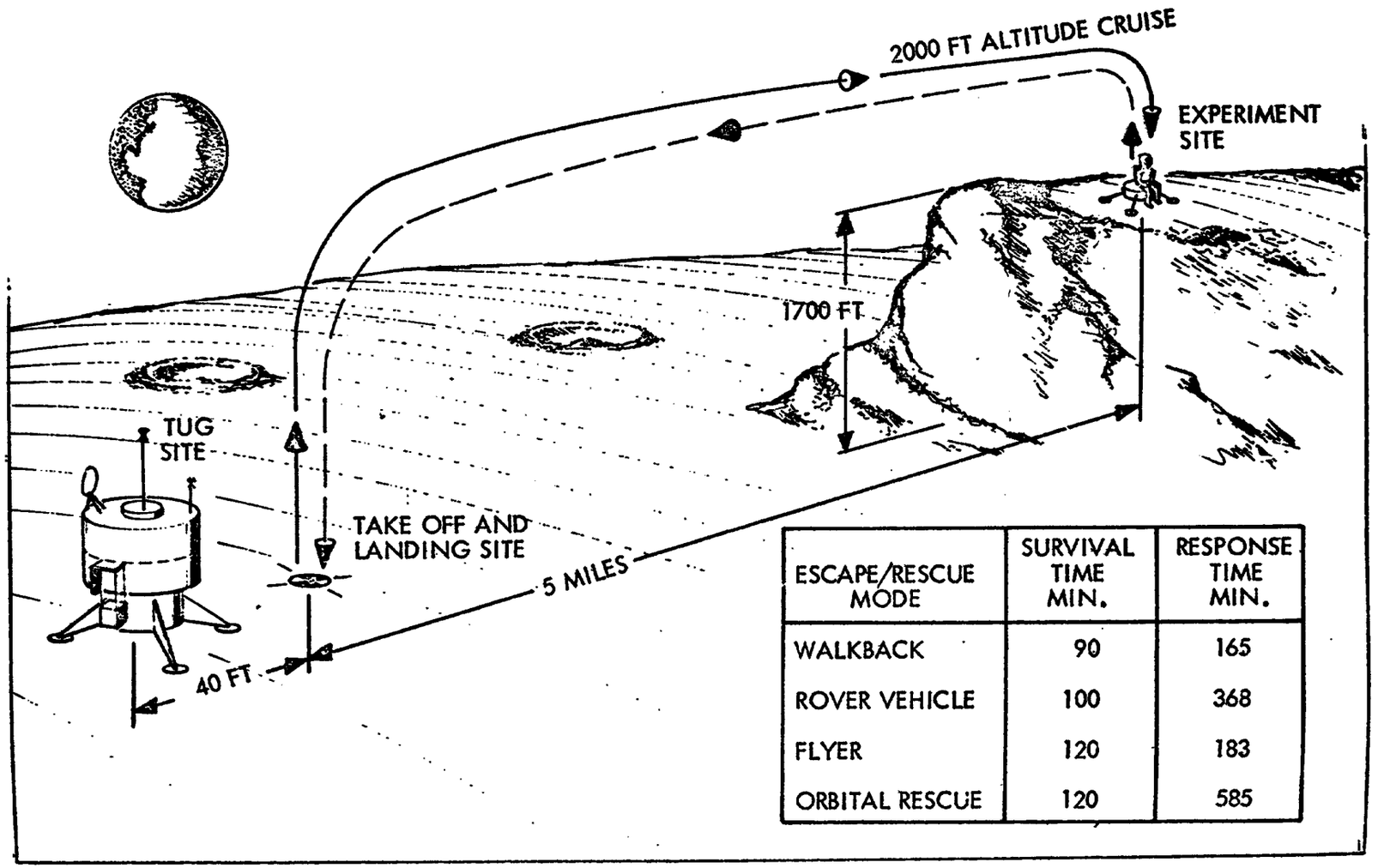
The rescue situations shown here are for the mobility vehicles described on the previous chart. The terrain limits represent the operational constraints for the particular vehicle. The rover position uncertainty is based on the nominal velocity capability of the rover and assumes that the malfunction occurred just before a planned 5-minute interval reporting time. The flyers could experience a malfunction at any point along their flight path and could overshoot a planned landing site by 4500 feet if the malfunction occurred just prior to landing. The ground effects vehicle could also malfunction at any point along its planned traverse path.

VEHICLE	CREW	TERRAIN LIMITS	POSITION UNCERTAINTY
ROVER	2	SMOOTH, GENTLE SLOPES	1700 FT X 4000 FT (5 MINUTE REPORTING PERIOD)
FLYER	1	ELEVATED LOCATIONS, SEVERE SLOPES	0-5 NM ALONG TRAVERSE PATH 4500 FT OVERSHOOT OF LANDING SITE
UPRATED FLYER	2	ELEVATED LOCATIONS, SEVERE SLOPES	0-15 NM ALONG TRAVERSE PATH 4500 FT OVERSHOOT OF LANDING SITE
GROUND EFFECTS MACHINE	1	SMOOTH TO ROUGH, GENTLE SLOPES	0-1.4 NM ALONG TRAVERSE PATH

LUNAR FLYER ESCAPE/RESCUE SITUATION

Here a typical flyer mission is presented. The one crewman is on PLSS and could experience a disabling flyer malfunction during activation and checkout just prior to returning to the base. There are four approaches available for escape/rescue as listed on the chart. The lower survival times for the walkback and rover vehicle modes is due to increased metabolic rates because the crewman is walking. For the rover vehicle he must walk until he reaches a terrain condition over which the rover vehicle can operate and meet him.

LUNAR FLYER ESCAPE/RESCUE SITUATION

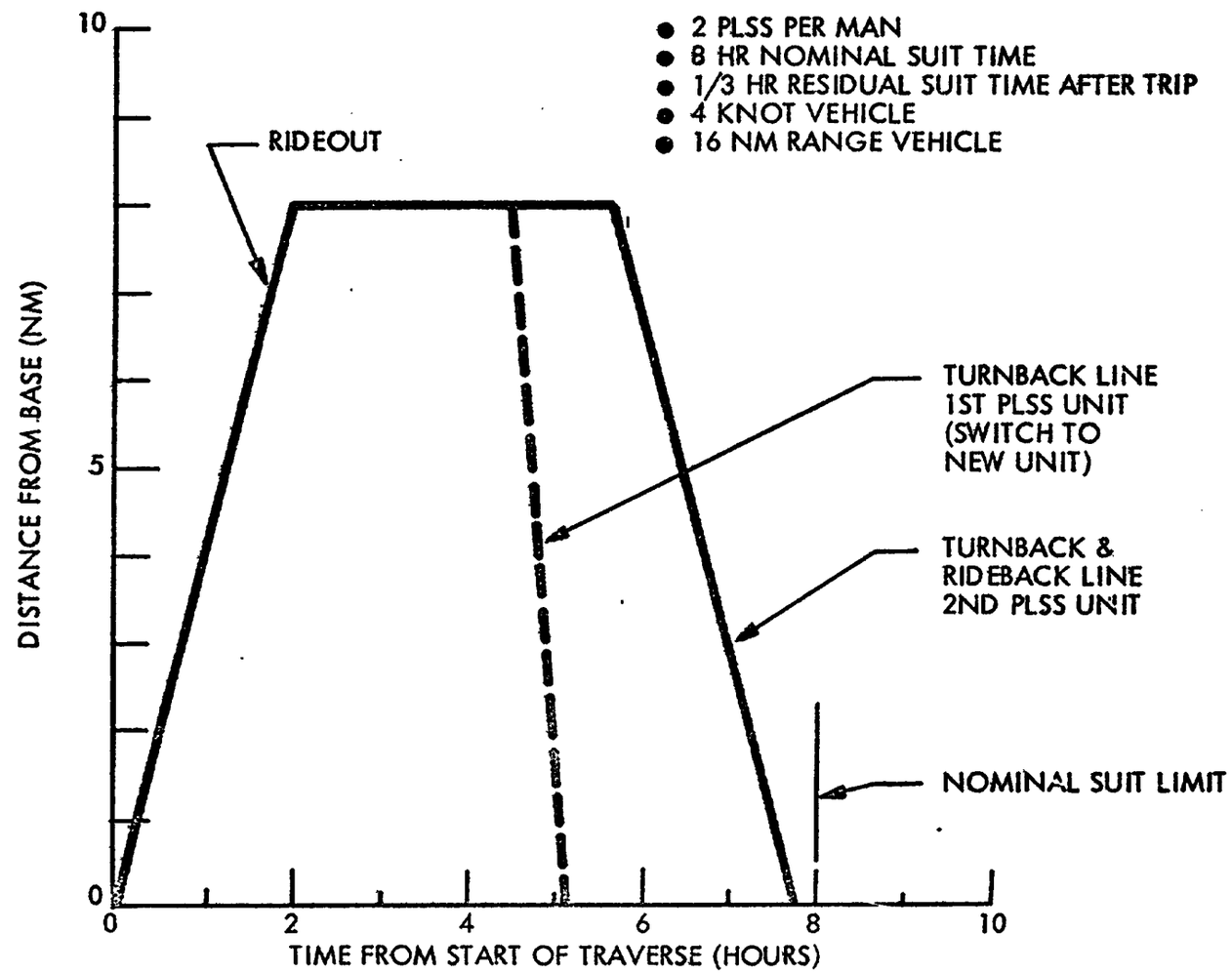


ESCAPE/RESCUE MODE	SURVIVAL TIME MIN.	RESPONSE TIME MIN.
WALKBACK	90	165
ROVER VEHICLE	100	368
FLYER	120	183
ORBITAL RESCUE	120	585

EVA ROVER VEHICLE TRAVERSE ENVELOPE

Here is depicted a typical EVA rover vehicle mission based on assumed 1980 PLSS capabilities. For the nominal mission, the vehicle traverses 8 nm to a planned mission site. The crew then carries out the mission objectives, completes the mission at 5-2/3 hours of elapsed time, and then traverses back to the base, arriving with 1/3 hour remaining of nominal suit capability. If a vehicle malfunction occurs during the return traverse the crew can switch to the second PLSS unit and either walk back or await rescue by another rover. However, it is possible that the second PLSS unit may be inoperable or the switch of PLSS units cannot be made for some other reason. In order to avoid this possibility it is required that the crew switch to the second PLSS unit at the time indicated by the dashed turnback line. If the second unit is inoperable the mission is terminated immediately and the crew returns on the rover. If the rover should then malfunction the crew has enough remaining capacity in the PLSS unit to either walk back or await rescue by a rover. If the PLSS switch is successful the crew continues the mission and returns to the base under nominal conditions.

EVA ROVER VEHICLE TRAVERSE ENVELOPE



CABIN ROVER TRAVERSE RESCUE SITUATIONS

The accidents and malfunctions that a cabin-type rover vehicle can sustain are characterized, for escape/rescue purposes, by the condition of its mobility subsystems and the integrity of the pressurized, shirtsleeve compartment. If this compartment should be damaged and inoperable, the crew must survive on their PLSS units. If this compartment is intact, the crew can survive a minimum of seven days by powering down all non-essential vehicle subsystems. If the communication subsystem is out, the crew must then decide on their own whether to drive on to the planned end of mission site, return to their base, or await rescue.

A vehicle position uncertainty of no more than three miles is based on a planned reporting period of 30 minutes. If driveback is attempted without communications capability this position uncertainty will become quite large.

CABIN ROVER TRAVERSE RESCUE SITUATIONS

	VEHICLE IS MOBILE	VEHICLE IS IMMOBILE
PRESSURIZED COMPARTMENT UNDAMAGED	COMMUNICATIONS FAILURE • SURVIVAL TIME ≥7 DAYS • DRIVEBACK LIMITED BY NAVIGATION CAPABILITY W/O COMMUNICATIONS • MAXIMUM DISTANCE FROM BASE ≤135 NM (SMALL ROVER) ≤200 NM (LARGE ROVER) • POSITION UNCERTAINTY <3 NM (NO DRIVEBACK) • NIGHT RESCUE	VEHICLE IS STUCK/WHEEL BROKEN/ PRIMARY ELECTRIC POWER LOST • SURVIVAL TIME ≥7 DAYS • DRIVE BACK = 0 • MAXIMUM DISTANCE FROM BASE ≤135 NM (SMALL ROVER) ≤200 NM (LARGE ROVER) • POSITION UNCERTAINTY <3 NM • NIGHT RESCUE
PRESSURIZED COMPARTMENT FAILURE	SKIN PUNCTURE • SURVIVAL TIME = PLSS LIFE • DRIVEBACK ≤ 38 NM (-6 PLSS) • MAXIMUM DISTANCE FROM BASE ≤ 97 NM (SMALL ROVER) ≤162 NM (LARGE ROVER) • POSITION UNCERTAINTY <3 NM • DAYLIGHT RESCUE	VEHICLE TIPS OVER AND BREAKS SKIN OR WINDOW • SURVIVAL TIME = PLSS LIFE • DRIVEBACK = 0 • MAXIMUM DISTANCE FROM BASE ≤135 NM (SMALL ROVER) ≤200 NM (LARGE ROVER) • POSITION UNCERTAINTY <3 NM • DAYLIGHT RESCUE

LUNAR TRAVERSE ESCAPE/RESCUE

This chart presents a matrix of candidate escape/rescue approaches for various traverse-type situations. For example, walk back to the base from the emergency site is a feasible concept for a stranded EVA-type rover vehicle or flyer. Note that a survival kit drop from orbit could extend the survival time for situations for traverse crews stranded a considerable distance from their base and depending on their PLSS units for life support.

LUNAR TRAVERSE ESCAPE/RESCUE APPROACHES

	EVA TRAVERSES				CABIN ROVER TRAVERSES	
	ROVER VEHICLE	FLYER	UPRATED FLYER	GROUND EFFECTS MACHINE	VEHICLE IMMOBILE	PRESSURE COMPARTMENT STRUCTURAL FAILURE
WALKBACK	X	X				
ROVER VEHICLE FROM BASE	X	X				
CARRY EMERGENCY LESS					X	X
LESS FROM BASE		X	X	X		
TUG BALLISTIC HOP			X	X	X	X
LUNAR LANDER TUG FROM ORBIT			X	X	X	X
CARRY EMERGENCY LEAP					X	X
SURVIVAL KIT DROP + LLT FROM ORBIT						X
SURVIVAL KIT DROP + SURFACE RESCUE			X	X		

ORBITAL ESCAPE/RESCUE

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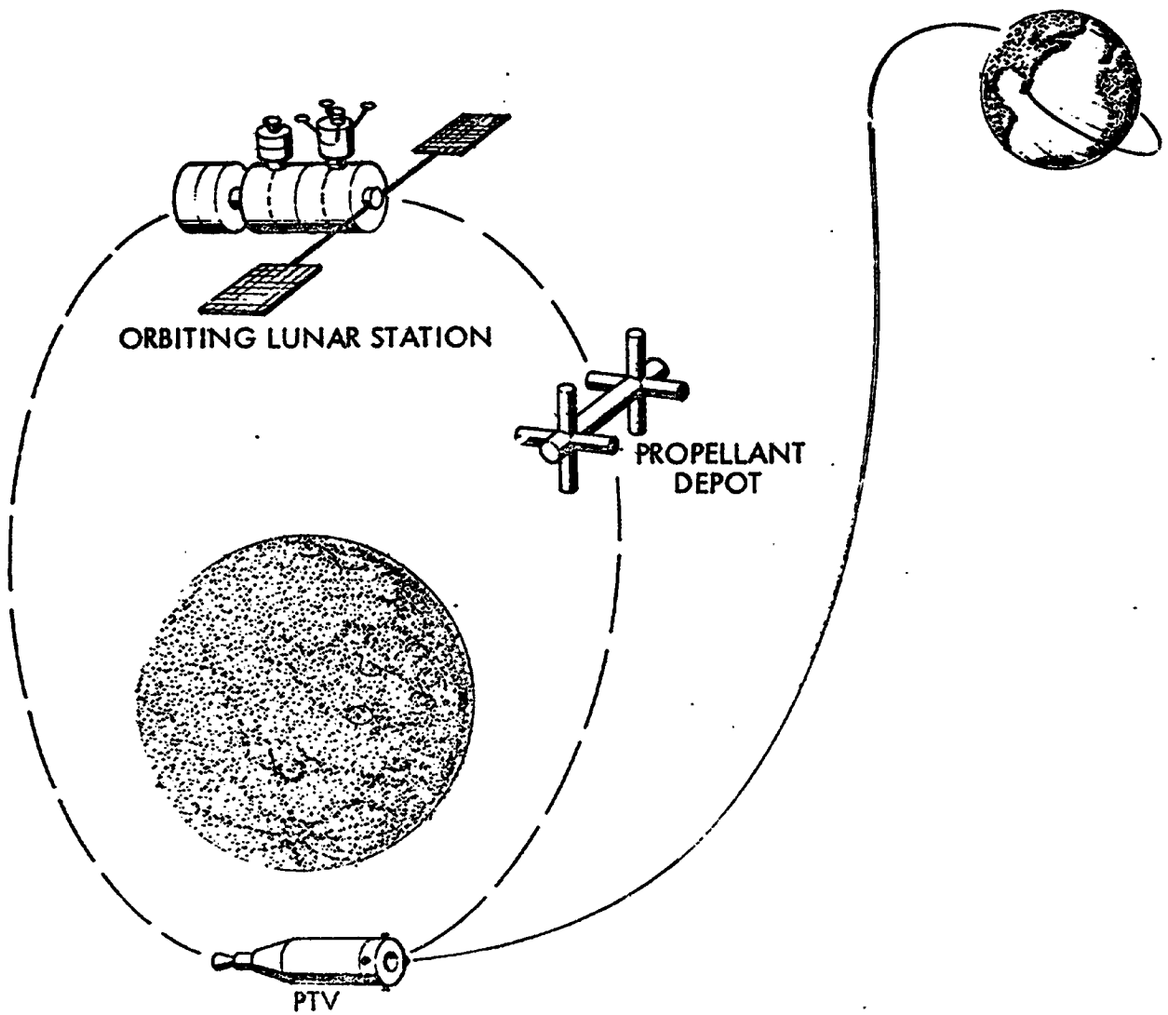
HARDWARE DEPLOYMENT

The key orbiting hardware elements are the orbiting lunar station, supporting fuel depot, and a primary transport vehicle. Final selection of orbit inclination and altitudes has not yet been made. It was therefore assumed that the station would be in a relatively low altitude orbit on the order of 60 nm and in any orbit inclination including polar.

HARDWARE DEPLOYMENT



ESCAPE/RESCUE SITUATIONS

Four orbital escape/rescue situations were selected for this presentation:

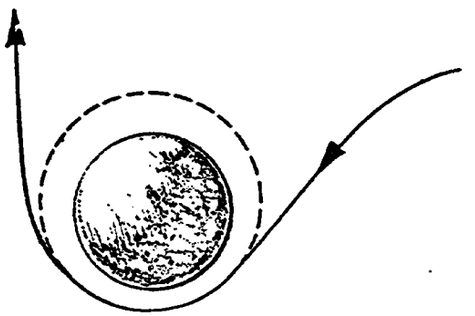
(1) Prime transport vehicle injection into lunar orbit and rendezvous with the orbiting lunar station. Included here is the case in which injection does not occur and the transport vehicle is on a lunar escape trajectory.

(2) Initial manning and activation of the orbiting lunar station.

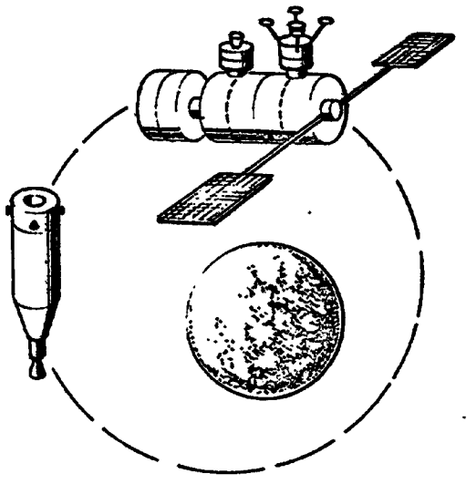
(3) EVA activities associated with normal orbiting lunar station activities.

(4) Fuel depot support of the orbiting lunar station.

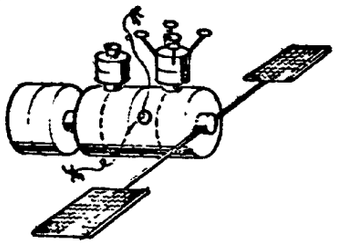
ESCAPE/RESCUE SITUATIONS



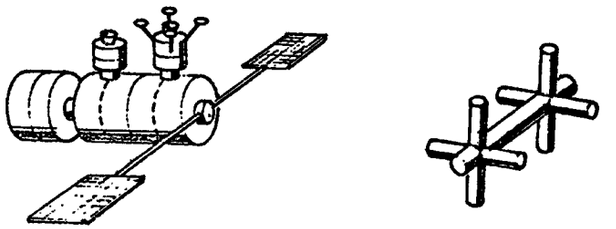
INJECTION/RENDEZVOUS



INITIAL MANNING & ACTIVATION



EVA ACTIVITIES



FUEL DEPOT

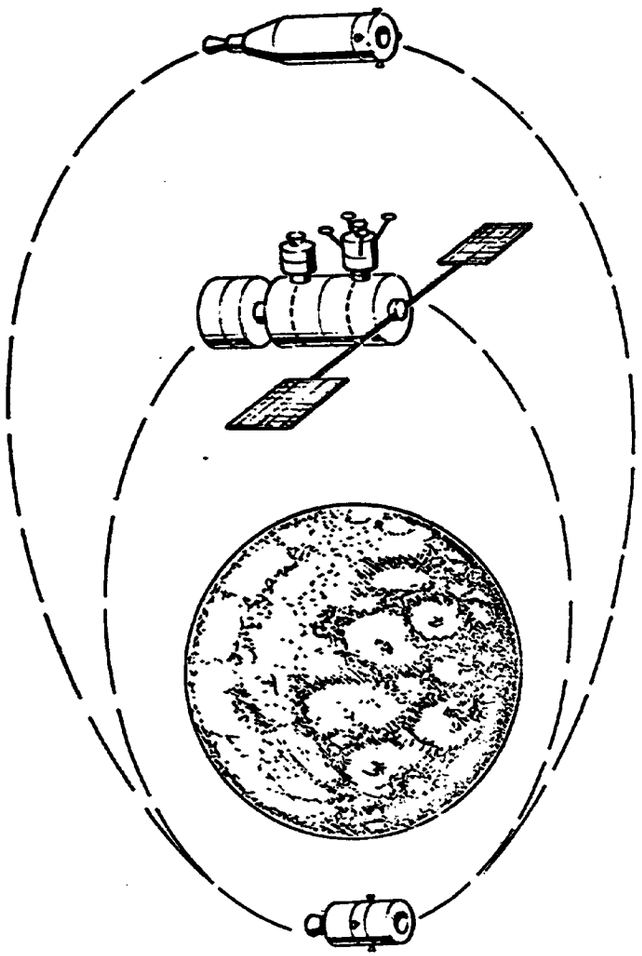
ELLIPTICAL ORBIT ESCAPE/RESCUE

Failure of the prime transport vehicle to inject as planned into lunar orbit would result in the vehicle being in a elliptical orbit as depicted on the chart. The Δ velocity requirements needed for a tug to separate from the orbiting lunar station, transfer to the stranded vehicle orbit, rendezvous, dock, pick-up the crew and then return to the station are also presented. These velocity needs are for a stranded vehicle in a worst-case 36 hour period elliptical orbit.

Two escape/rescue situations are possible: (1) the logistics cargo includes a manned and fueled tug, and (2) the crew is in a crew compartment with no tug. In the first case there is a choice between escape and rescue. In the second case the crew must be rescued.

Regardless of the choice, it is desirable to recover both the crew and the logistics cargo in order to minimize the impact on the planned lunar program. The critical situation could be for a maximum cargo payload and a crew in a crew compartment. For this case the rescue tug would separate from the station, intercept and dock with the crew compartment, separate the cargo and crew, and return both to the station. Even for this extreme payload weight the available tug velocity capability is 5570 ft/sec, well over the required 4400 ft/sec.

ELLIPTICAL ORBIT ESCAPE/RESCUE

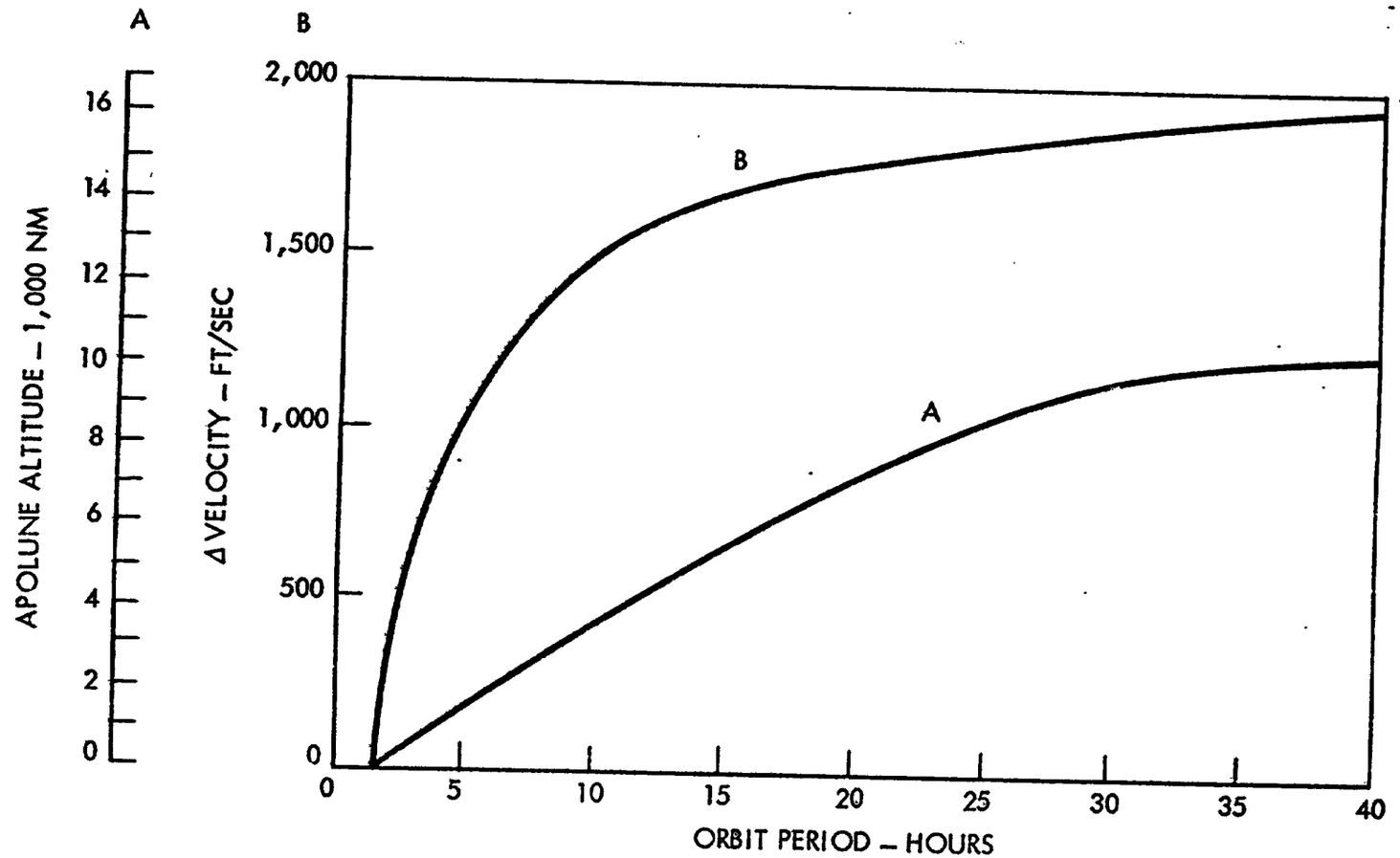


EVENT	Δ VELOCITY FT/SEC
1. SEPARATE FROM OLS & PHASE	150
2. ORBIT TRANSFER	1950
3. RENDEZVOUS & DOCK	150
4. SEPARATE	50
5. CIRCULARIZE	1950
6. RENDEZVOUS & DOCK	150
TOTAL	4400
AVAILABLE	5570

ELLIPTICAL ORBIT VELOCITY REQUIREMENTS

This chart presents the velocity required for a rescue vehicle to inject into the elliptical orbit of a prime transport vehicle that failed to inject properly into lunar orbit. Note that the maximum velocity requirement is about 1950 ft/sec corresponding to a orbit period of about 36 hours and a orbit apolune altitude of 1050 nm.

ELLIPTICAL ORBIT VELOCITY REQUIREMENTS



OLS INITIAL ACTIVATION

The initial activation of the orbiting lunar station (OLS) creates three possible escape/rescue situations. For this mission the manned logistics vehicle injects into lunar orbit, phases with the OLS and the manned tug then separates and docks with the OLS.

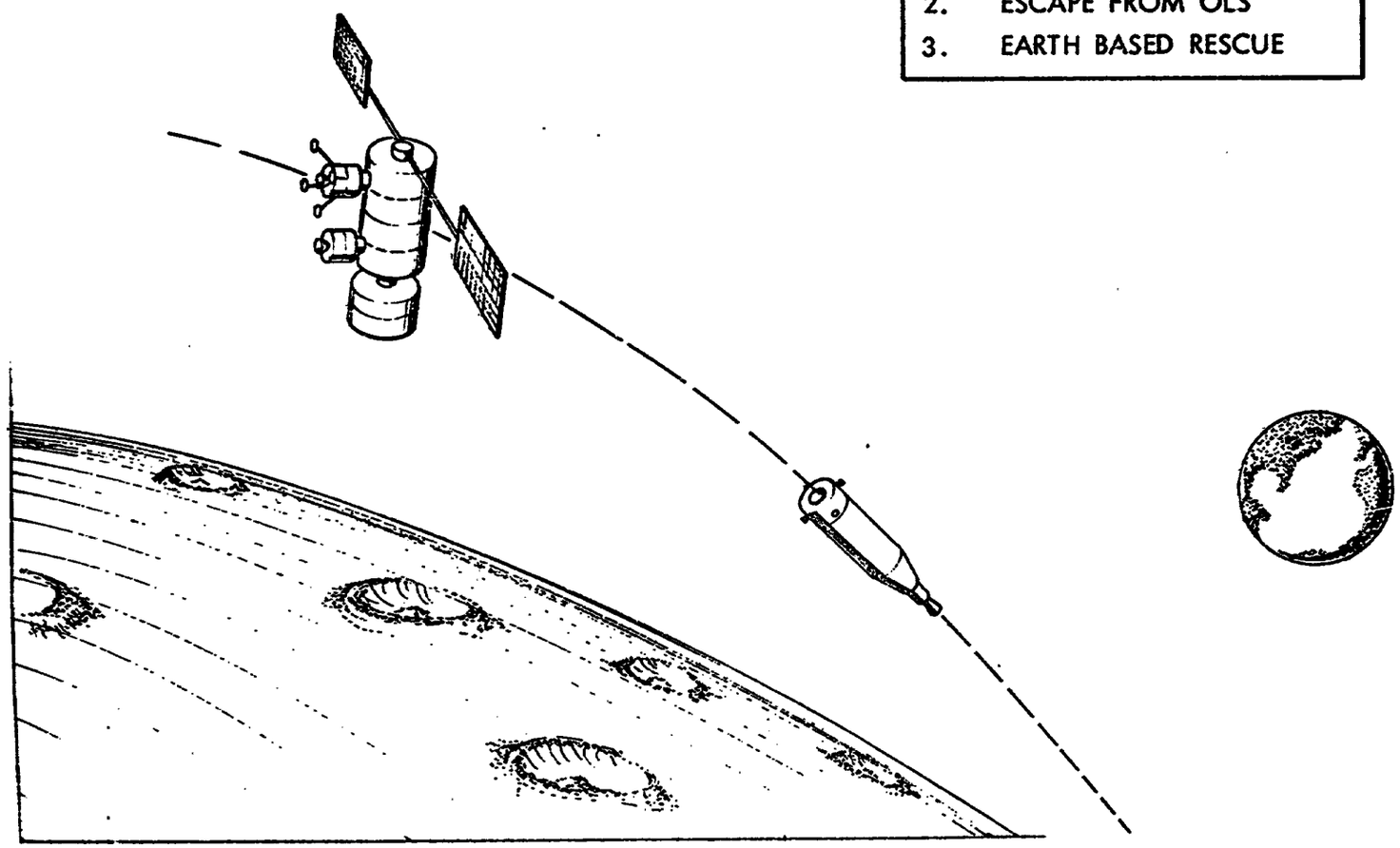
A critical malfunction in the prime transport logistics vehicle could be handled by the tug separating and proceeding to dock with the OLS in the planned normal manner and proceeding with the planned mission.

During OLS activation and checkout it is possible that one or more OLS subsystems could malfunction rendering the OLS either uninhabitable or inoperable. The crew could use the tug as a safe haven until repairs on the station could be completed or could even return to earth orbit.

A third possibility is that both the OLS and tug could be damaged (for example during docking) and become inoperable. In this case, assuming that local repair was impossible, earth-based rescue would be required.

OLS INITIAL ACTIVATION

ESCAPE/RESCUE SITUATIONS
1. ESCAPE FROM PTV
2. ESCAPE FROM OLS
3. EARTH BASED RESCUE



OLS EVA ACTIVITIES

There are two general EVA operational modes. In the first the EVA crewman is tethered and maintains his environmental control and life support via an umbilical connection to the OLS or tug. In the second the crewman is tethered but depends on a PLSS instead of an umbilical.

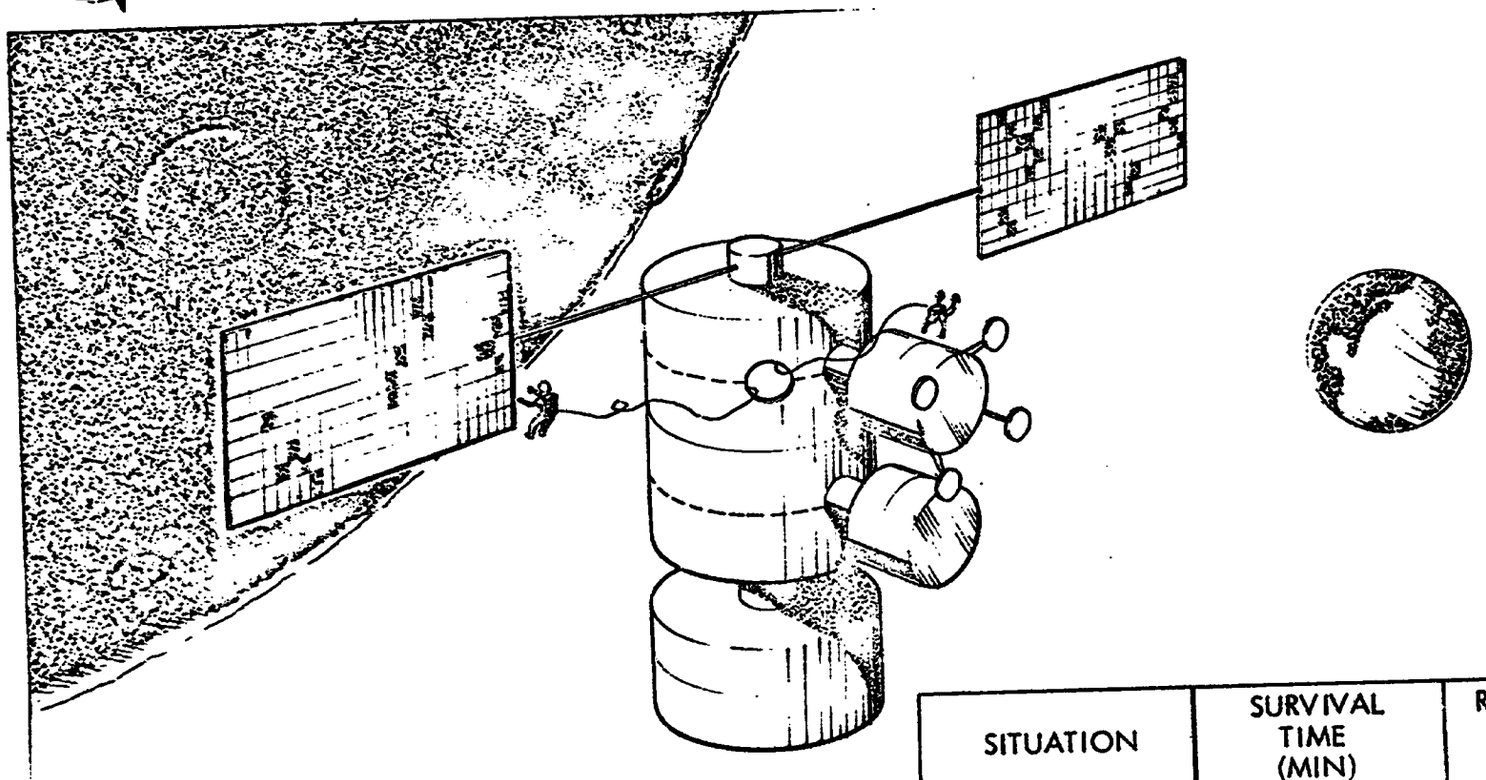
The inset on the chart shows the variations in response times for three rescue situations:

(1) the crewman has an umbilical and tether and is observed from the OLS or tug pressurized compartment

(2) the crewman is on PLSS, is tethered, and is observed from the OLS or tug pressurized compartment

(3) the crewman is tethered and is either on an umbilical or PLSS. In either case he is observed by a fellow crewman also on EVA with a quick disconnect type umbilical connection and a standby PLSS.

OLS EVA ACTIVITIES



SITUATION	SURVIVAL TIME (MIN)	RESPONSE TIME (MIN)
UMBILICAL AND TETHER	INDEFINITE	138
	120	138
TETHER ONLY & BUDDY SYSTEM	INDEFINITE	30
	120	30

PROPELLANT DEPOT

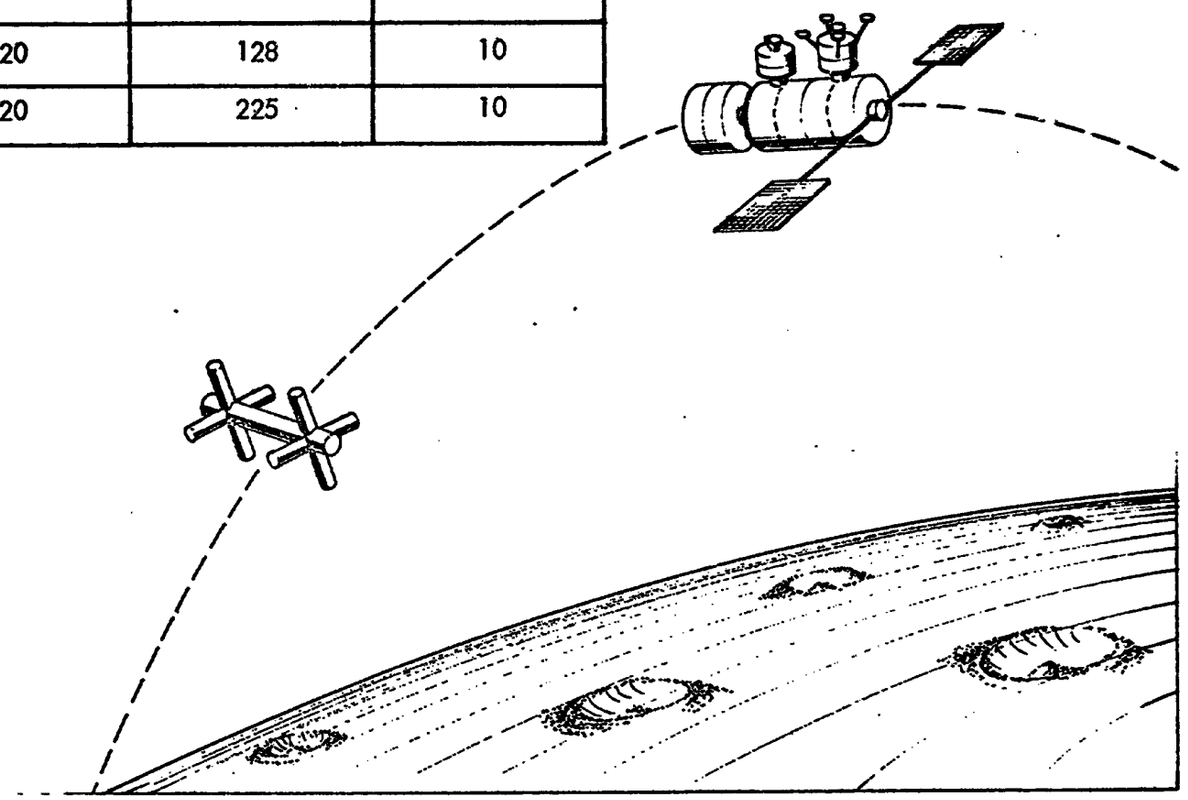
There are three approaches to location of the propellant depot relative to the Orbiting Lunar Station (OLS): (1) in close proximity to the OLS, (2) five miles or more range from the OLS, and (3) in a separate orbit plane and at a higher altitude.

During those periods of time that a crew is at the propellant depot the limiting survival time results from the crew being on partially depleted PLSS units.

For the situation in which the propellant depot is located 5 miles or less from the OLS the rescue operation could be made with a auxiliary maneuvering unit. For the case in which the propellant depot is in a different orbit the rescue operation would require the tug because of the substantially higher Δ velocity and response time needs.

PROPELLANT DEPOT

SITUATION	SURVIVAL TIME (MIN)	RESPONSE TIME	
		RESCUE	ESCAPE
CLOSE PROXIMITY	120	118	10
5 MILE SEPARATION	120	128	10
DIFFERENT ORBIT	120	225	10

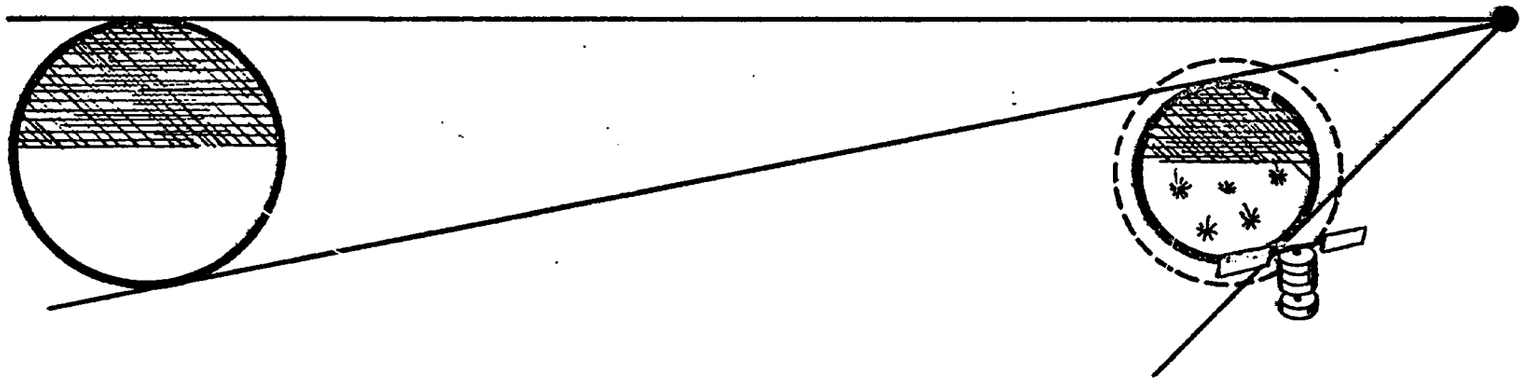


COMMUNICATIONS

This chart depicts the geometry associated with delays in communicating with the OLS under emergency conditions. In general a 60 nm altitude OLS will experience a 60 min delay in communication each orbit revolution. This delay is with respect to both the earth and the earthside lunar surface. For the orbit emergency situation a 120 min delay is possible if the OLS and the stranded vehicle are phased 180° apart and the stranded vehicle has just reached lunar backside orbital position when the emergency occurs.

A relay satellite will eliminate orbital communication delays and all surface delays unless the emergency occurs on the lunar surface in the vicinity of the south pole.

COMMUNICATIONS



OLS COMMUNICATIONS DELAY

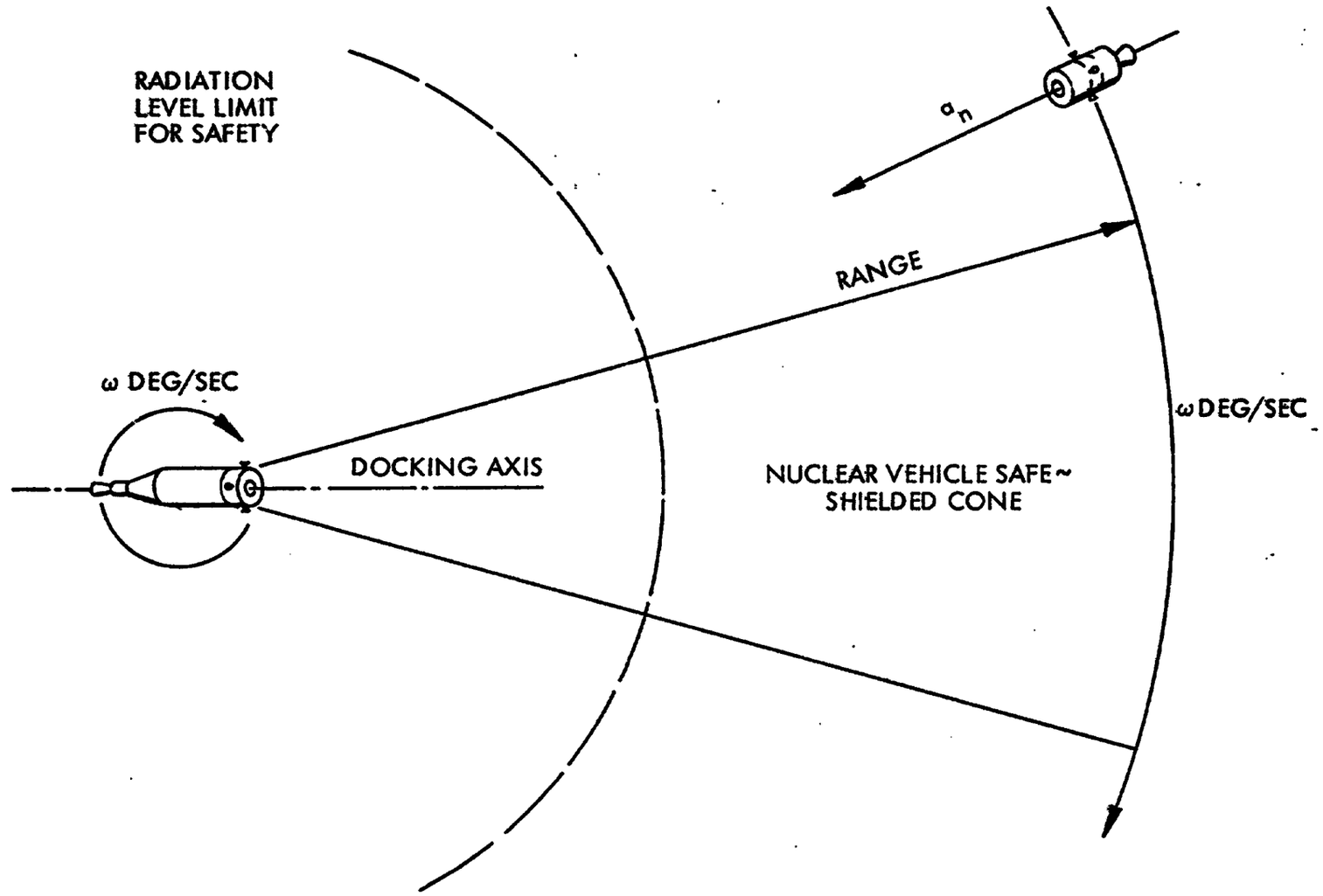
	WITHOUT RELAY SATELLITE	WITH RELAY SATELLITE
SURFACE	60 MIN	CONTINUOUS
ORBIT	120 MIN	CONTINUOUS
ARRIVAL & DEPARTURE	120 MIN	CONTINUOUS

TUMBLING VEHICLE GEOMETRY

The rescue of a stranded crew from a tumbling vehicle or fuel depot is a critical operation whose feasibility depends on a combination of several factors. In the chart the stranded vehicle is tumbling at some constant rate. The rescue tug must rendezvous with the stranded vehicle, phase with the tumbling rate and align itself along the docking axis. It must then move along this axis and complete a hard dock with the stranded vehicle.

If the stranded vehicle is a nuclear shuttle the consequent radiation and allowable rescue tolerance level imposes an additional constraint. For a given crew allowable radiation tolerance level there is a corresponding minimum range from the tumbling nuclear vehicle at which this tolerance level would be exceeded. The rescue tug must therefore match the nuclear vehicle tumble rate at a much greater range in order to complete the docking maneuver within the safe shielded cone.

TUMBLING VEHICLE GEOMETRY



RESCUE VEHICLE RENDEZVOUS AND DOCKING WITH A TUMBLING VEHICLE

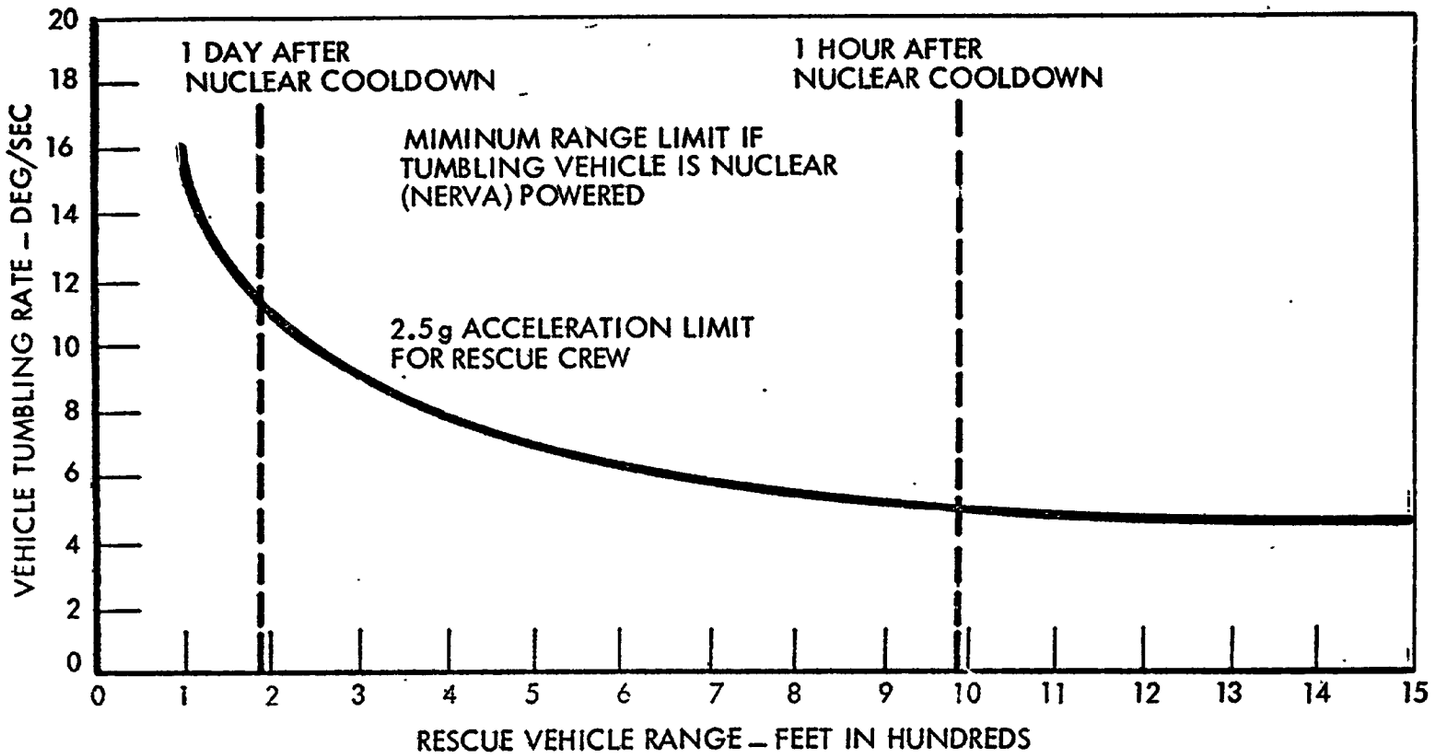
Here is presented the tumble rate and range limits at which a rescue vehicle can rendezvous and dock with a tumbling vehicle. The constant 2.5 g acceleration line represents the tumble rate, for any given range, at which the crew's acceleration tolerance level of 2.5 g's is attained.

The radiation level of a nuclear shuttle vehicle one hour after cooldown requires the rescue tug to have phased with the nuclear vehicle tumble rate and to be within the safe shielded cone at a minimum range of 980 feet. The maximum tumble rate at which this maneuver can be accomplished and stay within the crew's 2.5 g tolerance limit is 5°/sec. At one day after cooldown the maximum tumble rate limit is 11°/sec at a range of only 190 feet. It can also be seen on the chart that the absolute maximum at which docking can be accomplished is approximately 16°/sec.

For higher tumble rates, or for the case in which the stranded vehicle is under rotational acceleration, escape seems to be a prime candidate to ensure crew survival and a successful rescue.

RESCUE VEHICLE RENDEZVOUS AND DOCKING

WITH TUMBLING VEHICLE



LUNAR ARRIVAL ESCAPE/RESCUE SITUATIONS

INITIAL MANNING

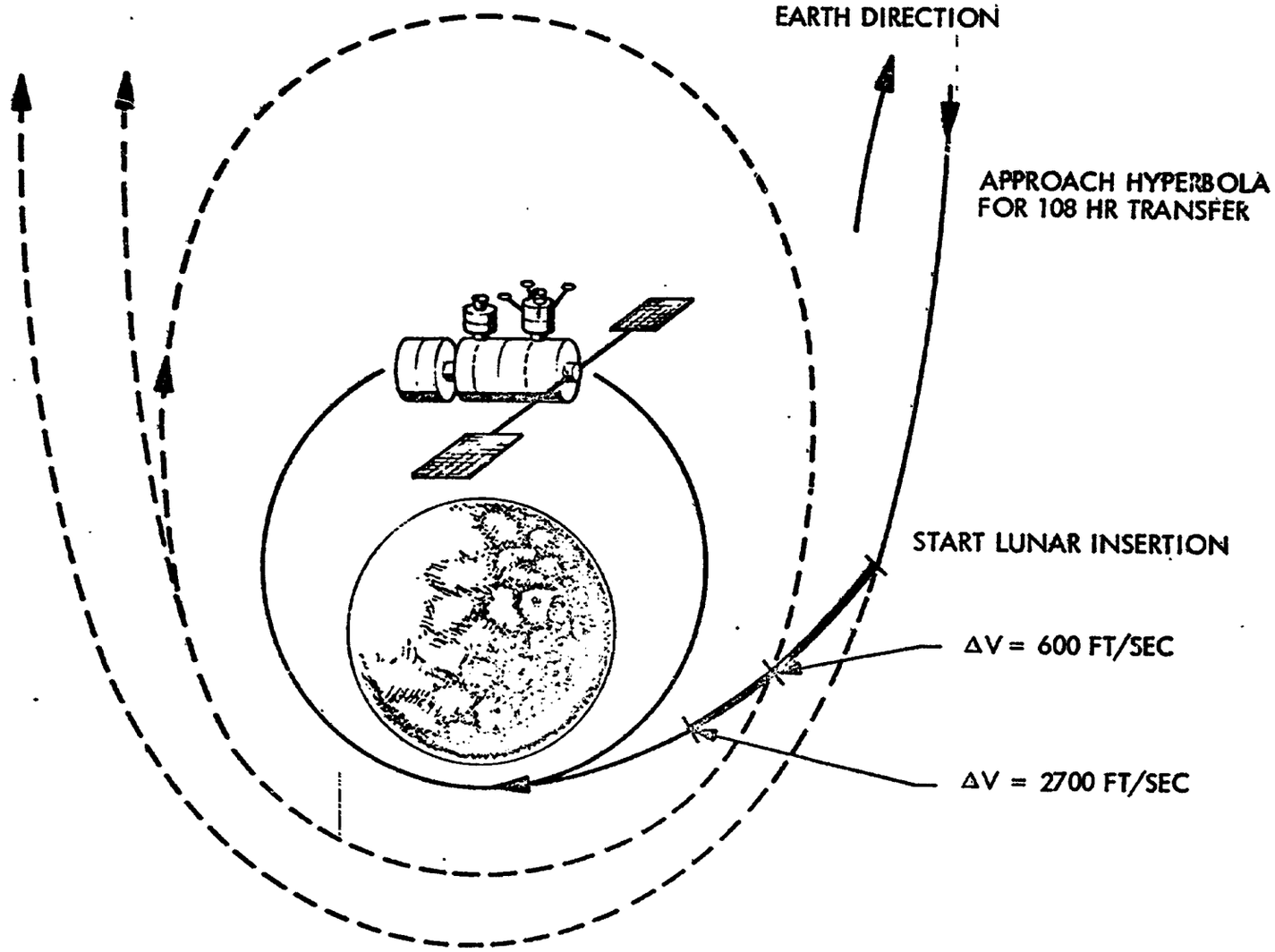
For the first manned flight, the crew will be in a fully fueled tug capable of returning to earth orbit if the nuclear shuttle fails to inject into lunar orbit. Similarly, the second crew will be transported in a fully fueled tug capable of earth return. The second crew will have the option of either returning to earth or rendezvousing with the manned OLS in the event escape is necessary. Either option will require minimum plane change because the basic shuttle trajectories are planned to be coplanar.

ROUTINE CREW ROTATION

The present nuclear shuttle/crew capsule combination planned for the logistics flights provides no escape capability. Consequently, outside rescue must be provided from either the OLS or the earth in the event of lunar injection failure.

Lunar injection failure could be the result of no burn or partial burn resulting in either a hyperbolic escape trajectory or an elliptical lunar orbit depending on the total ΔV imparted. The possibility of lunar impact due to short burn can be avoided by proper design of the arrival trajectory and insertion burn. The critical ΔV between a capture ellipse and an escape hyperbola is in the order of 600 ft/sec for 108 hour flight time. The case of zero burn would put the shuttle back on the lunar departure trajectory at maximum velocity thereby requiring maximum ΔV for the tug to catch up and rendezvous with the stranded crew.

LUNAR ARRIVAL ESCAPE/RESCUE TRAJECTORIES



LUNAR ARRIVAL RESCUE REQUIREMENTS

The case of zero burn at lunar orbit insertion places the shuttle on an earth return hyperbola with maximum velocity. The velocity and elapsed time requirements for rescue are referenced to the hyperselene of the approach/return hyperbola of a 108-hour translunar trajectory. The driving parameter is the delay between the time the distressed vehicle passes hyperselene and the time that the rescue vehicle is injected on the departure trajectory referenced to the hyperselene. Response or rescue time is the sum of the delay time plus the flight time of the rescue vehicle from hyperselene to rendezvous. Return time and ΔV allows return to 60 nm lunar orbit from the rendezvous point.

LUNAR ARRIVAL RESCUE REQUIREMENTS

RESPONSE TIME (DELAY + CHASE (HOURS)	ΔV* REQUIRED TO:					
	RENDEZVOUS INCLUDING A DELAY TIME OF:			RETURN TO LUNAR ORBIT IN:		
	2 HR	4 HR	6 HR	6 HR	12 HR	18 HR
4	9600	–	–	6,800	5100	4500
6	5700	16,000	–	8,500	5900	5100
8	4600	8,600	>20,000	10,200	6700	5700
10	4000	6,400	11,500	11,700	7500	6200
12	3600	5,400	8,300	13,000	8200	6700

* ΔV IN FEET/SECOND

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ESCAPE/RESCUE SUMMARY

SURFACE ESCAPE/RESCUE

This chart presents the key guidelines and requirements developed during this presentation pertaining to surface escape/rescue:

Lunar Surface Base

(1) The parked LLT is the primary escape vehicle for the LSB

(2) This vehicle must always be there with the capability to orbit and dock with the OLS

(3) The LLT must be capable of waiting 7 days on the surface in order to launch with no plane changes required to dock with the OLS

(4) A minimum 2-man rover vehicle must be available to carry personnel from the LSB to the LLT

Lunar Traverse

(1) A "buddy" flyer offers the only practical escape or rescue approach that meets the survival time limit of 120 min

(2) Loss of the cabin rover pressurized compartment integrity results in a survival capability limited by remaining PLSS capability

(3) Position uncertainties generate the need for position locator devices

(4) The minimum impulse orbital maneuver implies a need for 48 hour survival capability

(5) Critical malfunctions of traversing vehicles imply a need for an assured communications link with either the OLS or with the LSB.

SURFACE ESCAPE/RESCUE

LUNAR SURFACE BASE

- LLT IS PRIMARY VEHICLE
- DEDICATED LLT REQUIRED
- 7-DAY LLT SURFACE WAIT CAPABILITY NEEDED
- MINIMUM 2-MAN CAPACITY ROVER VEHICLE REQUIRED

LUNAR TRAVERSE

- FLYER TRAVERSES REQUIRE BUDDY SYSTEM
- CABIN ROVER SURVIVAL CAPABILITY IS CRITICAL
- LOCATOR DEVICES NEEDED
- 48-HOUR SURVIVAL TIME NEEDED FOR ORBITAL BASED RESCUE
- EMERGENCY COMMUNICATION CAPABILITY WITH EARTH

ORBITAL ESCAPE/RESCUE

Here are displayed key orbital guidelines and requirements:

Initial OLS Activation

(1) The manned tug must be able to separate from the prime transport vehicle in order to escape from a malfunctioning transport

(2) If both the tug and OLS are critically damaged, earth-based rescue will be required

OLS Operation

(1) A dedicated tug is needed to provide OLS escape capability and to support surface rescue operations and orbital fuel depot and logistics operations

(2) Fuel depot rescue requires a critically long response time making escape highly desirable

(3) EVA operations require a buddy EVA observer in order to minimize long rescue response times

(4) A communications relay satellite is required to eliminate a potential 1- to 2-hour delay time.

ORBITAL ESCAPE/RESCUE

INITIAL OLS ACTIVATION

- TUG CAPABILITY TO SEPARATE FROM TRANSPORT VEHICLE
- BACKUP EARTH-BASED RESCUE CAPABILITY

OLS OPERATION

- DEDICATED TUG
- FUEL DEPOT ESCAPE CAPABILITY
- EVA BUDDY SYSTEM
- COMMUNICATIONS RELAY SATELLITE

LUNAR ARRIVAL/DEPARTURE ESCAPE/RESCUE

The addition of approximately 1,000 feet/sec velocity capability to the crew compartment used to transport crewmen between the earth and moon would provide an escape option for a transport vehicle malfunctioning during lunar arrival or departure.

The capability for independent control of separation of the crew compartment and cargo from the transport vehicle is required to support either escape or rescue and possible recovery of the cargo.

LUNAR ARRIVAL/DEPARTURE ESCAPE/RESCUE

- ESCAPE CAPABILITY REDUCES NEED FOR RESCUE
- CREW COMPARTMENT Δ VELOCITY CAPABILITY OF 600-1000 FEET/SEC REQUIRED
- INDEPENDENT CONTROL OF SEPARATION OF CREW COMPARTMENT/CARGO FROM TRANSPORT VEHICLE REQUIRED

ESCAPE/RESCUE TASK STATUS

The current status of the escape/rescue analysis task is presented here. The task is on schedule and no serious difficulties are foreseen in meeting future schedule commitments and objectives.