NASA Technical Memorandum 83106

The Utilization of Nonterrestrial Materials

Proceedings of a Workshop
held at Palo Alto, California
June 1977

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NASA
National Aeronautics
and Space Administration

Scientific and Technical
Information Branch

1981

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1 INTRODUCTION AND SUMMARY

A one-week planning workshop was held at Palo Alto, California, to examine the utilization of nonterrestrial materials for the construction of large space systems. The purpose of this workshop was to generate recommendations to NASA regarding research and study requirements.

The use of nonterrestrial resources, including materials and energy, for space applications is a topic of interest to NASA. To enable NASA to develop plans relative to use of nonterrestrial resources, studies are required which will provide credible data regarding the viability of mining and processing such resources and ascertaining when it is economically beneficial, for space applications in far Earth orbits, to use products derived from nonterrestrial resources. More specifically, at what scale of operations does the use of nonterrestrial resources become competitive with the use of terrestrial resources, including the cost of transportation? Examples of topics which need to be studied include the mining of raw products, and conversion of raw materials into useful products (should skilled craftsmen perform these operations or should automated material operations be developed?).

This workshop was convened, therefore, to suggest examples of meaningful research and technology programs, including the definition of requisite experiments, for use by NASA in deriving a position about the use of nonterrestrial resources.

During the workshop, teams were formed to generate program requirements, study requirements, research and preliminary estimates of development needs, precursor flight missions, and human factors considerations. (The results of these team efforts are given in Secs. 2 through 6.) This report documents the definition of studies, research, development, and missions leading to the utilization of nonterrestrial materials. The space power satellite (SPS) was used as a model mission because it is illustrative of very large space systems for which the use of nonterrestrial materials may be economically viable.

A program implementation model was developed as an approach to answering the question about what technology requirements must be met for nonterrestrial resources utilization in order to acquire a state of readiness with sufficient proof data for a potential decision-making process. This schedule was selected arbitrarily for this planning "exercise" and should not be interpreted as being an official NASA schedule. Program requirements for an operational system were hypothesized. Utilization of asteroid resources for the construction of satellite power systems was reviewed. Study requirements that were formulated specify the activities required to assess the major systems and options involved in an operational system.

Research and development needs were also formulated and are concerned with those items which would require early endeavors to prove the technical feasibility of a space power system constructed largely of nonterrestrial materials. Precursor flight missions are identified and deal with lunar and other exploratory activities that can and should be carried out as part of the preparations for a nonterrestrial materials utilization program. Human factors planning was also addressed in the study.

The team members were briefed by the principal participants of the six-week Ames Summer Study on Space Industrialization, chaired by Gerard K. O'Neill of Princeton. Dr. O'Neill and the Summer Study participants provided valuable assistance to the NASA Workshop members and presented suggestions, for NASA planning consideration, which were greatly appreciated by the workshop team.

The plans and schedules contained in this document are not official NASA positions and represent the ideas of the workshop participants only. Several research and study recommendations submitted by the workshop participants have already been incorporated into NASA plans and activities.

2 STUDY NEEDS

2.1 INTRODUCTION

A series of study and analytic activities will be required to assess the details of the major systems and options described in Sec. 6.3. These studies should encompass analysis, design, planning, and a myriad of trade-offs leading to definition of demonstrations, flight missions, and final hardware concepts. The following sections provide a brief overview of the major studies needed. An estimate of resource requirements to accomplish these assessments is shown in Table 2-1. In many cases, these descriptions actually encompass several studies rather than just one as the format might indicate.

2.2 SYSTEM ANALYSIS AND DESIGN

2.2.1 Mission Analysis (Table 2-2)

This will be the central, continuing study which provides an up-to-date definition of the overall program. Its products will include:

- A definition of major system/mission elements and options
- Mission profiles for various options
- Requirements on performance, functions
- An analysis of options, their pros and cons, and justification for choosing certain options at critical decision nodes (permitting a retreat to a decision node and logical redirection, without a return to "square one," if difficulties develop)

ID

TABLE 2-1

SYSTEM AND PLANNING STUDIES

(Man-Year per Year Display)

		YEARS FROM START								IMPLEMENTATION (PHASE (YFS)
		1	2	3	4	5	6	7	8	
		←PHASE A				→	PHASE B	→		
(SYSTEM)	SYSTEM DESIGN-SPS (NONTERRESTRIAL)	8								
	MISSION ANALYSIS	4	10	30	60	100	150	175	200	Decrease
	SYSTEM STUDIES (6 MAJOR ELEMENTS)		20	50	100	200	300	400	500	Decrease
	PRODUCTS STUDY			1	3	4	2			
(PLANS)	R&T PROGRAM PLAN		1	2	2	3	1			
	PROG. IMPLEMENTATION MODEL				5	10	20	40	40	Decrease
	CENTRAL PLANNING AND CONTROL	4	10	30	60	100	150	175	200	Continual
	PERSONNEL MANAGEMENT PLAN					5	10	20	30	Decrease
	SIMULATION REQUIREMENTS PLAN				2	5	10	20	2	
	ALTERNATIVE BENEFITS OF NEW TECHNOLOGY		5	10	5					
	TECHNICAL ASSESSMENT				2	4	4	2		
(TRADES)	PROCESSING AND MANUFACTURING			2	5	2				
	ASTEROID RETRIEVAL			2	5	2				
	MATERIALS - SOURCES			3	5	5	3			
	MATERIALS - USES				2	5	2			
	EQUIPMENT SOURCES			2	5	2				
	LIFE SUPPORT	1	2	3	3	1				
	POWER SYSTEMS		2	5	2					
	HABITATS		3	5	5	3				
	TOTAL MAN-YEARS	17	43	145	271	451	652	832	972	
	Estimated Cost ($ x 10^6)	1	2.6	8.7	16.3	27	39.1	50	58.3	

TABLE 2-2

SUMMARY OF MISSION ANALYSIS

1. MISSION ANALYSIS
   - SPECIFY FUNCTIONAL, PERFORMANCE REQUIREMENTS
   - DESCRIBE OPERATIONS, CREW REQUIREMENTS, ETC.
   - ASSESS CONTINGENCY REQUIREMENTS, RISKS, ETC.
   - DEFINE MISSION/SYSTEM ELEMENTS
   - IDENTIFY, ANALYZE OPTIONS

2. SYSTEM STUDIES AND DESIGNS
   - MAJOR SYSTEM ELEMENTS
   - FEASIBILITY, PRELIMINARY DESIGN, COST, TECHNOLOGY NEEDS, ETC.

3. PRODUCTS (MARKET SURVEY)
   - MATERIAL
   - ENERGY
   - INFORMATION
   - SERVICES (MEDICAL, LEISURE, - - -)

- Overall specification of crew requirements, new technology, contingency requirements, etc., and basic data necessary for program planning, detailed system analysis and design, etc.

PRIORITY: Highest

TIMING: Initial study 3-6 months in early phase A at $100K to $200K

LEVEL OF EFFORT: Continuing update and refinements throughout program, growing to 200-man level

2.2.2 System Studies

System analyses and preliminary designs of major system elements identified in earlier broad system descriptions.

- Select system description from previous work (e.g., summer study, "Implementation Task Group," July 1977)
- Prepare preliminary design and analysis as necessary to:
  - Assess feasibility
  - Identify new technical needs
  - Provide inputs to other studies
  - Generate RDT&E cost data

TABLE 2-3

SUMMARY OF REQUIRED PLANNING STUDIES

(1) R&D REQUIREMENTS - LESS THAN 8 YFS

(2) IMPLEMENTATION MODEL

(3) CENTRAL PLANNING AND CONTROL

- FACILITIES
- STAFFING
- SCHEDULE
- FUNDING
- BASIS FOR CONFIGURATION/COST CONTROL

(4) PERSONNEL MANAGEMENT

(5) SIMULATION REQUIREMENTS

(6) TECHNOLOGY ASSESSMENT

(7) ALTERNATIVE BENEFITS OF R&D (SPIN-OFFS)

PRIORITY: Medium, except for "show stopper" candidates

TIMING: Early Phase A start and continual update with changing requirements

LEVEL OF EFFORT: 2 man-years/year ($150K/year contract)

2.3.2 Program Implementation Modeling

Generate models for implementation of a full-scale program for the development of a space power facility providing cumulative capacity in the order of 750 GW by the year 2010. These models will assume that readiness will be fully demonstrated by 1985 to support a new initiative proposal for phased program implementation beginning in YFS 10. The model will provide requirements for planning purposes including at least technology, operations, personnel, and facilities.

PRIORITY: High

TIMING: Late Phase A - early Phase B

LEVEL OF EFFORT: 20- to 40-man effort, 2 to 3 years

2.3.3 Central Planning and Control

Develop an overall systems planning model that will depict program development growth including the display of all options available for consideration. This master planning option tree provides a structure for organizing functional specifications and candidate cost and risk determinations, and is an integrated basis for assessing the progress of all system studies, trade studies, R&D development, and overall status. This task can be used as the basis for a project work breakdown structure (WBS). It can provide basic up-to-date information for control of configuration, cost, and schedule, and establish requirements for facilities, funds, staff, and new technology. This is visualized as the central planning activity.

PRIORITY: Very high - required for success

TIMING: Early Phase A

LEVEL OF EFFORT: 2 to 3 men first year. Establish high-level committee on initiation of Phase B, with staff support. About a 200-man staff for Implementation Phase.

2.3.4 Management

Develop requirement for recruiting, evaluation, and training of operational personnel for all space- and ground-based facilities. Develop plan, including schedule and cost estimates, to accomplish required staffing in consonance with overall program schedule.

PRIORITY: Medium

TIMING: After program plan is well defined (Phase B)

LEVEL OF EFFORT: 20- to 40-man effort for 3 to 5 years

2.3.5 Simulation Requirements Planning

Identify simulation facility requirements in support of the research and technology program for nonterrestrial materials space power. While simulation programs are primarily intended for ground use, needs may be identified for aircraft or even spacelab-based facilities (the latter may be agglomerated as test bed programs or as flight demonstration programs). Uses will be defined, effectiveness of simulation justified, and programs defined, scheduled, and costed for their implementation.

PRIORITY:	Medium
TIMING:	Phase B
LEVEL OF EFFORT:	10- to 20-man effort for about 1 to 2 years

2.3.6 Technology Assessment

Assess the potential side effects of the technology to be developed in the program, as well as the effects of the operations to be carried out. Plan work-around solutions if necessary.

Develop techniques for a continuing technology assessment program to be operated throughout the program.

PRIORITY:	Medium
TIMING:	Late Phase A
LEVEL OF EFFORT:	About 3 man-years per year for 3 to 4 years

2.3.7 Alternative Benefits of New Technology Developments

Evaluate alternative benefits on the basis of those technologies identified and the scopes of the readiness studies. Determine other opportunities for technology use in future NASA plans, and also the transfer ratio and an estimate of its potential indirect benefit return.

PRIORITY: Low

TIMING: Early Phase A

LEVEL OF EFFORT: 5 to 10 man-years

2.4 TRADE-OFFS (Table 2-4)

2.4.1 Processing and Manufacturing Trade-Offs

Analyze the engineering and economic trade-offs, based on preceding design studies of the lunar mining camp and R&D development exercises on nonterrestrial processing and manufacturing techniques, to determine the optimum division of beneficiation, refining, milling, fabrication, and assembly tasks between the lunar surface, L2 (or alternative catcher site), space manufacturing facility, and geosynchronous orbit. Include the effect of transport options on the optimum scenario.

PRIORITY: Medium

TIMING: Late Phase A

LEVEL OF EFFORT: 5 to 10 man-years

2.4.2 Asteroid Retrieval

Analyze the engineering and economic impact of variation of significant parameters associated with asteroid retrieval. Specifically, estimate the impact of varying degrees of separation en route, from none through beneficiation to complete refining and prefabrication of final product components. Also consider trade-offs between automatic and manned operations in each mission phase, and the effects of different propulsion systems in overall project effectiveness.

TABLE 2-4

SUMMARY OF TRADE-OFF STUDY REQUIREMENTS

1. PROCESSING AND MANUFACTURING
   - L2, L5, GEO, LUNAR SURFACE
2. ASTEROID RETRIEVAL
   - DEGREE OF EN ROUTE SEPARATION
   - MANNED/AUTOMATIC
   - PROPULSION TECHNIQUE
3. MATERIAL SOURCES/USES
   - MOON, ASTEROIDS, EARTH
   - FOR NONTERRESTRIAL MATERIALS POWER PLANT
   - FOR MANUFACTURING FACILITY, HABITATS, ETC.
4. EQUIPMENT SOURCES
   - WHAT TO BUILD
   - WHAT TO SEND FROM EARTH
5. LIFE SUPPORT
   - RESUPPLY VS. RECYCLING
6. POWER SYSTEMS
   - SOLAR VS. NUCLEAR
7. HABITATS
   - ATMOSPHERE
   - G-LEVEL
   - SIZE
   - EXTERNAL TANK VS. SPECIAL DESIGN
   - AUTOMATIC/MANNED OPERATIONS TRADE

PRIORITY: Low

TIMING: Late Phase A

LEVEL OF EFFORT: 5 to 10 man-years

2.4.3 Materials

Sources. Perform a systems analysis on the relative merits of lunar, asteroid, and terrestrial materials as feedstocks to space manufacturing facilities. Detail in each case necessary elements which are abundant, scarce, or nonexistent, and in the last two cases specify either processes used for extraction or alternative sources. Also, look at a scenario where both lunar and asteroid resources are developed and find if any necessary elements are still scarce or nonexistent.

PRIORITY: High

TIMING: Early Phase A

LEVEL OF EFFORT: 10 to 15 man-years

Uses. Analyze trade-offs in materials selection for industrial power plants, manufacturing facilities, habitats, and other structures based on nonterrestrial material. Factors in the analysis should include various forms of materials available (metals vs. ceramics), construction method (stressed-skin, semi-monocoque, plate, cable-wound, vapor deposited), and varying degrees of refinery capability. Results should include different choices based on materials available (terrestrial, lunar, asteroid).

PRIORITY: Medium

TIMING: Early Phase A

LEVEL OF EFFORT: 5 to 10 man-years

2.4.4 Equipment Sources

Look at all the equipment necessary in space for a base-line space manufacturing facility. Which could be manufactured in space, and which must be brought from Earth? What is the minimum in tooling needed to build all other machinery necessary on the SMF? What is the effect of "bootstrapping" on overall systems cost, and program risk?

PRIORITY: Low

TIMING: Late Phase A

LEVEL OF EFFORT: 5 to 10 man-years

2.4.5 Life Support Trade-Offs

Survey existing theoretical and experimental data base to find state of current knowledge in both recycling and resupply as life support methods. Do a systems analysis of a base-line space manufacturing scenario, assuming complete recycling, complete resupply, and various combinations of the two (varying degrees of partial closure). What are the potential "show stoppers" in each system at this time, and are any of these areas common to both systems?

PRIORITY: High

TIMING: Late Phase A

LEVEL OF EFFORT: 10 to 15 man-years

2.4.6 Power Systems

Study the trade-offs between various sources of space power, specifically solar thermal, solar photovoltaic, and nuclear generation systems. Which is technologically and economically desirable in the cases of the lunar surface base, an asteroid retrieval system, an inter-orbit propulsion system which regularly traverses the Van Allen belts, and an industrial power supply? Include details such as pointing accuracy requirements, optimum concentration ratios, and waste heat rejection details.

PRIORITY: Medium

TIMING: Early Phase A

LEVEL OF EFFORT: 5 to 10 man-years

2.4.7 Habitats

Perform trade-offs on habitat design based on variations in atmosphere, g levels, size, external tanks vs. special design, etc. Candidate designs should be based on established design criteria, such as fail-safe or safe-life structure, sized for both static and dynamic loads expected. Also include problems of energy and heat balance, docking designs, failure modes, etc. Psychological factors or interior design should not be neglected.

PRIORITY: Medium

TIMING: Early Phase A

LEVEL OF EFFORT: 10 to 15 man-years

2.4.8 Automatic/Manned Operations Trade

Various operational centers exist throughout a space manufacturing complex. These centers may be separated in terms of distance, such as L2 catcher, or function, such as a high-temperature refinery. For each location and process, a trade-off study should decide whether manned or unmanned automated operation is preferable. Because of the high cost of space labor, it is assumed that man's major presence in the industrialization scenario will be as an overseer, trouble shooter, and general repairman. For each process, is it more advantageous, technically and economically, to make the equipment redundant, self-repairing, or manually repairable? Which processes need a continual human presence? Which need only an occasional visit for emergency repair? Some equipment (nuclear reactors, for instance) must be highly reliable and repairable by machine. What is the role of teleoperators? What is their maximum range, before speed-of-light time lag causes them to become unmanageable? How heavy is the cost of manned operations? Is it so great that high priority should be placed on AI research? Can manned processes be grouped in one or two locations only, in order to minimize their logistics effort? Where in the system is the human presence necessary, desirable, and superfluous? It is envisioned that each study previously called out will implicitly encompass solutions to these problems.

3 RESEARCH AND DEVELOPMENT NEEDS

3.1 INTRODUCTION

The panel on R&D considered only those items which require early endeavors to prove the technical feasibility of a space solar power type satellite (i.e., a very large system) constructed largely of nonterrestrial materials. To a lesser extent consideration was given to the economic feasibility of the system which depends on technical advances. Lastly, because of the time available, consideration was given only to those aspects of the SPS which are related to the use of nonterrestrial materials. The technology requirements were analyzed by use of the matrix shown in Fig. 3-1. The major system elements are listed across the top. The technology disciplines, as established by NASA's technical interest, are presented under the appropriate system element. In the following section, R&D descriptions were developed for the technology requirements under each systems element that needs early attention. The titles given in the matrix of Fig. 3-1 are not meant to be exhaustive but merely examples.

3.2 LUNAR BASE AND ASTEROID COLLECTION

3.2.1 Overview

Although the Earth system will encompass the material resource base within the SPS model time frame, the economics of Earth launching of materials for large-scale space facilities have dictated a search for other sources. R&D would be directed toward assessing nonterrestrial resource alternatives such as the Moon or asteroids in the Earth-Moon system.

DISCIPLINE \ WORK AREA	LUNAR BASE & ASTEROID COLLECTION	TRANSPORTATION	HABITATS	NT RESOURCES MINING, PROC. & MFG.
POWER & PROPULSION	CONTINUOUS LUNAR POWER	+ CHEMICAL & ELECTRIC PROP.		POWER CONVERSION & UTILIZATION
STRUCTURES & MATERIALS		LARGE, LOW DENSITY STRUCTURES	NT MATERIALS UTILIZATION	MASS PROCESSING
ELECTRONICS & INFO. SYS.		MASS DRIVER ELECTRONICS		
GUIDANCE & CONTROL		MASS CATCHER		AUTOMATION
LIFE SCIENCES	LUNAR NIGHT LIFE SUPPORT		KILOPERSON LIFE SUPPORT	BIOPROCESSING
SPACE OPS. & GRD. SUP'T.		ROUTINE, LOW COST, OPEN SCHEMES		
RELIABILITY & SAFETY		REACTION MASS DEBRIS	POWER INTERRUPT ECO. UPSETS FIRE, ETC.	

Figure 3-1. R&D Areas (Examples)

It is generally conceded that lunar mining could provide materials based on Al, Fe, Ti, or glasses for construction, silicon for solar cells, oxygen for life support and propulsion, some possibility of hydrogen for water and fuel, and perhaps some minor elements if their extraction is tractable. Although present lunar evidence indicates homogeneity of materials, the presence of ores or concentrations would present such attractive economics as to justify considerable effort with necessary advanced R&T in their search. Asteroids, based on meteoritic evidence, may prove to be superior to lunar resources, because of their selectability for a particular composition "matched" to need. However, size and ΔV (velocity) are also important selection criteria. R&D supportive to locating asteroids with optimum characteristics is thus extremely important.

Two exceptions may exist which would affect this development scenario. First, the libration points must be surveyed for the possible existence of usable materials. Second, as a source of light elements and water, a comet may present itself at an opportune time or orbit. Although the ΔVs are probably too great to make this source attractive in the near term, a brief study is recommended in this area to assess the potential. Obviously, the reality of resource extraction from either of these sources will influence the R&D program.

3.2.2 R&D Element Descriptions

Power/Propulsion. No unique R&D needs are indicated in the propulsion discipline for this area unless trade-off studies and collaborative R&D show the mass driver to be an effective propulsion tool for general science and sample retrieval missions. Mass driver R&D is discussed in Sec. 3.3.2. Power requirements for flyby, in situ assay, and sample retrieval are not expected to exceed those required for similar missions currently in the NASA model or as anticipated for a new start. Such technology is already targeted to satisfy requirements.

Electronics/Information Systems. R&D in this area is very beneficial to search, remote sensing, and in situ analysis. Unfortunately, the relatively near-term need for resource-base assessment limits possible new R&D impact. Nevertheless, the continual need for new and different sources through the lifetime of the program coupled with possible program delays and the probable major positive impact of a "great" resource discovery warrants accelerated effort in developing improved instrumentation. Improvements in remote compositional analysis instrumentation for Earth-based, Earth-orbit orbiter or flyby is especially important because of the much higher costs associated with lander or sample return missions. Higher resolution and more sensitive spectral reflectance instrumentation will be required for categorizing from Earth or Earth-orbit-based observation the many candidate Amor/Apollo class asteroids. Similarly, improved ability to determine rotation rates and mass would be valuable. Enhanced sensors and detectors for general surveying and prospecting by the lunar polar orbiter (1981 mission) would also enhance the resource assessment. For LPO instrumentation, R&D preference should be given to those capable of providing the greatest economic payoff--the γ-ray spectrometer experiment for water, metal element concentration contour survey, the high-resolution mapper, and the search for a continuous insolation area. The coincidence of desirable characteristics in these areas would site a base and lunar development activities. Additionally, emphasis should be placed on visual and IR detectors if a decision is made to employ the LPO subsatellite in a post-lunar mission to L4 or L5. Long-life reliable electronics for special environments--temperature (lunar and asteroidal day-night conditions) and high-g load (penetrometers)--are needed for lander and in situ assays.

Software and general information system technology is required for autonomous search system applications in conjunction with the asteroid search and inventory program. Advances are also required in this discipline to enhance effectiveness associated with unmanned rover (lunar and asteroidal) vehicles used for in situ analysis and sample collection.

Guidance/Control. Presently developing and available technology is judged sufficient in these disciplines to handle most assay missions except for the following problems which are judged unique. First, additional acquisition R&D is needed, since a retrievable asteroid will not have to have the exact known ephemeris characteristics of planetary bodies and will not be visible from Earth or the approaching spacecraft for 99% of its orbit. Inertial guidance with inexact final coordinates will be used until such time as the craft is able to search a large volume for a small target, with the assorted difficulties of detailed on-board pattern recognition and/or calculation of Earth-to-craft transmission and control to assure proper lock-on. Second, the landing (docking) to a "zero"-g body with higher angular acceleration is unique and calls for new R&D. Third, the L4 or L5 probe may present new but probably not difficult problems in controlling a spacecraft around a "pseudo"-gravity field.

Life Sciences. As part of prospecting and survey, consideration must be given to selecting a site for operation that is amenable to human habitation. A continuous insolation site at the Moon's pole would be very favorable to human occupation. Increased importance is thus placed on the sensing discipline for identifying habitable sites. Man may be needed for further lunar exploration before a base site and mining locales can be selected. In this case, life support technology is required for the search and assay phase.

Space/Ground Operations. Since space operations and ground support are major cost drivers in search and assay, R&D emphasis should be continued here.

Safety/Reliability. No unique problems or R&D requirements are anticipated in this area.

3.2.3 Base Support

This section will be directed toward R&T needs associated with locating, establishing, and operating a lunar base to support the given mission model. Obvious extension of this discussion can be made with respect to asteroids if it should prove desirable to establish a manned lunar base for asteroid retrieval. If an asteroid is brought back to the Earth-Moon system, it will most likely be located close (distance and energy) to the processing and manufacturing site, and support will be provided from that facility.

Power/Propulsion. Lunar power requirements are judged to be about 7-200 MW (depending on scenario), but the majority of this is required to power the mass driver. Roughly 10% is needed for mining and about 1% to meet general base needs. Although the base proper is thus a weak comparative technology driver for power, it alone requires greater capacity and storage than our space experience has thus allowed. If alternative launch options to the mass driver are chosen or if considerable direct solar energy is used for extraction, then base support requirements are of increased importance to the power system chosen. If the operation cannot be located in a continuous insolation area, then storage requirements are of great significance and the choice to suspend launches and mining during the night must be considered. In any case, R&D is required in the area of long-term high-capacity storage. One apparently attractive option to avert the night problem is to provide continuous insolation by the use of lunar orbiting mirrors that reflect sunlight to the lunar site. R&D to support this option is discussed in the next section.

There are no unique propulsion needs associated with the lunar base itself. Propulsion needs exist in the Earth-to-Moon transport of the base and its soft landing.

Materials/Structures. Some unique materials problems exist with the base in that lightweight materials for construction must be selected (reduced transport cost), sound over the lunar temperature extremes, strong in order to support a cosmic ray shield of lunar soil, highly reliable, and easily joined for repair and modifications. A number of support systems must be workable at the temperature extremes; this calls for R&D in lubricants, valves, gaskets, etc. Additional heat-pipe R&D tailored to lunar conditions is also required. For mass driver operation, long-time cryostorage materials are needed. For this device, additional materials research in superconductivity has high potential payoff.

For structures, base design and constructability compatible with materials, functional needs, safety, and environmental constraints are most important. It is expected that new R&D needs will arise when the designs studied integrate these considerations. Concentrator/reflector research is needed if, as discussed, continuous insolation from orbiting reflectors is deemed a worthy option. This is a complex structural (actually systems) problem requiring new effort. The basic problem is to construct the largest, thinnest, lightest controllable structure possible (the general problem is analyzed in NASA TM-X73230). Even if this option is not chosen, numerous ground applications for small concentrators (heliostats) for power and direct heating and processing exist. R&D to optimize such structures is required.

Electronics/Information Systems. Electronics are needed for the specialized lunar (asteroidal) operating conditions. There is a special requirement for cryo-electronics (perhaps to 40 K) for lunar pole mining and maybe base support conditions.

New information systems technology is crucial, particularly in communications from the central lunar base to Earth, L2, the SMF, and the lunar mining sites, to control and monitor the accompanying large number simultaneously occuring autonomous teleoperator and AI operations. A study is recommended to assess the operations requirements and identify new R&D needs in this area.

Guidance/Control. For an asteroid base, the rendezvous (acquisition) problem exists as before except man is now in the loop--improving the decision process but requiring increased system reliability. As remote site preparation may be required with the asteroid, before the mass driver can be emplaced, remote operations and control problems will require new R&D. Remote lunar site preparation may also be required before the base can be landed on and established. Critical new control problems are expected with the resource retrieval of the asteroid in the area of gravitational assist by Earth, Venus, and Earth-Moon system because of the close, precise encounters required.

Life Sciences. Major R&D is needed here to satisfy the permanently habitable lunar-base life support needs. Fifteen lunar-stationed workers will be required on a continuous (but replaceable rotation) basis. This problem of long-term open-cycle support for a crew this size is new and quite demanding. Aside from life support, psychological support will be needed to meet the problems of long day/night cycles, recreation needs, closed community, etc.

Safety/Reliability. With man in the loop, increased safety and reliability procedures must be observed--these are generally in line with current standards. New problems may arise because of the need for long-term lunar base habitability, exposed asteroid surface work (a "zero"-g body), and long-term exposure to cosmic rays. It will probably be necessary to establish rescue or lifeboat techniques for the lunar-base or asteroid-base crew.

Space/Ground Operations. Operations and support will be a massive function when the facilities are being established and in the operational phase. R&D is needed here to develop methodology for achieving most effective operation options.

Spaceport Operations. At any major space complex (Earth orbit, near GEO, etc.), spaceport operations will essentially involve activities comparable to those of any major airport: the arrival and departure of a number of space vehicles and the attendant needs for the space equivalent to holding patterns, approach and "docking" control, management of approach and departure corridors (runways) for main engine plume impingement, etc. These typical activities must be executed in the orbital conditions where each vehicle "parked" in the same general volume in space will adhere to its own orbital parameters. Therefore, any situation involving two or more vehicles will produce a very dynamic situation due to their relative motions (tending to transpose their relative positions twice per orbit). Such dynamic and intimate circumstances are only controllable from the complex involved and require technical facilities associated with mission control, flight control, and spatial proximity management.

The analogy of airport traffic control is reasonably valid for the local vehicle management problem. The analogy can be further extended to structure the operations and services required after an arriving vehicle has docked: vehicle maintenance, servicing, fueling, etc., plus any cargo or passenger-related activity.

Technological issues associated with this interdisciplinary activity can include but are not necessarily limited to:

- Local spatial volume management
  - RF sensory systems (radar)
  - Position and velocity determination (computation)
  - Position and velocity management (command and control)
- Vehicle inventory management
  - RF communications
  - Transfer of control (remote from facility)

- Vehicle services
  - Fueling and oxidizer transfer
  - Consumables resupply
  - "GSE" services (power, A/C, etc.)
  - Maintenance (routine, "major," "minor")
- Passenger services
  - Health and well-being
  - Temporary accommodation, etc.
- Other
  - Payload transfer
  - Warehousing and inventory management
  - Operations planning and control
  - Vehicle fleet management

The R&D activity in this area needs clarification by study and therefore cannot be adequately prescribed at this time.

3.3 TRANSPORTATION

3.3.1 Overview

The proposed program will advance the competitive concepts associated with the use of nonterrestrial materials or Earth-based mission residuals as reaction mass in propulsion. This program will provide the fundamental knowledge necessary for identification of the R&D transportation option via systems studies. For simplicity, the mass driver option involves a space flight test in the 8 YFS time frame; however, as the picture is clarified by conduct of this R&D, some other propulsion concepts may be tested instead.

It will be necessary to keep this program in an interactive way with the evolving acquisition of data on the physical and chemical properties of nonterrestrial materials and products that would be useful as propellants. "Propellants" in this context may be in the form of raw or processed passive masses or processed chemical reactants. "Nonterrestrial" means soils, ores, or their process derivatives that come from the Moon or an Earth-approaching asteroid.

The program phasing eliminates elements of R&D that the system studies show to no longer be applicable. The phasing occurs in 4 YFS, when preliminary R&D will indicate which option or options to develop further.

Three basic propulsion concepts are to be carried through the preliminary R&D stage. Mass drivers, linear induction machines which accelerate masses by means of a magnetic field imposed on a magnetically suspended, superconductive carrier or bucket, are candidates because the nature of the propelled mass is independent of the function of the machine. Other electric thruster concepts such as arc jets, plasma devices, and electrostatic devices can also be considered for use with nonterrestrial propellants. Chemical rockets can be considered because of the known existence of fuels and oxidants on the Moon.

Figure 3-2 illustrates the logical flow of this R&D. Interactions between resource survey activities and systems studies are shown by dashed lines. Table 3-1 provides schedule and costing data for this program.

3.3.2 R&D Element Descriptions

Mass Driver. The mass driver and its applications have been well studied such that it is appropriate to proceed with a similar experiment program as early as possible.

Starting in 1 YFS, it is proposed to build and test a short-track-length device to provide fundamental information on the kinetics and structural integrity of the device. This mass driver will contain the basic components and concepts that are necessary for eventual space operation, but the length (hence, the velocity of the bucket) will be limited.

Later, a longer mass driver will be built and tested which will begin to corroborate the high-speed dynamic characteristics of the system. In parallel with this, investigations will take place to characterize certain automated elements of mass drivers such as methods of propellant pelletizing (including STS tankage), propellant loading, bucket cooling, and propellant packaging and design. In addition, elements of the mass driver's power electronics, such as the SCRs, will be optimized to the unique duty cycle environment of the mass driver.

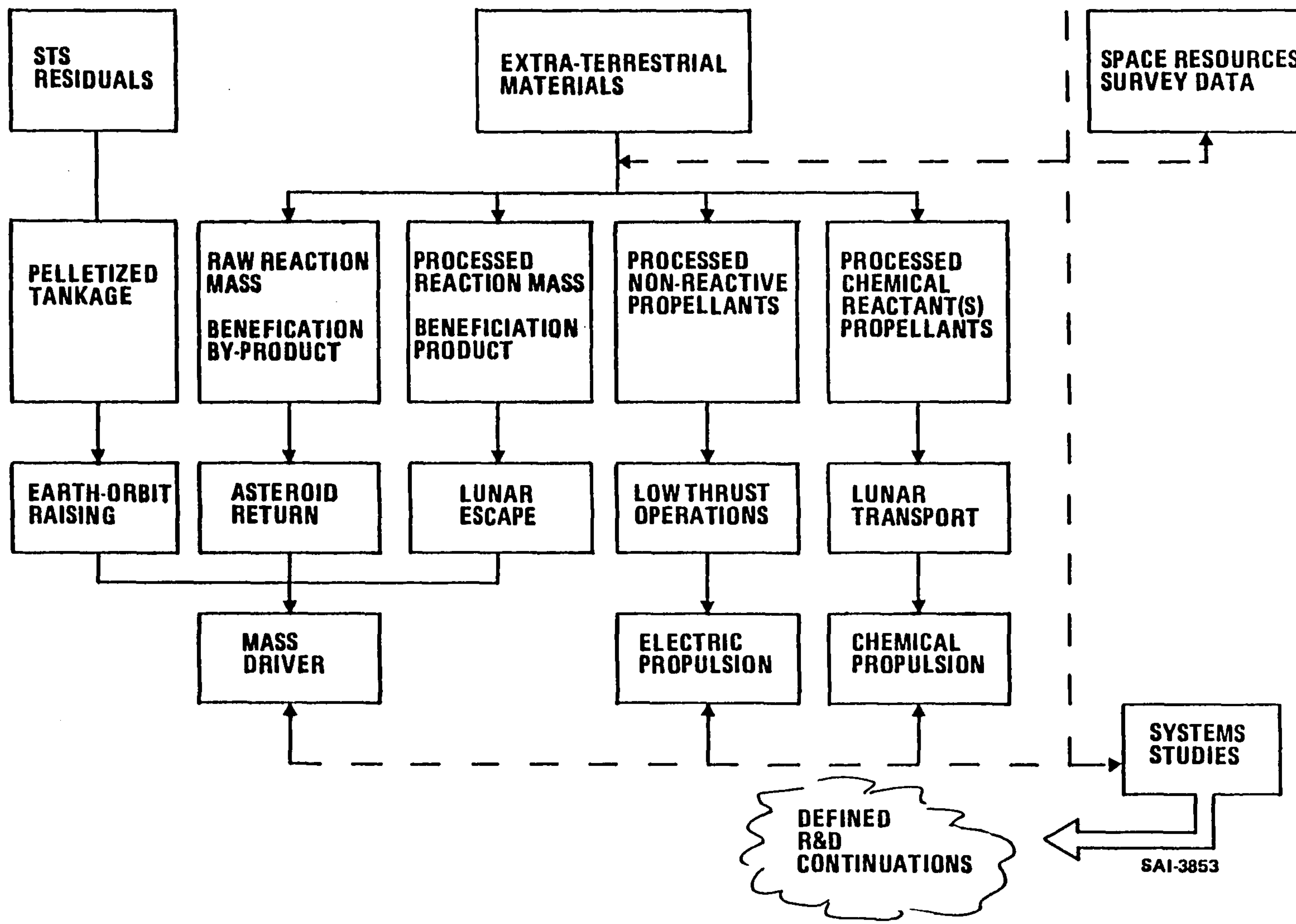

Figure 3-2. R&D Flow Transportation Program

TABLE 3-1

TRANSPORTATION R&D FUNDING BY YEAR FROM START

	YEAR FROM START						
	1	2	3	4	5	6–8	TOTAL
MASS DRIVER							
SHORT LENGTH TEST	0.1	0.2					0.3
MEDIUM LENGTH TEST		0.3	0.8	0.7	0.4		2.2
AUTOMATED ELEMENTS			0.2	0.6	0.3		1.1
POWER ELECTRONICS			0.2	0.6	0.3		1.1
SPACE TEST				1.4	7.0	21.0	29.4
MASS CATCHER							
CONCEPT DEFINITION	←	(1) →					
GROUND TEST			0.8	1.5	0.5		2.8
SPACE TEST				1.0	5.0	15.0	21.0
ELECTRIC PROPULSION							
PROPELLANT PERFORMANCE TESTS		0.1	0.1	0.5			0.7
HIGH THRUST TEST				0.1	1.0(2)	6.0(2)	0.1
CHEMICAL ROCKET							
PROPELLANT PERFORMANCE TESTS		0.1	0.1	0.5			0.7
THROTTLING AND COOLING EVALS.				0.5			0.5
SCALE-UP				0.1	1.0(2)	6.0(2)	0.1
TOTAL	0.1	0.7	2.2	7.5	13.5	36.0	60.0

(1) Schedule only – R&D $ appears elsewhere.
(2) Contingent funding – not included in totals

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Since it is both difficult and expensive to physically propel mass with the mass driver in a vacuum on Earth, the final proof-of-concept will be a space test of the mass driver, wherein the low-gravity performance, automated propellant feed system, and propellant/mass-driver interactions will be demonstrated.

Lunar Escape Payload Capture. One concept of lunar resources transportation is to use it to launch feedstocks to lunar escape velocity by expulsion from a mass driver which is fixed to the Moon. These payloads will follow a free ballistic trajectory to some point in space where they must be collected and "cargo-ized" for transportation by low thrust to some space processing site. The payloads, some 4 kg each, arriving on site at the rate of several per second, will have a velocity of tens to hundreds of meters per second. Their trajectory may be dispersed over an area of tens of hundreds of square meters normal to the trajectory line. A method of catching these objects and disposing of them in a cargo hold must be developed and demonstrated.

A model of this mass-catcher system, based on intensive concept studies, should be fabricated and ground tested. These tests would involve random drops of masses from a tower in one atmosphere at some dimensional or kinetic subscale of the true applications.

A space-operable mass catcher system will be fabricated on a scale to be compatible with the space mass driver test. As a second phase to the space mass driver test, the mass driver and the mass catcher will be separated by a scale distance in low Earth orbital space such that the mass catcher can be tested in a way which closely simulates its final use.

Electric Thruster. In the areas of nonterrestrial materials transportation, where "high" thrust is not a prerequisite, a possible specific impulse is in the 200-2000 sec range (which implies a large quantity of propellant). It is particularly advantageous to consider the use of nonterrestrial materials as propellants for electric thrusters. In many cases, power in the form of heat rather than electricity is input to the electric thruster, thereby minimizing the use of an expensive and inefficient solar energy conversion process.

Many electric thrusters have already been operated on water, oxygen, amorphous dusts and aerosols, metal vapors, etc., which occur naturally or could be easily refined from nonterrestrial materials. These devices have not, however, been operated at a thrust scale which is high enough to be useful in this scenario.

An R&D effort is therefore proposed to utilize our evolving knowledge of nonterrestrial materials to define and test various propellants in electric thrusters at an increased thrust scale.

Chemical Rocket. As an alternative to mass-driver transportation of lunar feedstocks to a space manufacturing site, chemical propulsion could be used to transport lunar feedstocks, finished products, and humans to and from the lunar surface in a more conventional way. Such an alternative would, however, be prohibitively expensive if considered in the context of Earth-derived propellants. The existence of certain lunar resources such as oxygen, water (hydrogen), and metals with high oxidation potential (magnesium, aluminum) introduce the possibility of lunar-derived chemical propellants. It is therefore conceivable that only a small fraction, possibly none, of the total propellant requirement would emanate from the Earth.

The proposed R&D activity here would consist of a series of small chemical rocket tests involving propellants, which simulate preprocessed or refined lunar materials. This would be followed by demonstrations of throttling and cooling techniques which would also involve static firings. Scale-up of a selected system could conceivably follow, starting in 5 YFS, but resources for this are shown as being contingent on the initial R&D outcome.

3.4 HABITATS

3.4.1 Overview

The key R&D problems related to the development of large space habitats required by the space solar power satellite system are fundamental to long-term exposure of man to life in space. Additional technology is required for the economical development of life support and protective systems. Much research is needed to understand man's reaction to long-term space habitation. However, this report only treats the systems required to support man.

Habitats are required in low Earth orbit, geosynchronous orbit, high orbit, and on the lunar surface or during asteroid retrieval. The system requirements are similar except that the lunar base must survive the long night and the low Earth orbit habitat does not have the radiation protection required of the other orbits.

3.4.2 R&D Element Descriptions

Life Support and Protection Systems. Life support and protective systems, as a technology discipline within NASA, encompasses (1) the control and revitalization of a habitable atmosphere; (2) food and water provision; (3) solid and liquid waste management; (4) space suits and emergency equipment for personnel safety and rescue; (5) personal hygiene and crew appliance facilities; and (6) special instrumentation and data management equipment.

Air Revitalization. Air revitalization consists of CO_2 collection, CO_2 reduction, oxygen generation, humidity and temperature control, and trace contaminant control. These technology areas have received significant attention during the past 10 years, and given a mission need, these technologies can currently support flight prototyping and demonstration hardware.

The current activities in these areas are directed toward improvements in efficiency, reducing expendable requirements, increasing reliability, and developing instrumentation/control methodology for the air revitalization subsystem technologies. Examples of these R&D programs are:

- The present stipulated acceptable CO_2 level for manned spacecraft is 3 mm Hg partial pressure. The electrochemical CO_2 concentrator can reliably perform this function; and research and development in this technology area is being pursued to reduce the space cabin CO_2 partial pressure to 1-1.5 mm Hg and increase the efficiency of the subsystem.
- Oxygen generation subsystem technology (water electrolysis) development hardware has been demonstrated, but this technology inherently requires significant power from the spacecraft. The theoretical electrolysis voltage is 1.23 V; and the purpose of this R&D program is to reduce the actual attained electrolysis voltage (increasing efficiency) and thus reduce the power requirement for generating oxygen. Preliminary test data on water electrolysis cells has demonstrated the achievability of 1.42 V for electrolyzing water. Continued R&D is required to demonstrate long-term reliable operation of water electrolysis subsystems.
- Life support system instrumentation and control methodology is required for efficient reliable operation. This methodology must provide control for the operational modes and transitional modes for all subsystems (normal, standby, shutdown, purge, etc.). It must provide the capability to monitor

all critical operating parameters of each subsystem and must detect, isolate, and identify subsystem faults. It must be capable of predicting operating trends and providing maintenance instructions to the crew. This technology is currently being demonstrated at the subsystem level utilizing a programmable minicomputer; and further R&D is required both at the subsystem and system level as a forerunner for flight hardware.

- Air revitalization prototype systems or subsystems must be evaluated in space (zero-g, reduced-g) prior to selection of a base-line spacecraft life support system; and early spacelab flight demonstration of all air revitalizaton subsystem technology is recommended.

Food and Water Provision. The plan for the first habitats is to supply Earth-type food to be reconstituted on board the habitat. Therefore, the primary concern for R&D is the reclamation of water. Water reclamation technology deals primarily with the processing of lightly contaminated water (humidity/condensate, wash water) or highly contaminated water (urine, fecal water). Additional R&D efforts are required in each of these areas.

With solar power augmentation, the processing of humidity/condensate and wash water could provide partial water reclamation for extended space shuttle missions. The current activities in this technology area are directed toward demonstration of reliable subsystem technology.

Reliable urine water recovery subsystems have yet to be demonstrated. Significant subsystem R&D (alternative approaches) must be performed in order to define and refine the alternative processes. The current SR&T program is being directed in this manner.

Waste Management. The handling and storage/treatment of solid waste products (food waste, wet waste, and fecal matter) probably requires more concerted R&D effort than any other life support area. The solid waste can be stored as a stabilized dried mass; but as mission durations are increased solid waste treatment processes will be required to reduce the stored mass requirements. Continued development of feasible approaches to this problem are planned in order to demonstrate reliable operation and acceptable quality of effluent gases and stored mass.

Water reclamation and solid waste handling/treatment prototype systems or subsystems must also be evaluated in space (zero-g, reduced-g) prior to selection of a base-line spacecraft life support system; an early spacelab flight demonstration of all water reclamation and solid waste management technology is recommended.

Life support system control methodology (similar to that for air revitalization) must also be developed for water reclamation and solid waste handling/treatment subsystems.

Solid Waste Processing. Four solid waste processing approaches have been investigated for manned spacecraft utilization. These include vacuum drying, wet oxidation, dry incineration, and an integrated system utilizing radioisotope thermal energy (RITE).

The vacuum drying process utilizes space vacuum to evaporate water and achieve a dried stabilized mass. An adaptation of this process was utilized on Skylab and the process is being developed for the Space Shuttle.

The wet oxidation process utilizes an aqueous slurry which is contacted with oxygen at elevated temperatures and pressures (550°F, 2200 psi). This process produces a stabilized sterile ash and sterile water (which would require post-treatment).

Dry incineration systems consist of thermal decomposition (pyrolysis) of the solid wastes and subsequent oxidation of the vapors. This process produces a sterile ash.

The RITE process combines solid wastes and liquid residues and evaporates the water with catalytic oxidation of the vapor prior to venting. The remaining solid wastes are then thermally decomposed (pyrolized) and incinerated, and the gases are vented. A sterilized solid ash is produced.

The three oxidation process concepts offer feasible and viable approaches to solid waste handing. Two of the processes combine concentrated waste water with the solid wastes, while the dry incineration process provides for a separate processing of solid wastes.

Each of the oxidation subsystem approaches has been operated in the batch mode, but a continuous feed operation has not been attained. The problems of transporting the wastes to the processing units for a continuous process operation have not been solved. Each process has its own unique problems in this regard. Further testing of these processes must provide for thorough characterization of the composition, flow rate, temperature, and pressure and provide a complete material and energy balance of the process. There is also a significant lack of design and performance data on the catalytic oxidizer units. The RITE system appears to be the most advanced from a development viewpoint; but until further R&D on the processes has been performed, it is not possible to select the best candidate oxidation process. It is also apparent that the selection of a solid waste oxidation process must be considered in the context of a total life support system. This could result in a situation where each of the solid waste oxidation processes could be the best trade-off for a particular life support application.

A significant amount of R&D work is required in each of these solid waste oxidation processes.

Space Suits. Because of the large number of man-hours of EVA expected for the construction of the SPS even under the most automated construction scenario, advanced space suits are a must. Current suits operate on pure O_2 and require prebreathing and decompression during transition from habitat to space. New suits in standard sizes are needed (to reduce cost); they should operate with pressures of 10-14 psi O_2-N_2, and be easily donned and removed. Work in this area is very important to make manned operation in space practical and economical.

Habitat Design. The habitats must obviously be designed for pleasant and efficient living in space. Many Earth-based studies and activities are reliable indicators for the habitat interior design. Experience in submarines and in Antartica are notable examples. One major factor remains: the question of gravity or no gravity. The design of habitats will be greatly influenced. Physical arrangement, structural design, and stability and control systems will be vastly different, depending on design. There is presently only limited or no data on:

1. Requirement for gravity (or simulated gravity) over long periods (at least 2 years).
2. Effect of rotation (torus habitat) for long periods (at least 2 years).
3. Effect of moving from rotating g environment to zero-g environment and back frequently.

These and similar questions will be answered or the habitat will need to be designed for all eventualities at greater cost.

The economic pressures on the design of the habitat and the life support and protective systems are large. The 1977 space settlements study projected that 60% of the logistics cost and one-third of the weight during the last year of the initial SPS build-up were directly attributable to the requirements to transport people and their supporting supplies.

3.5 NONTERRESTRIAL MINING, PRODUCTION, AND MANUFACTURING

3.5.1 Overview

This list of technology needs has been developed assuming that a program will start in 8 YFS to develop space systems using lunar or asteroid raw materials. The purpose of the technology work between now and then is to provide enough new knowledge to support sound judgments on the initial course and probable cost of the post-Phase B programs.

3.5.2 R&D Element Descriptions

Lunar Resources. The first need, of course, is to identify the "ores" to be mined. Returned lunar samples and other data indicate what is available at the surface in a few equatorial mare and highland regions of the Moon. Knowledge of the subsurface is slight, depending as it does upon models created to fit limited seismic, heat-flow, gravity, magnetic, and microwave sounding data. Nevertheless, some useful products can be recovered from the Moon, even if no highly concentrated areas exist there.

Lunar Soil. "Average" lunar soil is suitable for some simple beneficiation processess (such as magnetic separation of iron and titanium minerals) because it is already a mixture of small particles. Lunar soil is, however, sticky and clumpy, as are many materials in high vacuum, and therefore ordinary Earth-type equipment may be inadequate for handling it.

Lunar Rocks. The rock samples returned by Apollo and Luna missions are rich in refractory elements and depleted in volatiles. Lunar silicates contain about 40% oxygen. Mare basalts contain useful amounts of titanium and other structural materials; and highland rocks contain aluminum in anorthite, which would on Earth be considered an aluminum ore were it not for the presence of better ores such as bauxite. Glass may readily be made from lunar rocks; lunar soil already contains much impact-melt glass. However, a presorting of unknown extent may be necessary to get a glass furnace feedstock that will yield consistently correct properties in the product. Prominent among the return lunar rocks are breccias, rocks composed of smashed and comminuted mixtures of other rock fragments. The reworking of lunar surface rocks by aeons of impacts means that an average soil-rock sample from one site is sure to be contaminated with material from the other sites.

Since crushing and processing rocks to prepare for separation of usable minerals requires strong and heavy machinery, the early efforts in lunar mining technology should concentrate on seeing whether or not all needed products can be recovered from the soil, which nature has already ground. If the higher purity of rock materials wins out in this trade-off, then unconventional rock-processing techniques (such as solar-furnace melting) should be explored as alternatives to crushing.

Lunar Volatiles. Because the Moon's equatorial surface materials were formed in the absence of water and then vacuum baked, lunar minerals contain only very small amounts of hydrogen and other volatile elements. There is some hydrogen implanted by the solar wind on grain surfaces and though small in quantity (0.3 cc at standard temperature and pressure per gram of average soil) it is easily recovered by moderate heating and may prove to be a usable resource. However, the only real hope for finding concentrated and easily accessible lunar water and other volatile compounds now appears to lie in the permanently shadowed polar craters, whose bottoms presumably have acted as cold traps to collect any lunar volatiles existing over geologic time. Should such permafrost deposits be found at or near the surface, techniques for extracting, handling, and conserving their products will become a prime technology need.

Lunar Mine Location. The mine should of course be near the base. If a lunar polar orbiter finds permafrost in the polar cold traps, this will virtually dictate a polar base location--at least for mining the volatiles. Such a location has other advantages but may not be optimum as a mass driver site. Even if available permafrost is not found and hydrogen has to be imported, the polar cold traps can provide cryogenic storage for the hydrogen, for water as ice, and for oxygen extracted from lunar soil. Therefore, there is a possibility that lunar materials technologies must include cryogenic processes as well as the high-temperature techniques mentioned earlier.

Technology Directions. It is thus evident that technology needs will differ depending upon what is learned about the Moon between now and 8 YFS. If the Apollo and Luna samples prove to be representative of all the lunar materials available (i.e., if no higher grade ores, no carbonaceous deposits, and no permafrost are found by polar orbital surveys), techniques will be needed for mining, sizing-sorting, and perhaps simple beneficiation of lunar soils. If it is decided to go beyond simple (e.g., magnetic) beneficiation on the Moon, both moderate-temperature (crucible) and high-temperature (plasma arc or solar furnace) techniques for extracting oxygen from silicates and for converting lunar soil and rocks into other products usable on the Moon will be needed. If only solar-wind-implanted hydrogen is available, an efficient process for extracting it from large volumes of lunar soil must be devised, or hydrogen must be transported to the Moon. Timing is an important element in these choices. To build up the inventory of oxygen, water, and other products needed for initial operation of a lunar base, either a small plant can operate for a long time or a larger plant can operate for a shorter time. The earlier a small automated plant on the Moon can start up, the sooner the realities of sustained operations there will be learned, and the sooner stockpiling useful materials will begin. Therefore, there is urgency in developing the requisite automated technology on a small scale. Should larger throughput rates be needed for later expansion, plants using later generation technology could be designed; instead of being entirely automated, these could be man tended but it would probably still be economical to have a high degree of automation.

Technology Need Description. In general accord with the above rationale, Group V of the Summer Study and the NASA Planning Group developed technology need concepts. The appendix comprises copies of query sheets collected. They include need descriptions for processes ranging from iron-titanium extraction out of lunar ilmenites to the synthesis of binders and adhesives using lunar raw materials. In addition to these individual process developments, there is, of course, a need for integrative trade-off analyses and for thinking about unconventional processes, unconventional products, and unconventional uses of the products. An example might be network-type inorganic polymers made from silicate raw materials. The needs list of the appendix should therefore be regarded as a first cut at the problem. It does identify some tasks that could be usefully started now, but it leaves open the prospect for inventions.

Asteroid Resources. Direct knowledge of some lunar resources is available from returned samples, but what may lie elsewhere on the Moon can only be inferred. For the asteroids the picture is different. Although no attempt has yet been made to sample an asteroid deliberately, meteorite samples and some evidence, both direct and indirect, are on hand that indicate some meteorites and some asteroids are chemically and mineralogically related; indeed, there is a growing opinion that at least some meteorites are in fact asteroid samples. If true, this makes the asteroids extremely interesting as a resource, because many of them would be rich in organics and water, and others may consist almost entirely of metals. On the Moon, the first need is to find out whether or not the presently known materials are typical of the whole Moon. For the asteroids, the analogous need is to find accessible bodies which do in fact contain the abundant resources promised by the meteorite data ("accessible" is meant to include orbits favorable for recovery into the Earth-Moon system; for example, the Apollo and Amor asteroid families). Assuming that one such object is found and tracked, then visited by remote-sensing flyby spacecraft to confirm its surface chemistry, techniques will be needed for bringing it into the Earth-Moon system, as described in other reports of the Summer Study.

In this section the concern is only with the mining, processing, and manufacturing that go on once the asteroid is in hand. Some of these processes may not need to wait until the end of the journey toward Earth-Moon. For example, if the asteroid's own material is to be used for reaction mass, en route beneficiation to throw away the less valuable fraction and keep a concentrate as part of the payload becomes attractive. Since a typical transit may take several years, with multiple Earth and Venus flybys before the final Earth-Moon capture, any en route processes should be completely automated so that it is not necessary for a crew to ride along all the way. Because the thrust direction must change many times during transit, a simple solar-powered continuous beneficiation plant such as that proposed for the lunar polar base may not be practical; thus a more advanced (but still conceptually simple, e.g., magnetic) beneficiation technology may be required. In any event, with or without beneficiation, a residue of the original asteroid will eventually arrive in the Earth-Moon system and at that point technologies will be needed for extracting and using its products.

Some of these technologies (for silicates, etc.) can be similar to those discussed earlier for the Moon. For materials such as those of the nickel-iron meteorites, little more than mechanical hot-working may be needed to form useful products. However, as mentioned earlier for lunar rock crushers, blacksmith's machinery tends to be heavy, so that unconventional vacuum techniques (plasma arc extraction and deposition, electron beam machining and welding) should also be considered. For materials resembling those of the carbonaceous meteorites, a whole range of gentler techniques should be developed: crushing of the friable matrix with capture of released volatiles, then moderate heating to a few hundred degrees centigrade to release hydrocarbons, water, and other gases. Technology needs of this kind, yielding processes which could be used with carbonaceous materials from either the asteroids or (if any are found there) the Moon, are also listed in the appendix.

3.6 PROGRAMMATICS

The key areas of research and development are shown in Table 3-2. The schedule and budget levels were rather arbitrarily selected based on the premise that major increases in the NASA budget were unlikely without a national mandate. However, such a mandate could substantially accelerate the R&D described, but not to less than about 3 years, which would move the ready data for the key issues to 4 YFS. In addition to the key R&D items enumerated, technology needs in other areas must be advanced. Because of the time available, these areas are not specifically identified and must wait for the completion of the early system studies. However, rather than ignore these requirements, an R&D allocation was recommended beginning in 4 RFS and is shown in Fig. 3-3 as "other"; it was arbitrarily set equal to the funding requirements for the key R&D areas.

The budget shown here is felt to be the most ambitious one likely without a national mandate to move as rapidly as possible toward the development of a non-terrestrial solar power satellite.

TABLE 3-2

KEY R&D QUESTIONS

- **POTENTIAL SHOW STOPPERS & HIGH PAYOFF AREAS**

$, M

Years From Start	1	2	3	4	5	TOTAL TO END OF PHASE B
LUNAR MATERIAL TO ORBIT TRANSFER CATCHER; CHEM OPTION		0.2	0.8	2.5	3.5	10.0
BASE LOAD POWER - MULTI MW PHOTOVOLTAICS – SPECIAL CONCENTRATORS	0.1	0.2	0.4	0.4	0.2 0.2	1.0 1.5
LARGE STRUCTURES – DYNAMICS		0.2	0.5	1.0	2.0	10.0
BENEFICIATION AT SITE		0.1	0.4	0.8	1.0	2.5
LIFE SUPPORT >6			0.2	0.3	0.3	0.8
MASS DRIVER	0.1	0.5	1.5	5.0	10.0	50.0
ET PROCESSES	0.1	0.3	1.5	2.0	5.0	20.0
TOTAL	0.3	1.5	5.4	12.0	22.0	100.0

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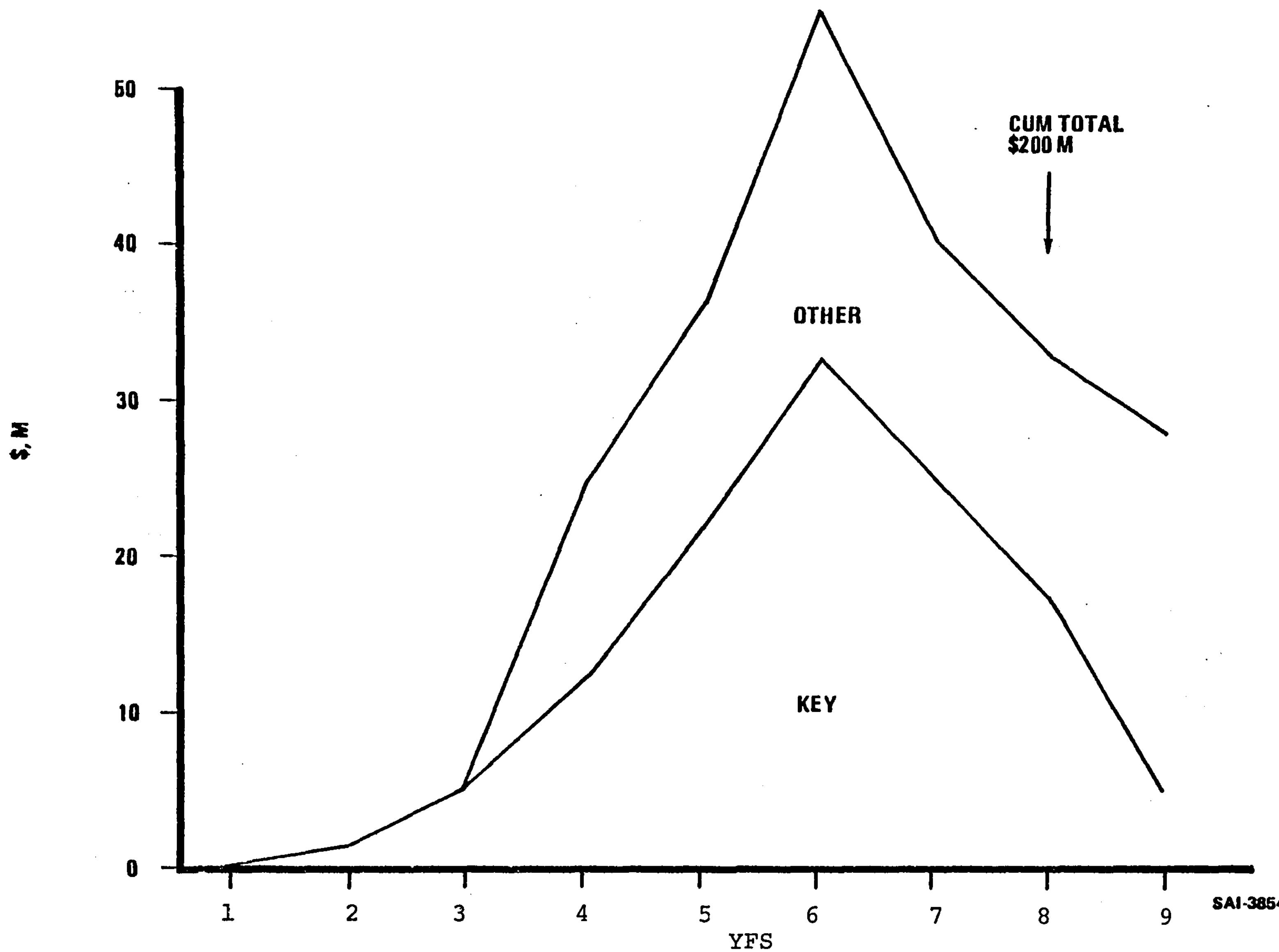

Figure 3-3. R&D Funding

3.7 COMPONENT TECHNOLOGY TEST BED PROGRAMS

It is assumed that the research and development program covering ground- and space-based technology advancement experiments and verification activities previously described will be carried out prior to 8 YFS the technology readiness planning date. Within this time period, five basic technology test-bed programs will verify and update integrated system elements (components) in preparation for larger scale systems demonstration programs. Attention is drawn in Table 3-3 to those technology test-bed requirements that are pecular to nonterrestrial resources utilization. It is assumed that the ongoing and planned satellite power systems activities will cover all areas peculiar to those systems. Rough cost estimates are presented, however, for all test-bed programs. Study and research activities defined elsewhere must be undertaken to support final refinement of these estimates.

TABLE 3-3

REQUIRED COMPONENT TECHNOLOGY TEST BEDS

COMPONENT TECHNOLOGY TEST BEDS	$\$ \times 10^6$
Material Process SMF	100-200
Space Manufacturing System	200-500
*High Efficiency OTV Engineering	(200-500)
*Construction Systems	(200-500)
*Long-Term Habitats	(200-300)
Mass Catcher	200-300
TOTAL	500-1000 (1100-2100)

*Covered by present SPS planning.

4 PRECURSOR FLIGHT MISSIONS

4.1 EXPLORATION PROGRAMS

4.1.1 Introduction

This section describes lunar and other exploratory activities that can and should be carried out as part of the preparations for a space settlement program. Since these explorations are largely justified in their own right as science, some of them are already proposed or planned. The effect of a space settlement initiative would be to enhance the priority of these efforts and broaden their support. There is no reason to suppose that the result would not still be good science--but the data would also be useful, and in some cases critical, for designing and planning the space settlement program. Further information on lunar and asteroidal resources, with program recommendations, will be forthcoming in the report of the 1977 Summer Workshop on Near-Earth Resources chaired by Dr. J. R. Arnold.[1]

4.1.2 Lunar Exploration

We already know enough about the Moon to be able to design base systems that could operate at an Apollo landing site. We have some idea of the geophysics and geochemistry of the Moon and the surface distribution of such useful elements as aluminum, titanium, and iron. Much of this knowledge is limited to the equatorial region surveyed by Apollo. What we need now is to learn answers to the following questions:

1. Are there higher local concentrations of usable resources?

2. Are there superior base sites with access to these resources?

3. What is needed for the recovery and use of the resources?

With regard to resource concentrations, Earth-based and orbital maps already show striking variations in composition across the lunar surface, in some cases correlated with the age and morphology of geologic units. We need a global, high-resolution survey to pursue this lead, to develop models of lunar processes that can serve as a guide to prospecting, and in particular to search for unique, local phenomena that could indicate higher grade ores including, for example, water and other volatiles trapped as permafrost in permanently shadowed polar craters.

Even if no permafrost is found, the polar regions should be closely examined as possible base sites because of their unique environment combining constant sunlight and constant darkness, which can be exploited in the design of base power, life support, and other thermodynamic systems.

Once a potential resource and a potentially suitable base site are identified, the next need is for prospecting on the ground. In addition to confirming orbital observations, the prospecting mission must survey the site as well as possible, determine the chemical, mineral, and physical state of the mineral to be mined. and measure the environment parameters that are critical to base design.

Following the prospecting, it will be logical to set up a small-scale processing demonstration at the chosen site. The purpose of this mission should be not only to confirm operation in the real lunar environment with real lunar feed materials but also to begin building a stockpile of products for later use. Even a small automated plant, if run continuously over a long period, could produce a vital inventory of materials (e.g., water) which would then be used and recycled on the base. If this automated processing demonstration were located in a polar region, its volatile products could be frozen and stored in the dark cold traps, obviating the need for heavy tanks.

In addition to the resources of the Moon itself, there is a resource represented by the dynamic properties of the Earth-Moon system, for example, the stable libration points where orbiting masses can be maintained with small amounts of propulsion. There are also stable orbits in the vicinity of the Moon, some of which would permit a continuous communications relay to the lunar far side as well as being suitable for the capture of materials launched from the lunar surface. To explore the perturbations and guidance error properties of these weakly bound libration orbits should be a straightforward task for a small automated spacecraft which could also be instrumented for magnetospheric science. Such a mission would be an important pathfinder for any systems making use of this class of orbits in Earth-Moon space.

To provide the knowledge needed for all of these purposes, one can visualize a series of precursor activities as follows:

1. Continued ground-based spectrophotometric mapping of the Moon, and continued lunar research using samples and other data to develop fundamental resource understanding
2. Lunar Polar Orbiter (LPO)
3. Libration dynamics explorer
4. Surface prospector
5. Automated processing station

Ground-Based Activities. The potential of ground-based spectrophotometry has been demonstrated[2,3] but by no means exhausted. Mineralogical mapping of the Moon's earthward face should be continued and accompanied by further development of instrumentation techniques (which will also benefit the higher resolution mapping from orbit) as well as by correlations and modeling to develop understanding of the observed mineral variations. These same techniques can then be applied to higher latitude, limb, and far-side regions by observing from lunar orbit. Other ground-based lunar research, involving lunar samples and other data with specific reference to resource utilization, is described elsewhere in this report.

Lunar Polar Orbiter. The Lunar Polar Orbiter, illustrated in Fig. 4-1 and described in Refs. 4 and 5, has been extensively studied. Eight scientific investigations have been selected, and some preliminary developments have been started. The mission was, in 1977, proposed for launch in late 1981 or early 1982; estimated project cost was $120M. The NASA-sponsored 1977 Summer Workshop on Near-Earth Resources[1] reviewed the mission and concluded that it should be flown as soon as possible with its present complement of investigations. Some extensions of the mission in specific support of a resource survey are feasible and desirable; the workshop concluded that these should be limited to what can be done without delaying the flight. In addition to its global geochemical and geophysical survey, the LPO has the potential for discovering polar permafrost if it exists, for measuring the regional topography of base sites, and for investigating anomalous areas of possible resource interest, such as volcanic provinces, lunar rilles, and dark-haloed rimless carters.

Libration Dynamics Explorer. The LPO mission incorporates a small subsatellite in high orbit whose purpose is to relay radio Doppler tracking to and from the orbiter while it is over the Moon's far side, out of sight of Earth. With modification, this subsatellite could, upon completion of its mission in support of LPO, become a libration orbit explorer. Alternatively, that mission could be launched separately from Earth. Neither approach would be highly costly; the choice would probably be based on program and schedule considerations and on the perceived need for a precursor mission combining

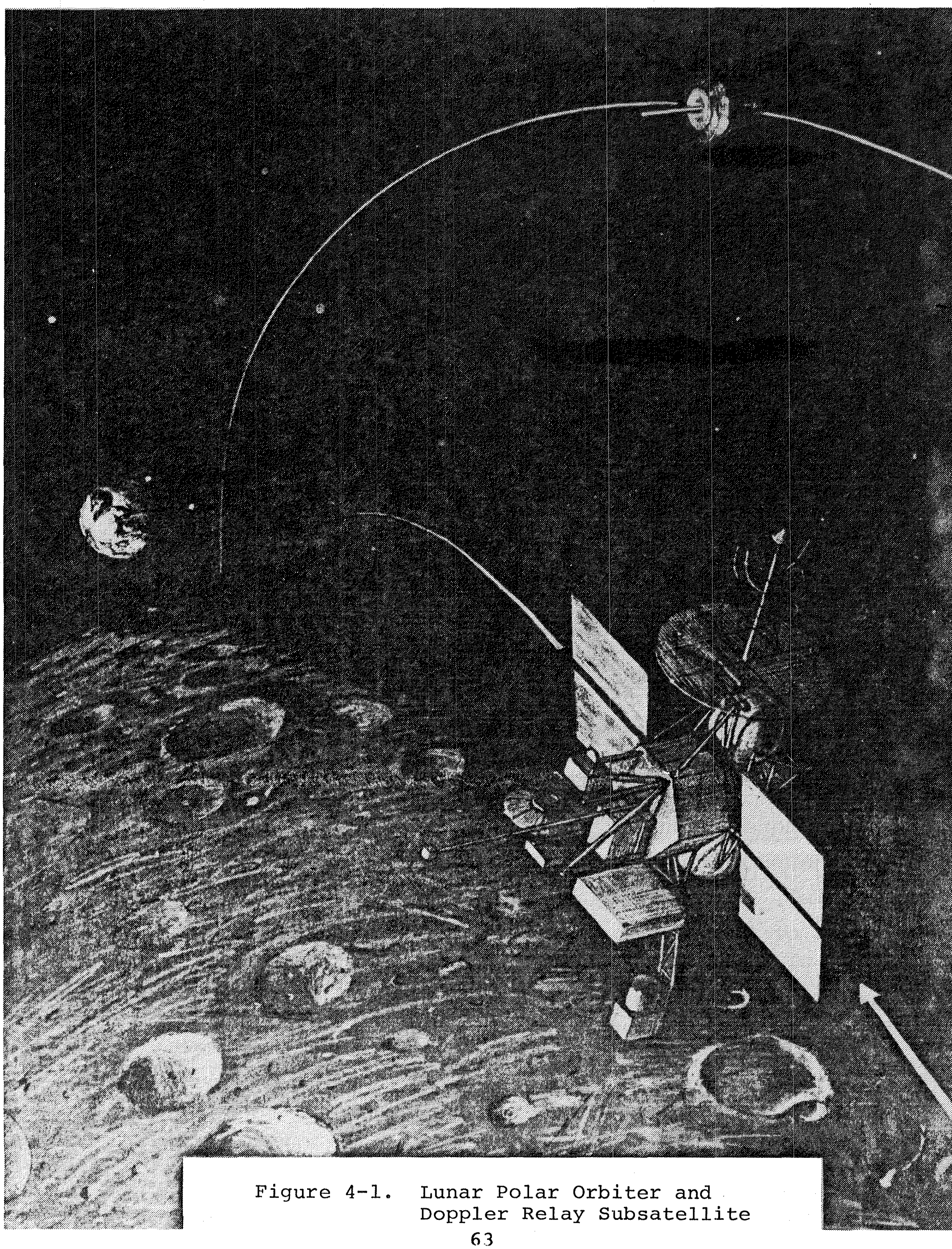

Figure 4-1. Lunar Polar Orbiter and Doppler Relay Subsatellite

orbital pathfinding and magnetospheric science. This mission is a good candidate for international involvement in the lunar program, and is already being discussed in a preliminary way by the European Space Agency. Previous missions in this class have included IMP (Explorer 35) and RAE-B (Explorer 49), both now orbiting the Moon.

Surface Prospector. Automated lunar rovers have been the subject of many studies (Refs. 6-9, for example), and their practicality has been demonstrated by operation of the two Soviet Lunokhod machines on the Moon. Long-range, long-duration surface traverses have undoubted scientific merit for exploring both the Moon and Mars, but because of their relatively high cost such missions have yet to compete successfully with other candidate missions in the U.S. lunar and planetary program. The short-range mobility provided by the Apollo manned lunar rover was a great asset to geological reconnaissance and sampling, and the prospecting mission is clearly feasible with only modest improvements in mobility, range, and endurance of the rover. The main new needs are for (1) remotely controlled prospecting instrumentation with support systems such as sampling manipulators and drills), and (2) systems permitting operation out of sight of Earth, for example, within the polar shaded craters. Figure 4-2 is a sketch of such a rover. In addition to lighting and imaging devices for visual reconnaissance and topographic mapping, the machine should carry instruments for measuring the chemical, mineral, and physical properties of soils, rocks, and volatiles (X-ray, gamma-ray, alpha particle and/or

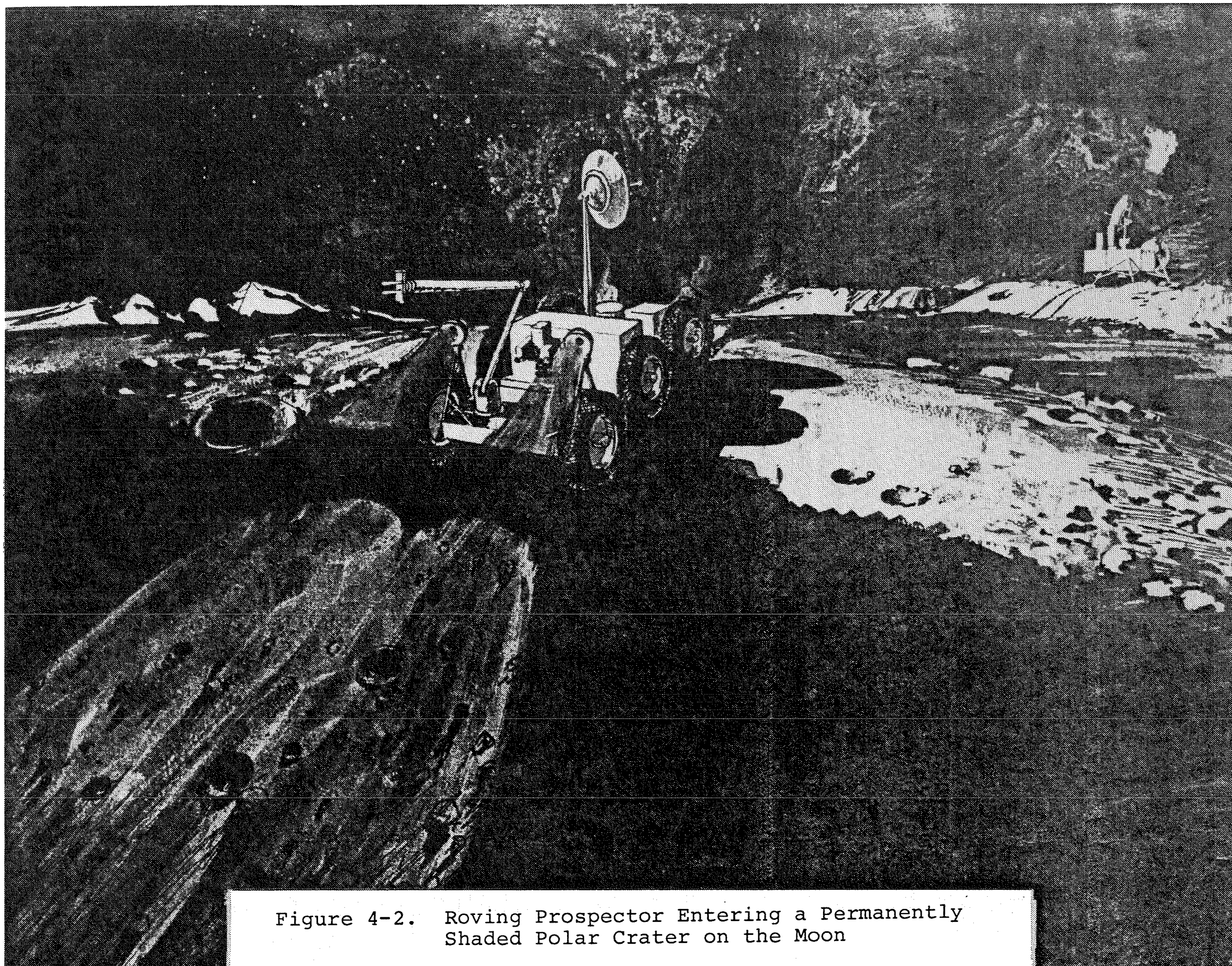

Figure 4-2. Roving Prospector Entering a Permanently Shaded Polar Crater on the Moon

neutron spectrometers, for example) as well as devices such as a drill or soil auger for sampling below the surface. If designed for a long lifetime not specifically limited by on-board consumables or wear, such a machine could have continuing utility in later phases of the program. It could serve as a local transport (see below) or, alternatively, after completing its local resource-prospecting survey it could be sent off on a long scientific traverse.

Because their objectives were to some extent preempted in 1971-73 by Apollo 15-17 and Lunokhod 1 and 2, there has been little recent study of specific automated lunar roving missions. Support for research and development of some of the required automation techniques has, however, continued. Therefore, the first need now is for a mission study using assumptions appropriate to today's technology and to today's understanding of the scientific and resource-prospecting objectives. A second need, already mentioned, is for R&D on prospecting instruments. With the results of such work in hand, the next step will be to develop a specific project definition and cost estimate so that the mission can be proposed, reviewed, and approved through NASA and the Office of Management and Budget. The mission study should be done in 1 YFS or 2 YFS and the project-definition study should be done in 2 YFS or 3 YFS so that the prospector development could be ready to proceed as soon as warranted by LPO results. Costs for these preproject phases, including related instrument technology work, would be a few million dollars; the cost of the project itself would probably be of the order of $300M. A Soviet prospector derived from the Lunokhod, perhaps with communications support via a U.S. relay satellite, is a possibility that should be explored if international conditions permit.

Automated Processing Station. Figure 4-3 is a sketch of an automated lunar material processing station, intended to illustrate one possible concept for using solar energy directly to extract useful substances from lunar materials. The prospector rover is shown operating as a transport. What goes on inside the processing station is not shown and has not been studied. Elsewhere in this report, recommendations for such studies are discussed. If the lunar soil contains frozen volatiles, simple heating to a few hundred degrees centigrade will release them. At higher temperatures the soil can be sintered or fused into various products; it already contains substantial amounts of impact-derived glass. Beyond mere melting, a variety of thermochemical or electrochemical processes may be used; the salient need now is for a study of the various possibilities and initial development of those that appear promising for lunar application. Reference 1 and its bibliography give relevant information for such studies.

The system sketched in Fig. 4-3 is shown operating at a permanently illuminated polar site; the lunar polar orbiter is a needed precursor to finding and evaluating such locations. Pros and cons of a polar location are briefly discussed in Ref. 10, but obviously more lunar data and more trade-off studies are required before a decision can be made on polar vs. equatorial base sites.

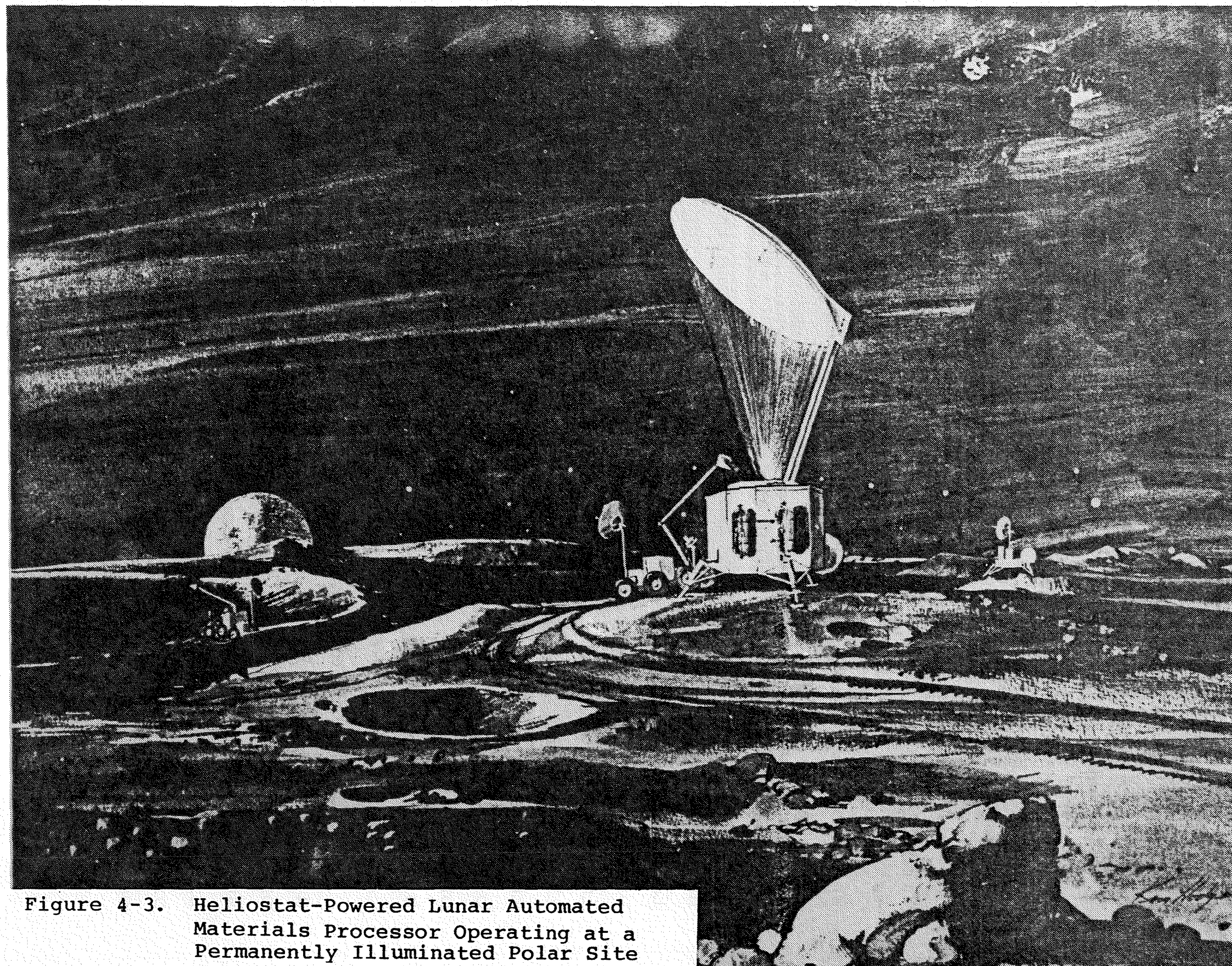

Figure 4-3. Heliostat-Powered Lunar Automated Materials Processor Operating at a Permanently Illuminated Polar Site

Depending on the outcome of early studies on processing principles and techniques, and also on the LPO survey which is critical for site selection, preliminary design of the automated processing station should begin about 3 YFS or 4 YFS with the intent to go into a project-definition phase by 5 YFS for launch and lunar operations beginning in 8 YFS. Preproject and SRT costs would rise to a few million dollars per year; costs for the actual project cannot be estimated at this time because of the many uncertainties remaining about lunar resources and how and why we will use them. In any event, this precursor demonstration would probably be kept quite small not only to hold down its cost but also to allow for the possibility of major changes in objectives or methods as a result of what is learned in all of the precursor missions. As mentioned previously, however, even a small and perhaps inefficient demonstration plant could, if started early enough, build up a vitally important inventory of products for later use on the Moon.

The series of lunar missions just outlined is, of course, only one of a number of program options. The lunar polar orbiter is in any event the first flight mission, because all versions of the later program depend on its results. After LPO, however, the course of events may be different from that given above. For example, if anomalous but very interesting data are obtained in the polar regions, radar mapping from orbit may be desired to investigate the shadowed areas where visual imaging from orbit is not practical. Another option would be to do the prospecting with manned instead of automated systems. However, the demonstration processing station would in any case be automated, because of the likely requirement for a long-duration mission (at least several months) and the certainty that the full-scale plant would be largely automated. Thus these precursor mission options relate more to the pace and scope of the follow-on settlement program than they do to the main questions that need to be answered about the Moon.

4.1.3 Asteroid and Comet Investigations

As in the case of the Moon, but to a greater degree because of our much earlier state of knowledge, precursor activities are required for developing the prospect of using asteroidal resources. Much can be learned by ground-based observation, as outlined in other parts of this report and also in Ref. 1, but ultimately flight missions will be required just as in the case of the Moon. There is, however, an important difference: as of today, we do not know which bodies should be visited first--and it is possible that the best candidate has not yet even been discovered. Clearly the first need is for increased searches in the realm of the Earth-crossing asteroids.

Four main lines of investigation pertinent to asteroid resources are apparent:

1. Discovery and characterization of more near-Earth asteroids.
2. Continued investigation of main-belt asteroids (those between Mars and Jupiter).

3. Investigation of comets, particularly those which appear to be genetically related to near-Earth asteroids (comet Encke may be the prime example).

4. Continued research on meteors and metorites, which are natural examples of solar-systen material intercepted by the Earth and so must in some ways be representative of near-Earth material resources.

Discovery and Characterization. As outlined in Ref. 1 and its bibliography, the near-Earth asteroid search can be immediately expanded at low cost (less than $1M/yr). Discovery, orbit determination, and prompt spectrophotometric observation using dedicated and on-call telescopes could rapidly augment the known number of near-Earth objects that are candidates for close examination and possibly retrieval.

Investigation of Main Belt. Polarimetric and spectrophotometric observations of the main-belt asteroids have proven valuable for sorting the asteroids into compositional families (for recent reviews, see Refs. 11 and 12). Apart from its great scientific interest in relation to the origin and evolution of bodies in the solar system, this research is relevant to the question of resources, because it shows us which asteroids are the most likely to be predominately rocky, metallic, or rich in carbonaceous and volatile substances. A key resource question is whether or not the same wide range of compositions is available near the Earth. Meteorites suggest that, at least in modest quantities, it is. These ground-based observations are fully justified on scientific grounds and are not costly.

Comet/Asteroid Relationships. Of similar scientific interest is the relationship between certain asteroids and short-period comets. According to one model, comet Encke is now in the process of losing the last of its available volatiles, and in a few hundred or thousand years will be indistinguishable from an asteroid. Since the population of near-Earth objects is expected to be rapidly swept up or ejected by encounters with the inner planets, it seems to have a source of replenishment--perhaps comets, of which Encke is an example, that have been perturbed into short-period orbits by planetary encounters. Since asteroidal volatiles are among the prime resources to be sought, this question is also of more than scientific interest. As shown by the campaigns that were mounted for comets Kohoutek and Bennett, important observations can be made from Earth, from aircraft, and from spacecraft in Earth orbit, with costs ranging up to a few million dollars. Ultimately, however, a spacecraft mission to a selected comet will be needed. The scope and cost of such missions can vary widely depending on the target, the measurement objectives, and the program context.

Meteorite and Meteor Studies. The infall of solar-system materials presents a continuing opportunity both for science and for planning the recovery of asteroidal resources. The key links that need to be explored are those relating meteorites to Earth-crossing asteroids and meteors to comets, together with the selection effects that make the known meteorites nonrepresentative of the materials that are potentially available for use in space. Meteorite and meteor research is scientifically justified and not costly, but may yield data of much importance to a resource program.

Clearly there is still a lot that can be done, in all four of these lines of investigation, by the methods and at the costs typical of ground-based, air-borne and Earth-orbital astronomy. Soon enough, however, the time will come when flight missions to the target bodies must be mounted to maintain progress. Figure 4-4 is a sketch suggesting a comet rendezvous. Preliminary studies of such missions should begin now. As outlined in Ref. 1, a wide range of choice is available; flyby vs. rendezvous, single vs. multiple targets, ballistic vs. low-thrust propulsion, for example. In our present state of knowledge a ballistic mission to a single target, with either a true rendezvous or a very slow flyby, appears to be the first choice, with later program phases leading to an asteroid sample return. Trade-off studies of such missions should be made in 1 YFS or 2 YFS, with the intent of developing a first project definition by 3 YFS or 4 YFS. As in the case of the lunar missions following after LPO, these preproject efforts (with appropriate SRT on, for example, rendezvous techniques and compositional sensors) could be usefully carried forward on a scale not exceeding a few million dollars per year. Cost of the first flight mission itself cannot now be predicted because, as mentioned previously, the

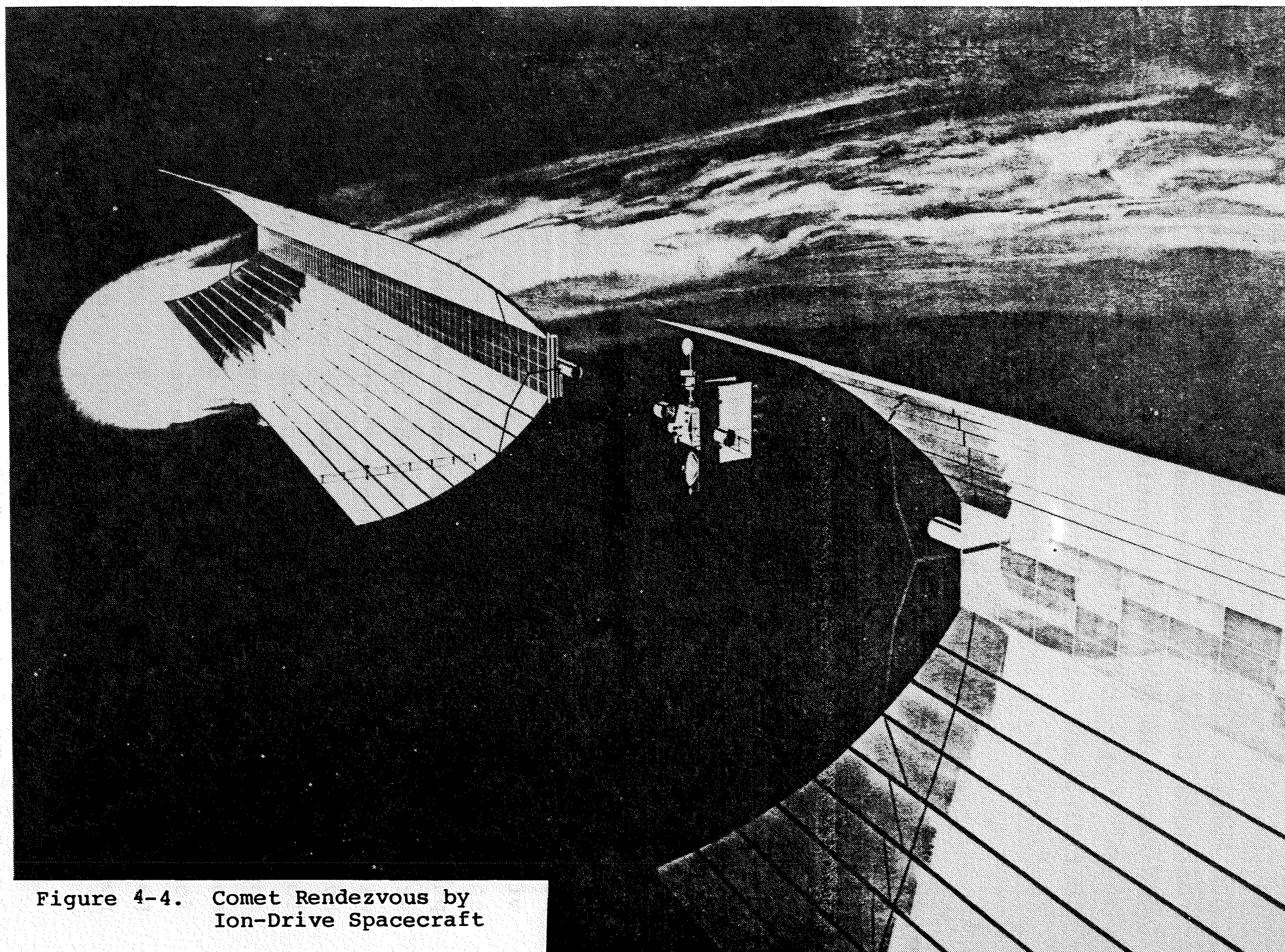

Figure 4-4. Comet Rendezvous by Ion-Drive Spacecraft

range of choice remains very broad; however, it would be very desirable to find a useful mission in the cost range similar to LPO ($100M to $150M) to enhance the chances of approval for a first asteroid flight in the early eighties.

4.1.4 Precursor Program Summary

One way to combine the lunar and asteroidal ground-based observations, supporting research and development, and flight missions into a program with moderate annual expenditures is shown in Fig. 4-5. The costs shown are all rough order-of-magnitude estimates, except for LPO which is the only project to have reached the project-definition study phase. As pointed out above, studies should be made soon to bring the next following flight projects (for example, the lunar prospector and the asteroid or comet rendezvous) up to a similar stage of definition so that their objectives, general design approach, management plan, and costs are known. This to some extent depends upon progress in developing concepts for the later program of space settlements and use of near-Earth resources. However, definition of the early precursor missions can and should proceed soon because we can already visualize the need for their results in almost any version of the final program. With some such series of projects as illustrated in Fig. 4-5, perhaps involving some international contributions, we would be doing good solar-system science and also making direct progress toward understanding and using the resources of near-Earth asteroids and the Moon.

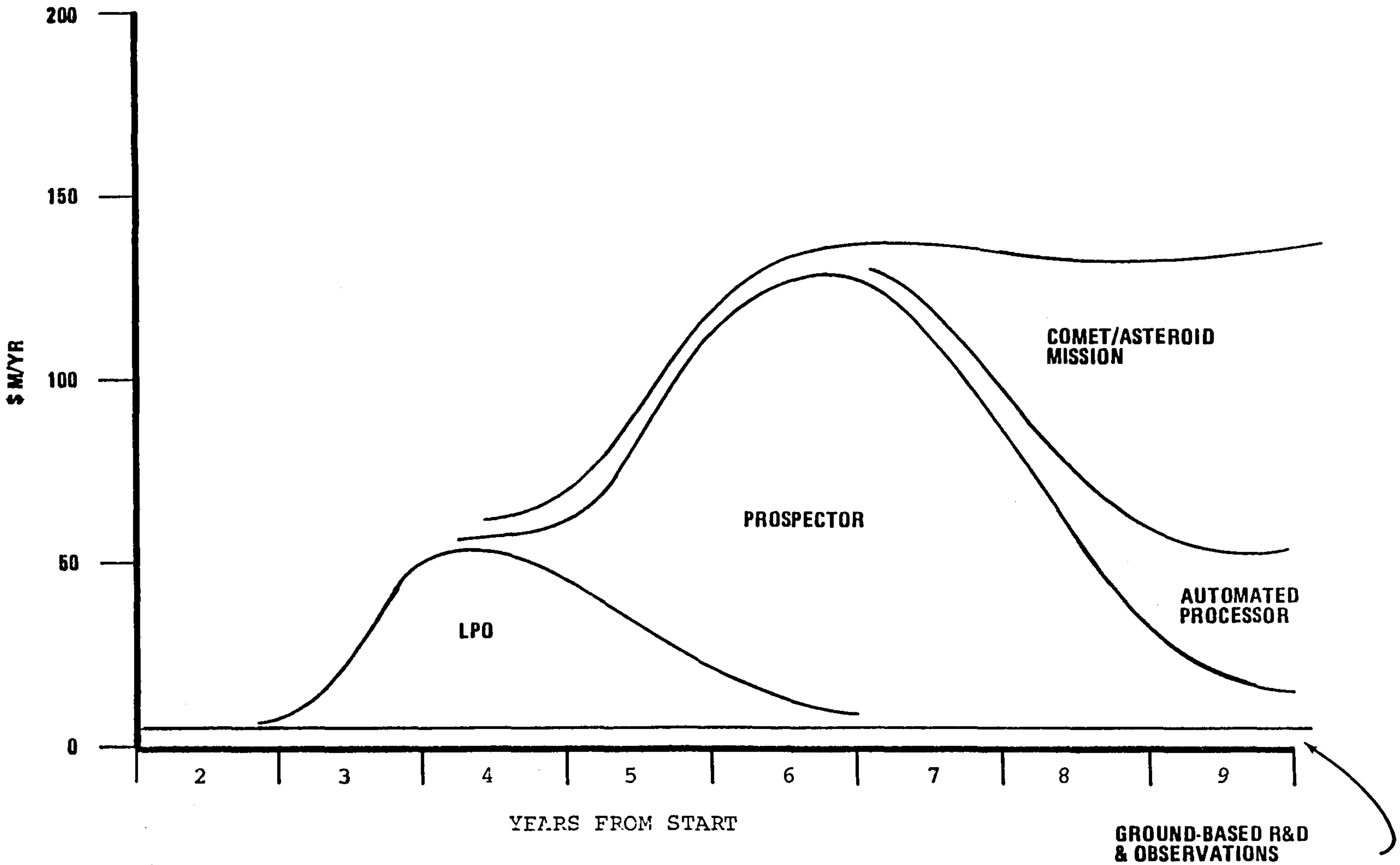

Figure 4-5. Approximate Spending Rates for Precursor Activities

The second demonstration may employ a considerable number of simulated (terrestrially produced) lunar resources in its configuration. It would, however, be accompanied by a parallel (real) lunar resource acquisition and processing system which has contributed in part to the fabrication of the demonstration system and exhibits practical expansion up to the capacity needed for complete production of the end operational product. It should be recognized that, in the use of nonterrestrial resources, a demonstration of this class must have instituted program growth to include those basic capabilities illustrated in Fig. 4-6. This capability is basic to a following buildup (given a "go" decision) to bring the end products into being and should therefore be compatible to such evolution.

Figure 4-7 draws attention to the need to recognize other possible major alternatives which can require pursuit of other critical technology. The figure indicates a need for technology development of SPS systems that is relatively independent of the means and resources for their operational construction, in concert with two independent paths of technology development relating to sources of resources and implementation techniques (nonterrestrial vs. terrestrial). Relative assessment and selection among these basic alternatives must occur before the fundamental scope of the demonstration program (user oriented, 99.5% confidence) can be initiated.

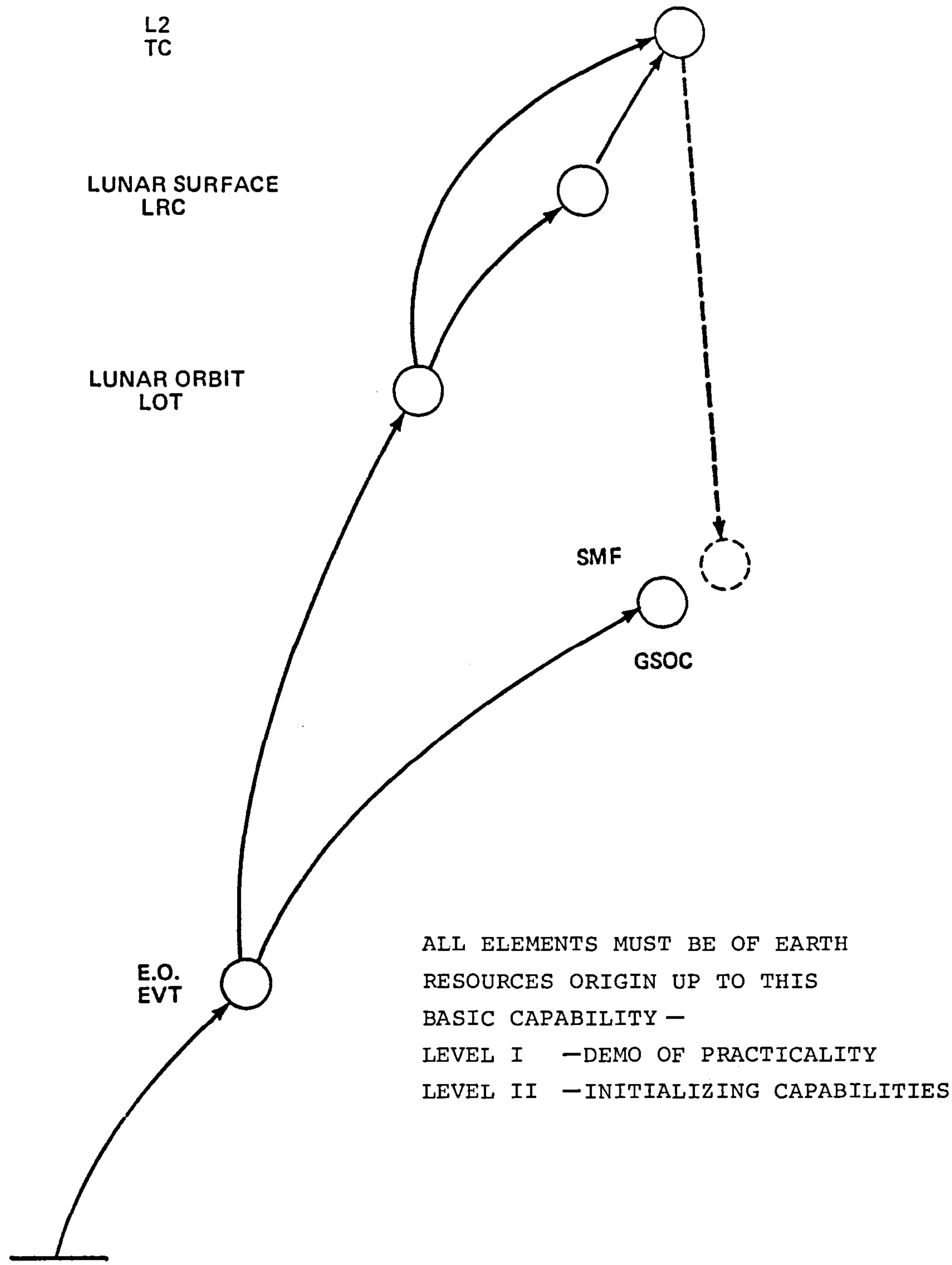

Figure 4-6. Basic Capability

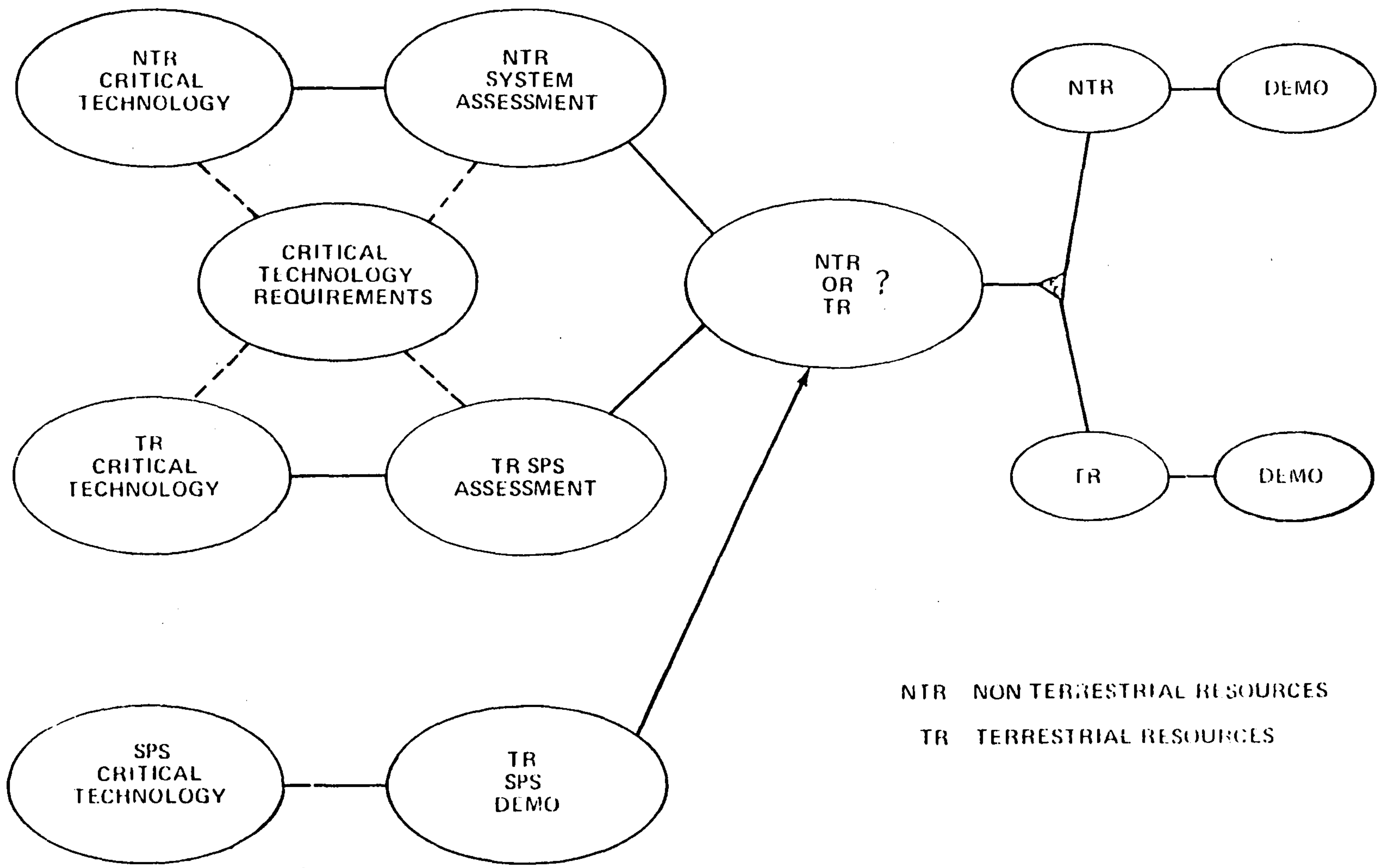

Figure 4-7. Logic Flow for Demonstration Program

The following requirements discussion deals only with the technology for the use of nonterrestrial materials in the development of solar power systems.

4.2 SYSTEMS DEMONSTRATION

4.2.1 Objectives

The objective of the systems demonstration program is to convincingly (99.5% confidence) demonstrate to the industrial and finance communities the capability to:

- Construct economically competitive and technically sound satellite power systems in space.
- Utilize extraterrestrial materials for the construction to the maximum extent.
- Provide extraterrestrial materials of the quantity and quality and at the rate required for satellite power systems construction.
- Receive continuous electrical power at a selected ground station on Earth from the constructed demonstration power system. A power level necessary and sufficient for an acceptable demonstration must be defined by the recommended analytical studies.

The earliest demonstration will be focused about a low Earth orbiting power satellite or module primarily intended to demonstrate and qualify the basic power conversion and transfer technology, and it contributes one "go" input to the decision structure for the second demonstration. The second demonstration in geosynchronous orbit embodies all of the elements and processes involved in the planned end product and should satisfy the economic concerns and need for confidence in the technical aspects of the prospective funding institutions (electrical utilities, etc.).

4.2.2 Requirements

In order to clearly define the requirements of the system demonstration program, this phase must be considered in conjunction with preceding and subsequent phases. As shown in the section on program requirements for an operational system and the section on major test programs, two major phases of a technology readiness effort are planned to occur prior to the demonstrations: a component technology test-bed program and an exploration program. These must provide required information to decide on a system demonstration program leading toward a full operational capability demonstration of a prototype system.

The Phase A and B component technology test-bed program will exercise all critical technical aspects of systems and subsystems in subscale tests and demonstrations to develop a level of confidence in the concept feasibility. The post-Phase B system demonstration program will exercise all critical vital functions and processes in the required spatial locations necessary for subsequent full-scale operation of a prototype operation. The systems demonstration program, therefore, has the following general requirements:

- Initiation of a program which develops and operates on the lunar surface and in space the complexes, facilities, and elements required to be able to initiate the access and use of extraterrestrial materials and begin the processing and production of the required satellite power system elements from which a demonstration satellite could readily be constructed and assembled.
- Initiation of a program which develops and operates in geosynchronous orbit a 1-GW satellite power system which has been fabricated, constructed, and assembled from simulated extraterrestrial materials of terrestrial origin.

The system demonstration program after successfully implementing the two initiating programs above should allow, if the decision of program continuation were given, to proceed directly toward a build-up program which would produce a satellite power systems and extraterrestrial manufacturing prototype operational program.

This prototype operational demonstration of an operationally sized system will be the key to achieve a minimum of 99% confidence level for a maximum production rate program (5 satellites per year). This, then, would constitute the actual production program if the prototype operations are successful. An unresolved key problem of the program build-up sequence is the decision between two demonstration options:

- A build-up limited to produce a demonstration satellite of minimum acceptable capacity with a capability of subsequent expansion to an operational production cycle.
- A build-up to produce a full-size operational prototype satellite with full operational production capability shortly thereafter.

Obviously each option affects overall availability schedules for operational satellites and program costs. The overall R&D efforts, however, are not affected by these options.

A crude first estimate of the funding requirements for a system technology demonstration program is shown in Table 4-1.

4.2.3 Demonstration Systems

The demonstration systems presented here cover only the most critical areas and issues to be resolved and verified through systems demonstrations. It is merely the foundation upon which the final convincing step must rest: the prototype operational demonstration.

Any satellite power systems particularly related to critical systems are excluded because it is assumed that these systems will be demonstrated as planned and studied within the ongoing satellite power system program covered by DOE/NASA efforts. Only systems peculiar to the utilization of extraterrestrial resources are covered here:

TABLE 4-1

REQUIRED SYSTEM TECHNOLOGY DEMONSTRATION PROGRAMS

SYSTEM TECHNOLOGY DEMONSTRATION PROGRAM	$\$ \times 10^6$
*Power Demonstration	(500-1000)
Lunar Launcher	500-1000
Mass Catcher	500-1000
*High Efficiency OTV Engine	(500-1000)
Material Processing SMF	1000-2000
*Construction Systems	Included in other programs listed here
Lunar Power Systems	200-400
*Long-Term Habitats	(2000-3000)
Manufacturing Systems	500-1000
TOTAL	2700-5400 Nonterrestrial Materials Peculiar
	(5700-10,400)

*Covered by present SPS planning.

- Lunar launcher
- L2 payload interceptor (mass catcher)
- Materials processing
- Manufacturing systems
- Lunar power systems
- Long-term habitats

All human and automated operations must be included in each system demonstration. All required habitat and transportation sytems for personnel and cargo must be included in each system demonstration.

Lunar Launcher. The lunar launcher systems demonstration consists of:

- Payload extraction and delivery
- Payload packaging and transport
- Lunar launcher operational installations
- Lunar payload trajectory control
- Lunar payload trajectory verification
- Payload interceptor control verification

Shortly after initial launcher demonstrations, it will be necessary to initiate the L2 payload interceptor demonstration to absolutely verify the lunar payload trajectory and flight mechanics characteristics.

Assumed demonstration performance criteria:

- Operation period: 30 days over 365 days
- Launcher throughput rate (periodic): 4×10^6 kg/day

L2 Payload Interceptor (Mass Catcher). The L2 payload interceptor systems demonstration consists of:

- Lunar launch control receiver
- An interceptor
- Interceptor attitude and position control systems
- Interceptor sequencing command center
- Interceptor mass control systems
- Interceptor propulsion and power systems
- Interceptor guidance and flight control systems
- Interceptor data and communication system

This systems demonstration must be initiated shortly after the lunar launcher demonstration activation and be performed in conjunction with it.

Assumed demonstration performance criteria:

- Operating period: 30 days over 300 days
- Mass flow (periodic): 4×10^6 kg/day

Materials Processing and Manufacturing Systems. This systems demonstration can be performed with simulated lunar materials to a large extent. Actual lunar material processing will be done based on the then-limited quantities available and the need for actual lunar material where simulation falls short in providing acceptable characteristics.

Since the purpose of SMF is the production of a satellite power system, the demonstration has to produce all critical and significant satellite components and elements required except those that would be delivered from Earth. This systems demonstration consists of the following operations:

- Raw materials processing
- Manufacturing of system components from processed raw material
- Fabrication and construction of system elements from manufactured components
- Quality assurance, accounting, and storage of products

Assumed demonstration performances criteria:

- Operating period: 30 days over 300 days
- Materials processing: 4×10^6 kg/days
- Product flow (periodic): 1.5×10^6 kg/day

Lunar Power Systems. Lunar power systems demonstrations must be performed in conjunction with the lunar launcher demonstration and the associated operations.

The systems demonstration consists of:

- Base power plant
- Peak power plant
- Waste heat radiation system
- Utility interface and control system
- Distribution system

Assumed demonstration performance criteria are:

- Operating period: 30 days over 365 days
- Power capacity: 50 MW

Long-Term Habitats. This systems demonstration consists of simultaneous habitat demonstrations at the following space locations:

- Earth Orbital Terminal (EOT)
- Lunar Orbital Terminal (LOT)
- Lunar Resources Complex (LRC)
- Transition Complex Spacecraft (TC)
- Space Manufacturing Facility (SMF)

Each demonstration will include the following subsystems:

- Life support and ecological systems
- Structures
- Attitude control and station keeping (except LRC habitat)
- Power supplies
- Thermal control

Assumed demonstration performance criteria are:

- Operating life: 30 years
- Population:
  - EOT and LRC 50-100
  - LOT 5-10
  - TC 5
  - SMF 6500

4.3 REFERENCES FOR SECTION 4

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5 HUMAN FACTORS PLANNING IN THE INDUSTRIALIZATION OF SPACE

The listings on the following pages summarize the workshop discussions on the human factors element in nonterrestrial industrialization. It is anticipated that a planned addendum to this report will contain discussions amplifying these summaries.

HUMAN FACTORS IN THE INDUSTRIALIZATION OF SPACE

WHAT MEANT BY INDUSTRIALIZATION

USE OF SPACE TO PRODUCE AND TRANSMIT

- ENERGY
- MATERIALS
- INFORMATION

(EXPLICIT REQUIREMENT THAT MAN WILL OCCUPY CIS-LUNAR SPACE)

HUMAN FACTORS IN THE INDUSTRIALIZATION OF SPACE

WHY STUDY HUMAN FACTORS?

- GIVEN THE UNKNOWNS OF LONG-DURATION MANNED SPACE FLIGHT
- TO ASSURE SUCCESS OF THE PROGRAMS
- TO ESTABLISH SUITABLE HABITAT DESIGNS
- TO BETTER UNDERSTAND HUMANS, THEIR INSTITUTIONS AND THEIR ROLE IN THE UNIVERSE

HUMAN FACTORS IN THE INDUSTRIALIZATION OF SPACE

WHAT ARE THE HUMAN FACTORS?

- ECONOMICS
  - MACRO - THE WORLD'S ECONOMIC OUTLOOK
  - MICRO - THE COST EFFECTIVENESS OF SPACE ENERGY MATERIALS AND INFORMATION
- ORBITAL HUMAN PHYSICAL, PSYCHOLOGICAL, SOCIAL AND CULTURAL REQUIREMENTS
- ORBITAL POLITICAL, INSTITUTIONAL, LEGAL AND FINANCIAL REQUIREMENTS

HUMAN FACTORS IN THE INDUSTRIALIZATION OF SPACE

WHAT ARE THE STUDY OBJECTIVES?

- DETERMINE ALTERNATIVE POSSIBILITIES FOR FINANCING SPACE INDUSTRIALIZATION PROGRAMS
- DETERMINE THE COST EFFECTIVENESS OF SPACE INDUSTRIALIZATION PROGRAMS
- DETERMINE THE PHYSICAL, PSYCHOLOGICAL, SOCIAL AND CULTURAL REQUIREMENTS FOR HUMANS LIVING AND WORKING IN SPACE FOR LONG PERIODS OF TIME
- IDENTIFY THE RESEARCH PROGRAMS REQUIRED TO EVALUATE THE PERFORMANCE OF LARGE GROUPS OF HUMANS IN SPACE
- DETERMINE THE POLITICAL, INSTITUTIONAL, LEGAL AND FINANCIAL REQUIREMENTS FOR GROUPS OF HUMANS LIVING AND WORKING IN SPACE FOR LONG PERIODS OF TIME
- IDENTIFY THE RESEARCH PROGRAMS REQUIRED TO EVALUATE THE PERFORMANCE OF THESE SOCIAL SYSTEMS IN SPACE
- CARRY OUT THE APPROPRIATE TECHNOLOGY ASSESSMENTS, INCLUDING THE HUMAN FACTORS, FOR THE VARIOUS PROGRAMS IN SPACE INDUSTRIALIZATION

HUMAN FACTORS IN THE INDUSTRIALIZATION OF SPACE

OUTLOOK FOR SPACE - A BEGINNING FOR THE STUDY

- THE FUTURE ENVIRONMENT - U.S. AND WORLD TRENDS FORECASTING INTERNATIONAL/FUTURE GROUP, 1975
- IMPLICATIONS OF PUBLIC OPINION FOR SPACE PROGRAM PLANNING, 1980 - 2000, HUDSON INSTITUTE, 1975
- THE EXPLORATION ETHIC, ITS HISTORICAL-INTELLECTUAL BASIS GEORGE WASHINGTON UNIVERSITY, 1975
- PROCEEDINGS OF THE OUTLOOK FOR SPACE SEMINAR, HAMMERSMITH FARM, SEPTEMBER 30 - OCTOBER 4, 1974 SMITHSONIAN INSTITUTE, 1975

<u>HUMAN FACTORS IN THE INDUSTRIALIZATION OF SPACE</u> .

WORKSHOP IN ORBITAL HUMAN CHARACTERISTICS

TOPICS (PARTIAL LIST)

: AGE : SEX : SIZE OF GROUP ; SKILL DISTRIBUTION
: CONFLICT RESOLUTIONS : SELECTION CRITERIA;
CULTURAL ACTIVITIES : CRITERIA FOR HABITAT DESIGN, ETC.

EIGHT - TEN PARTICIPANTS

ORGANIZER: J. SHURLEY

OBJECTIVE: DEFINE WHAT ISSUES ARE AND IDENTIFY PROCESS FOR DEVELOPING ANSWERS

HUMAN FACTORS IN THE INDUSTRIALIZATION OF SPACE

WORKSHOP IN ORBITAL HUMAN INSTITUTIONS

TOPICS (PARTIAL LIST)

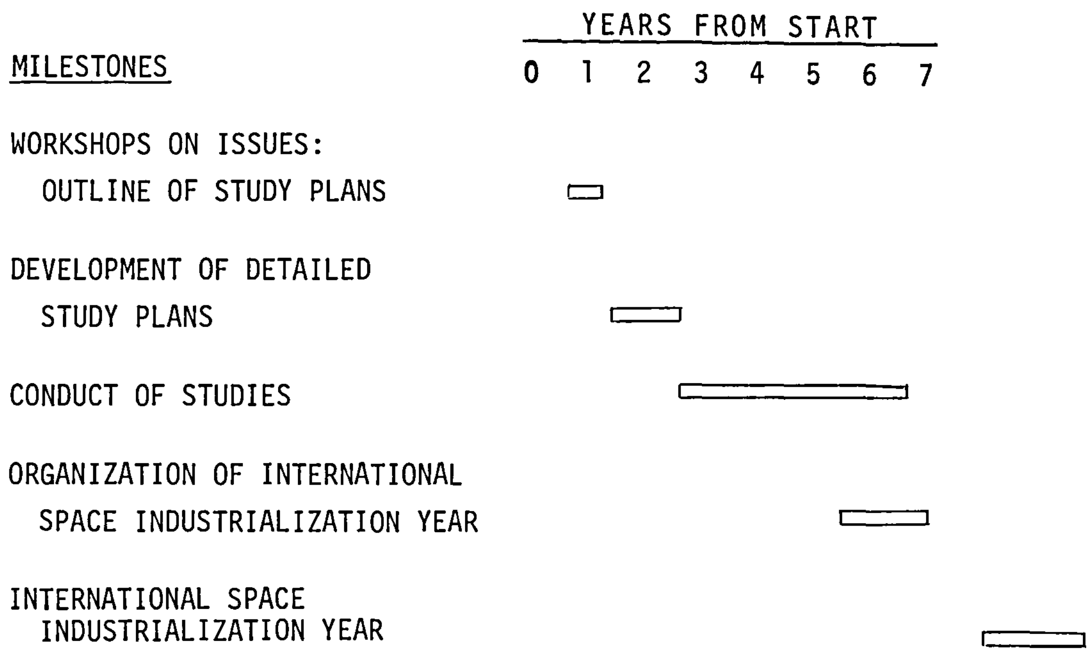
: COMPENSATION : LEGAL RESPONSIBILITIES ; GOVERNANCE
: FINANCIAL TRANSACTIONS : LABOR RELATIONS ; CRIMINAL/
CIVIL JUSTICE ; ETC.

EIGHT - TEN PARTICIPANTS

ORGANIZER: S. CHESTON

OBJECTIVE: DEFINE WHAT ISSUES ARE AND IDENTIFY PROCESS FOR DEVELOPING ANSWERS

HUMAN FACTORS IN THE INDUSTRIALIZATION OF SPACE



6 PROGRAM IMPLEMENTATION MODEL

6.1 INTRODUCTION

Present and past major systems studies on space-power satellites[1-5] involve the definition of major large space systems, the materials of which must be transported from the ground for construction and assembly in space. The studies highlight the major cost impact of transporting the required millions of tons of material from Earth and the potential environmental impact of thousands of heavy-lift vehicle launches through the Earth's atmosphere.

A number of NASA-sponsored summer studies and independent university efforts[6-11] indicated the possibility that space-power satellite material delivered and construction from nonterrestrial sources may have potential economic and environmental advantage. To approach the question of what technology requirements must be met to achieve readiness for nonterrestrial resources utilization, with sufficient proof data for a potential decision-making process, a program model has been constructed. The extraordinary complexity and the interrelations of a large number of program elements and subelements required this model to visualize the complete program scenario. The following subsections briefly describe the program model and its major elements.

6.2 DESCRIPTION OF PROGRAM IMPLEMENTATION MODEL (Fig. 6-1)

According to present and past summer studies[6-11] the nonterrestrial satellite power system implementation program consists of the following major program elements:

- Ground Base (GB)
- Earth Orbital Terminal (EOT)
- Lunar Orbital Terminal (LOT)
- L2 Transit Complex (TC)
- Lunar Resources Complex (LRC)
- Space Manufacturing Facility (SMF)
- Geosynchronous Orbit Complex (GSOC)
- Asteroid Resources Complex (ARC)

The last program element is covered only in order for completeness. The main emphasis will be placed on the lunar resources utilization. Each program element involves a family of required activities to be performed and a set of program subelements which enables these activities.

6.2.1 Ground Base (GB) (Table 6-1)

Here, all program implementation activities are centrally controlled and managed. This model does not include any direct satellite-power-system (SPS) related operational activities since these are described in Refs. 1-5. However, the overall management of the various extraterrestrial activities and facilities and the extensive communication network required for operational program flow is located here. The management and control of several thousand personnel in all space arenas involving the total logistics, transportation, status, and emergency operations management are located at the Ground Base.

And, finally, since this is a major industrial investment operation, an accounting and business management system controls the inputs and outputs of the total enterprise.

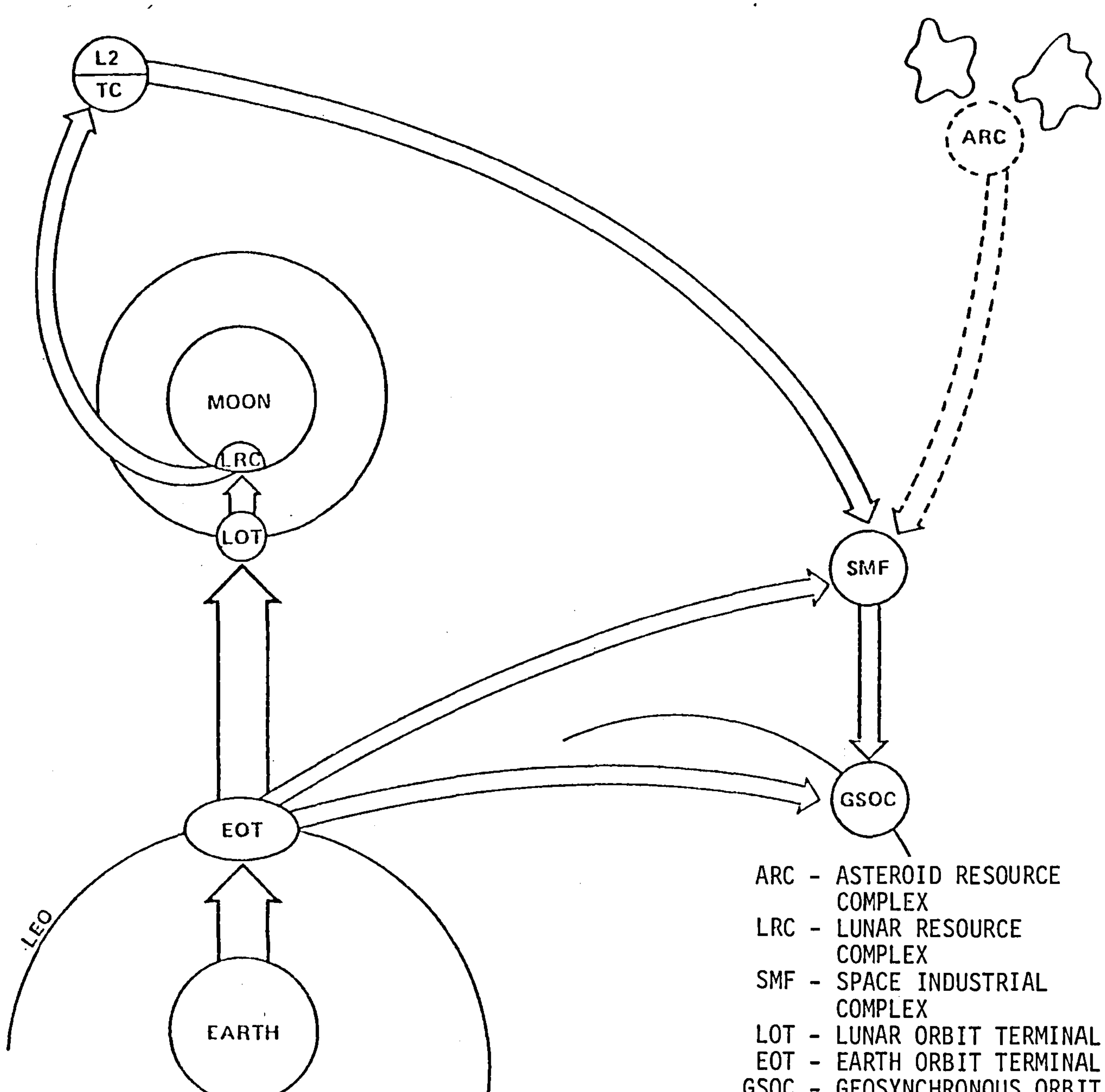


Figure 6-1. Program Implementation Model

TABLE 6-1

GROUND BASE (GB)

<u>REQUIRED ACTIVITIES</u>

- All SPS-related activities as being defined in ongoing system studies

PLUS

- Overall space facilities management and communication
- Overall personnel management for all space arenas involved
- Total logistics and emergency management
- Accounting

<u>PROGRAM SUBELEMENTS</u>

- To be defined by proposed system studies

6.2.2 Earth Orbital Terminal (EOT) (Table 6-2)

This terminal is the main thoroughfare for all required cargo and personnel traffic for the program build-up phase and the program implementation. Here, traffic loops from the ground, from LOT, SMF, and GSOC will be handled, interfaced, and scheduled.

A sizable personnel testing and training facility will, throughout the program, establish and maintain the personnel force in space with qualified people. Cargo to LOT, SMF, and GSOC must be stored and transferred; personnel of 50-100 individuals in residence and in transit must be housed. In addition, in- and outgoing as well as local traffic require management and launch control. A major operation is the checkout and maintenance of local and in-transit facilities or their elements. Particularly, space habitats to be installed at the LOT, LRC, and SMF will undergo extensive qualification testing in EOT.

The program subelements of the EOT are:

- Earth-to-LEO transportation for both personnel and heavy cargo
- Staging and cargo base for docking and exchanging payloads between transportation systems
- Habitat
- Operational control station for EOT
- Launch control station for outgoing vehicles

TABLE 6-2

EARTH ORBITAL TERMINAL (EOT)

REQUIRED ACTIVITIES

- Personnel and cargo reception from Earth, LOT, SMF, GSOC
- Personnel testing and training
- Personnel habitation and cargo storage
- Control and management of operations and local traffic
- Control of launch operations to LOT, SMF, GSOC
- Personnel and cargo transfer from to LOT
- Maintenance
- Habitat checkout

PROGRAM SUBELEMENTS

- Earth-LEO transportation (P&C)
- LEO staging and cargo base
- LEO habitat base
- LEO operations control station
- LEO launch control station
- LEO equipment and operations
- LEO local transportation
- Propellant storage facility
- LEO power

- A multitude of equipment to perform required operations to be identified by system studies
- Local transportation for cargo and personnel between stations and vehicles
- Propellant storage facility
- A power station for electric energy required for all facilities and operations

6.2.3 Lunar Orbit Terminal (LOT) (Table 6-3)

This terminal is the main thoroughfare for all lunar surface personnel and equipment as well as for cargo and personnel for the L2 TC. This involves docking and launch operations for flights to and from EOT, LRC, and TC, the provision of cargo storage and transfer between different vehicles, the control of all launch operations, and the overall control and management of operations, maintenance, and local traffic.

The program subelements of the LOT are:

- EOT-LOT transportation for both personnel and cargo
- Staging and cargo base for docking and exchanging payloads between transport systems
- Habitat
- Operations control station for LOT
- Launch control station for outgoing vehicles
- Propellant storage facility
- A multitude of equipment to perform required operations to be defined by system studies

TABLE 6-3

LUNAR ORBIT TERMINAL (LOT)

REQUIRED ACTIVITIES

- Personnel and cargo reception from EOT and L2
- Personnel habitation and cargo storage
- Control and management of operations and local traffic
- Control of launch operations to EOT and LRC
- Personnel and cargo transfer from EOT to LRC, L2, SMF
- Maintenance

PROGRAM SUBELEMENTS

- LEO-LOT transportation (P&C)
- LOT staging and cargo base
- LOT habitat base
- LOT operational control station
- Launch control station
- Propellant storage facility
- LOT equipment and operations
- LOT local transportation
- LOT power

- Local transportation for cargo and personnel between stations and vehicles
- A power station for electric energy required for all facilities and operations

6.2.4 Lunar Resources Complex (LRC) (Table 6-4)

This complex is the source of all material required at the SMF to construct and assemble solar power satellites. Here, incoming equipment, logistics, and personnel from EOT via LOT are received. Cargo is moved, stored, and deployed; personnel are provided with habitation. All flight operations and surface transportation for personnel and cargo is controlled and managed.

Large-scale mining operations on the order of 1,500,000 tons per year involve mining, drilling, scraping, loading, and other operations, including equipment maintenance. A major LRC operation is the continuous cargo transfer to the SMF via the TC at L2. In addition, periodic personnel transfer to these points is required for maintenance and logistics.

A personnel testing and training program is also part of the lunar surface activity requirements.

The program subelements of the LRC are:

- LOT-LRC transportation for both personnel and cargo
- Staging and cargo base for refitting of vehicles, unloading, and storing equipment and supplies
- Habitat

TABLE 6-4

LUNAR RESOURCES COMPLEX (LRC)

REQUIRED ACTIVITIES

- Personnel and cargo reception from LOT
- Personnel habitation and cargo storage
- Control and management of operations and surface traffic
- Personnel and cargo surface transportation
- Surface operations: mining, drilling, scraping, mucking, loading; surveying, marking, analyzing
- Maintenance
- Personnel and cargo transfer to L2 and LOT
- Cargo and personnel launch to L2 and LOT
- Personnel testing and training

PROGRAM SUBELEMENTS

- LOT-LRC transportation (P&C)
- LRC staging and cargo base
- LRC habitat base
- LRC operational control station
- LRC mining subcomplexes
- LRC equipment and operations
- LRC materials conditioning station
- LRC ground transportation
- LRC launch facilities and operations
- Propellant storage facility
- Power systems

- Operational control station for all lunar operations
- A number of mining subcomplexes depending on the selenographic distribution of required ground materials
- Strip- and deep-mining, surveying, and prospecting equipment
- Raw material conditioning and processing station
- A fleet of surface transporters for cargo and personnel
- Launch facilities for cargo and personnel transport to LOT, TC, and SMF
- Propellants storage facility
- Power stations for electric energy required for all facilities and operations

6.2.5 <u>L2 Transit Complex (TC)</u> (Table 6-5)

This complex forms an interim station for a ballistic trajectory supply line to the SMF. A direct delivery approach for materials transport would negate the need for this facility. The L2 area contains equipment and facilities that receive cargo from the LRC. After certain cargo masses have accumulated, they are transferred to the SMF.

The main requirement of this complex is the interception of free-flying compact cargo packets arriving from LRC in a continuous sequence. A superior navigation, attitude control, and station-keeping capability is required

TABLE 6-5

L2 TRANSIT COMPLEX (TC)

REQUIRED ACTIVITIES

- Cargo and personnel reception from LRC
- Personnel habitation
- Control of LRC and SMF launch operations
- Cargo transfer from reception to launch
- Local transportation

PROGRAM SUBELEMENTS

- LRC-TP transportation (P&C)
- TC cargo receiving terminal
- TC staging and cargo base
- TC habitat base
- TC operational control station
- TC propellant storage
- TC equipment and operations
- TC launch facility and operations
- TC local transportation
- TC power station

for a sustained interceptor operation. Personnel arriving for periodic maintenance must be safely accommodated during their stay time. They require local transportation; facilities and cargo transfer operations require control and management.

Personnel return launches and cargo transport launch operations to SMF require control activities.

The program subelements of TC are:

- LRC to TC transportation for cargo and personnel
- Cargo interceptor ("catcher") facility
- Staging and docking base for personnel transporter
- Cargo accumulation facility
- Temporary habitat
- Operations control station, manned or automated for interceptor and launch control
- Various auxiliary equipment to be defined by system studies
- Launch control facility for LRC and SMF transports
- Temporary local transportation for facility maintenance
- Power station for required electrical energy
- Propellant storage facility

6.2.6 Space Manufacturing Facility (SMF) (Table 6-6)

Here a line of satellite power systems will be constructed and assembled at a rate of up to 5 per year from material received from the LRC via the L1 TC. This requires receiving cargo from EOT (supplemental material to the lunar material) and L2 TC as well as personnel from EOT. Personnel habitation must be provided for an assembly and operations crew of several thousand resident people and a contingency for transit personnel to be defined. Major control, management, and government functions covering operations, traffic, and population relations have to be carried out.

Launch operations control for transfer flights of produced satellite power systems to GSOC and of personnel flights to EOT are required. Local mobility for personnel and cargo must be provided.

Incoming material and produced hardware elements will require storage. Major operations for the production of satellite power systems involve chemical materials processing, the manufacturing of hardware building blocks and elements, the mass production of photovoltaic blankets and of various components. This requires close production control, management, and quality control. Component assembly checkout and testing requries extensive facilities, equipment, and again management activities. A local transportation fleet for both cargo and personnel is required.

The program subelements of the SMF are:

- EOT-SMF transportation for cargo (initial facilities build-up and maintenance) and personnel

TABLE 6-6

SPACE MANUFACTURING FACILITIES (SMF)

REQUIRED ACTIVITIES

- Personnel and cargo reception from EOT and L2
- Personnel habitation
- Control and management of operations and local traffic
- Control of launch operations to GSOC and EOT
- Personnel and cargo local transport
- Cargo storage
- Chemical materials processing
- Metallurgical manufacturing
- Photovoltaic blanket manufacturing
- Component manufacturing
- Production control
- Assembly and test
- Local transportation

PROGRAM SUBELEMENTS

- LEO-SMF transportation (P&C)
- TC-SMF transportation (P&C)
- SMF cargo receiving station
- SMF staging and cargo base
- SMF habitat base
- SMF operational control station
- SMF chemical processing facility
- SMF metallurgical manufacturing facility
- SMF silicon photovoltaic manufacturing facility
- SMF component manufacturing facility
- SMF production control station
- SMF assembly complex
- SMF test station
- SMF equipment and operations
- SMF local transportation
- Power systems

- TC-SMF transportation for cargo (satellite power systems material)
- Cargo and personnel receiving station
- Vehicle and cargo docking station
- Habitat
- Operations control station
- Chemical processing facility
- Metallurgical manufacturing facility
- Silicon photovoltaic manufacturing facility
- Component manufacturing facility
- Production control station
- Assembly complex
- Test station
- Various equipment to be defined by system studies
- Local transportation for cargo and personnel
- Power station for electric energy required

6.2.7 Geosynchronous Orbit Complex (GSOC) (Table 6-7)

This complex is the final location of the operational satellite power systems. The final completion of the satellite power system assembly may take place here utilizing supplementary system elements manufactured from terrestrial sources. That final assembly may also be done at the SMF. This complex has been defined essentially by ongoing studies.[1-5] The nonterrestrial resources utilization requires additional activities if final assembly takes place at GEO. These are:

TABLE 6-7

GEOSYNCHRONOUS ORBIT COMPLEX (GSOC)

This complex has been defined essentially by ongoing studies of SPS-type systems. Non-terrestrial resources utilization requires the following additional activities and subprogram elements if final satellite assembly takes place at geosynchronous orbit.

REQUIRED ACTIVITIES

- Reception of product cargo (SPS) from SMF
- Integration and final assembly of terrestrial components of SPS-type systems

PROGRAM SUBELEMENT

- SMF-GSOC transportation (C)

- Reception and position of prefinished satellite power systems from SMF and of terrestrial components from EOT

- Final assembly of terrestrial components and integration of the complete satellite power system

The program subelement for GSOC (in addition to those covered in Refs. 1-5) is:

- SMF-GSOC transportation (of satellite power system)

6.3 PROGRAM SCHEDULE

6.3.1 Introduction

The objective of the program schedule is to depict the time period between a "technology readiness date" and the demonstration of the capability to construct a satellite power system from lunar materials.

6.3.2 Approach (Table 6-8)

The technology readiness milestone has been set for 8 YFS and the demonstration period is planned to be in 17 YFS. After this milestone, a 2-year period is allowed for decision making and for final production facility build-up. The planned production rate after a build-up period will level at five satellite power systems per year. The program schedule as discussed in this section reflects the estimates of the NASA Technical Planning Group and, therefore, may not conform to certain schedule estimates generated by the other working groups. Any differences are expected to be resolved by the recommended systems and economic analysis studies.

TABLE 6-8

PROGRAM SCHEDULE

SYSTEMS DEMONSTRATION MODEL (Fig. 6-4)

The construction demonstration will consist of two parts:

1. Demonstration of an SPS constructed from simulated (terrestrial) lunar materials in GSO in 17 YFS.

2. Demonstration of providing lunar material at the Space Manufacturing Facility required to construct as SPS also in 17 YFS.

OVERALL PROGRAM SCHEDULE (Fig. 6-3)

- Time period: from 8 YFS (technology readiness date) to 19 YFS (first operational SPS).

- Steady state SPS production after build-up period will be 5 SPS per year.

The demonstration program will involve a dual approach:

- A satellite power system demonstration based on simulated (terrestrial) lunar material
- A space manufacturing facility system demonstration, including the lunar material extraction, that is able to produce the required satellite power system feedstock elements

A schedule sequence is shown in Figs. 6-2 and 6-3. Figure 6-4 depicts the construction demonstration model.

6.4 PROGRAM REQUIREMENTS FOR AN OPERATIONAL SYSTEM

6.4.1 Introduction

This section covers presently envisioned program requirements for operational nonterrestrial resources delivery systems (Table 6-9). Recommended system and economic analyses studies will update these preliminary requirements listed here.

The requirements are presented in two parts:

- General requirements, which are applicable throughout the whole program scenario. These are:
  - Transportation
  - Habitat
  - Power systems
- Specific requirements, which are applicable only to certain elements of the program scenario. These are:

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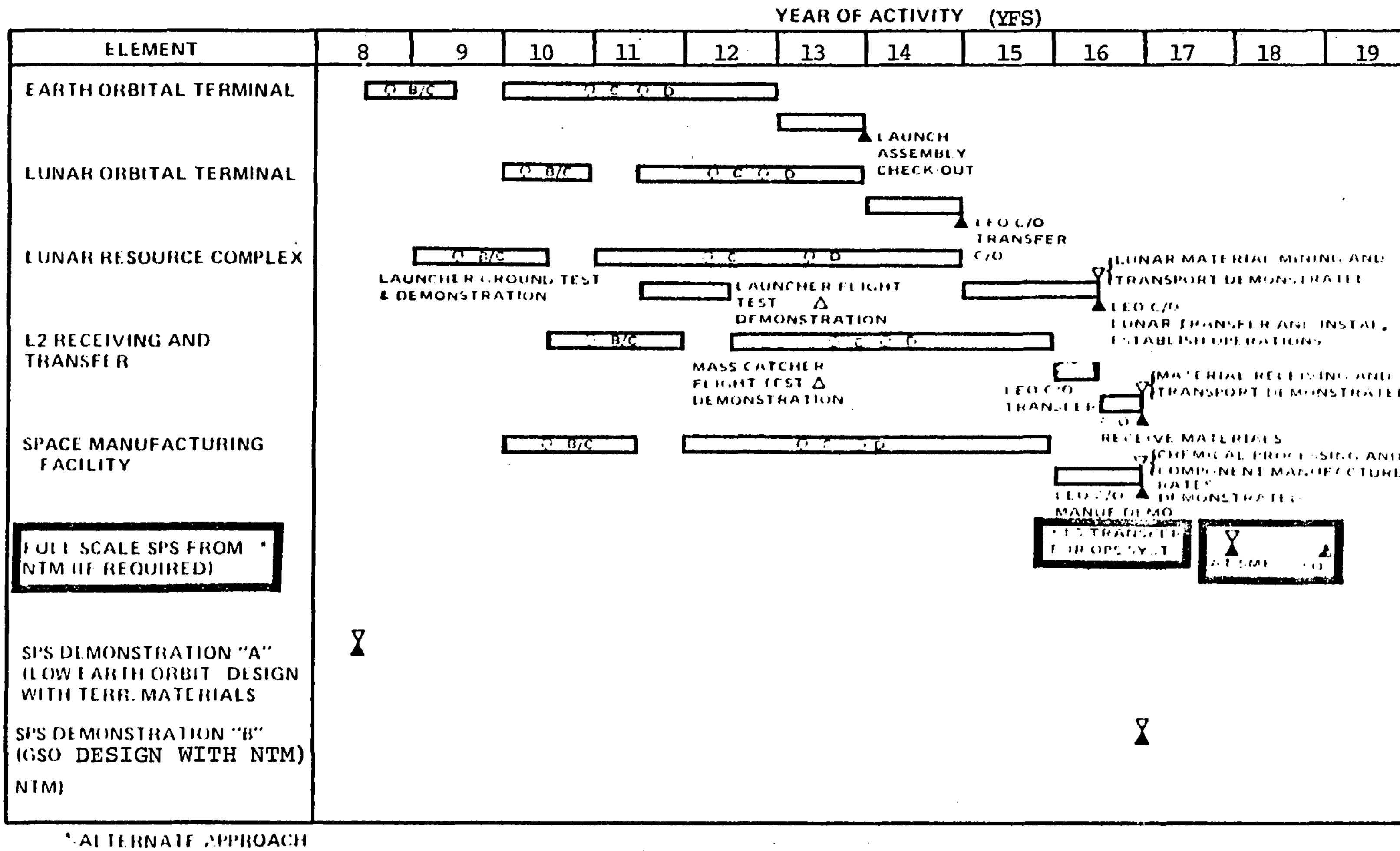

Figure 6-2. Program Schedule

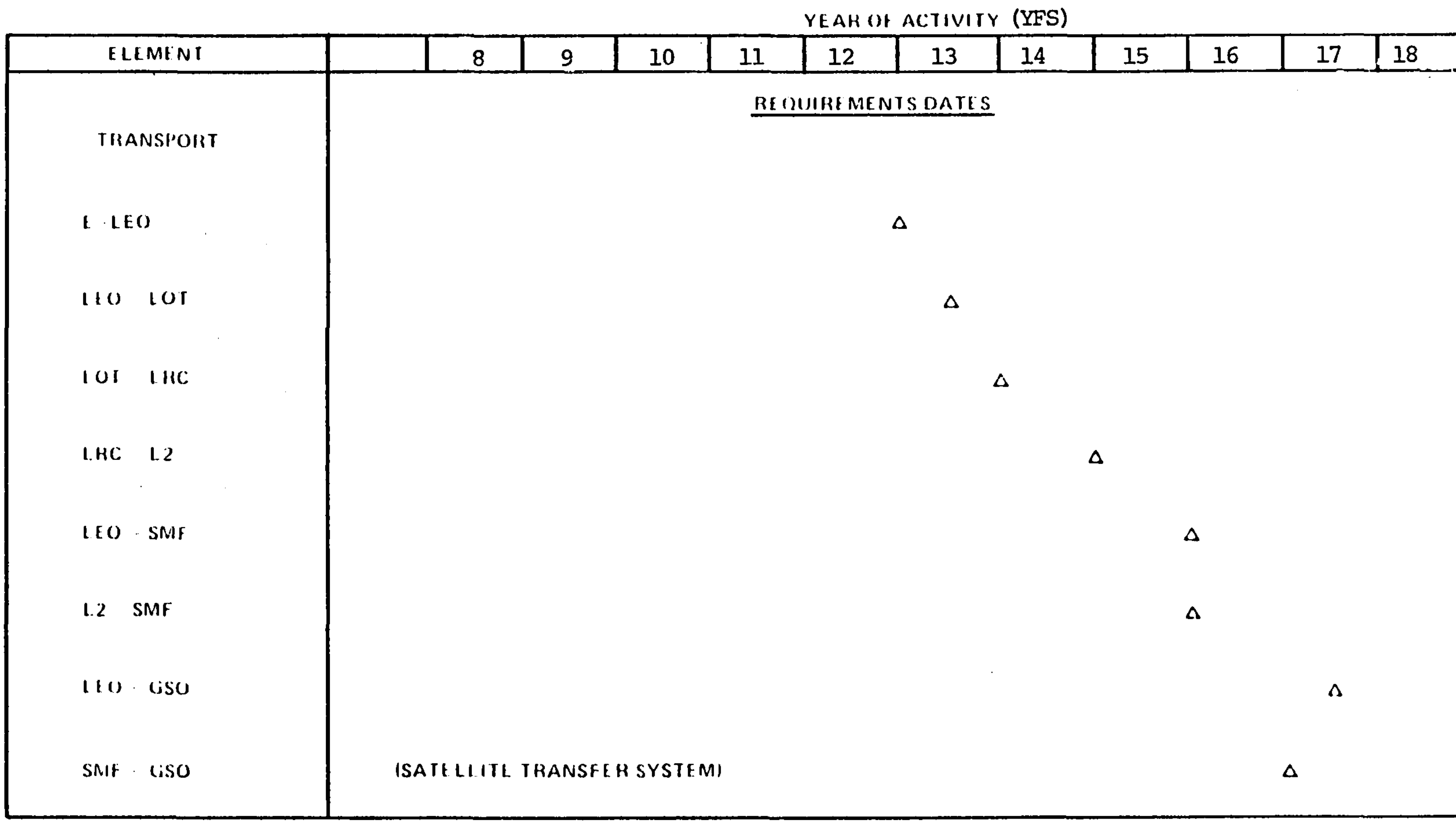

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Figure 6-3. Transportation System Availability Requirements

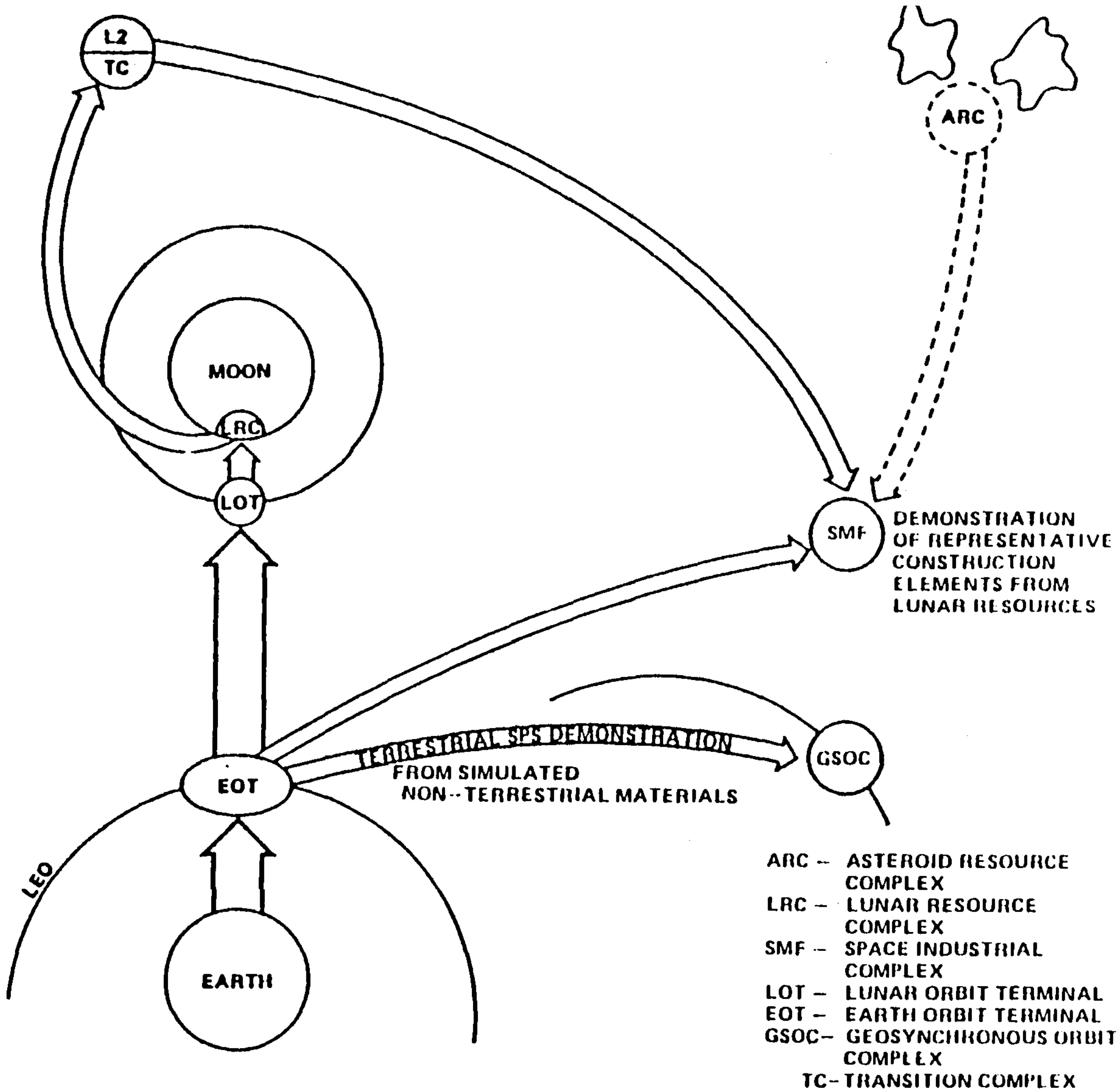

Figure 6-4. Nonterrestrial Construction Demonstration Model for Satellite Power

TABLE 6-9

PROGRAM REQUIREMENTS FOR OPERATIONAL SYSTEMS

GENERAL REQUIREMENTS (applicable to total program)

- Transportation
- Habitat
- Power systems

SPECIFIC REQUIREMENTS (applicable to specific program elements)

- ARC
- LRC
- TC
- SMF

- Lunar Resource Complex (LRC)
- Transition Complex (TC)
- Space Manufacturing Facility (SMF)

6.4.2 General Requirements

6.4.2.1 Transportation (Fig. 6-5; Table 6-10)

There are 19 different transportation requirements within the extraterrestrial materials utilization program. If asteroid resources are also included, this number increases to 25 requirements. It appears necessary to consider common elements to the maximum extent. This may be quite a challenge due to the many different requirements but would be a potential move toward maximum economy. The commonality approach should involve all major transportation system elements like propulsion, structures, guidance and control, power, and payload interfaces. Particular attention must be paid to commonality and standardization of personnel transport modes and local transportation systems. An overall transportation operations analysis must be undertaken to optimize this total space mobility system.

6.4.2.2 Habitat (Fig. 6-6; Table 6-11)

There are six different habitation requirements within the extraterrestrial materials utilization program. If asteroid resources are also included, this number increases to seven requirements.

All that has been said about common elements in the various required space transportation systems applies also to habitation. This commonality approach should involve all major habitat system elements like life

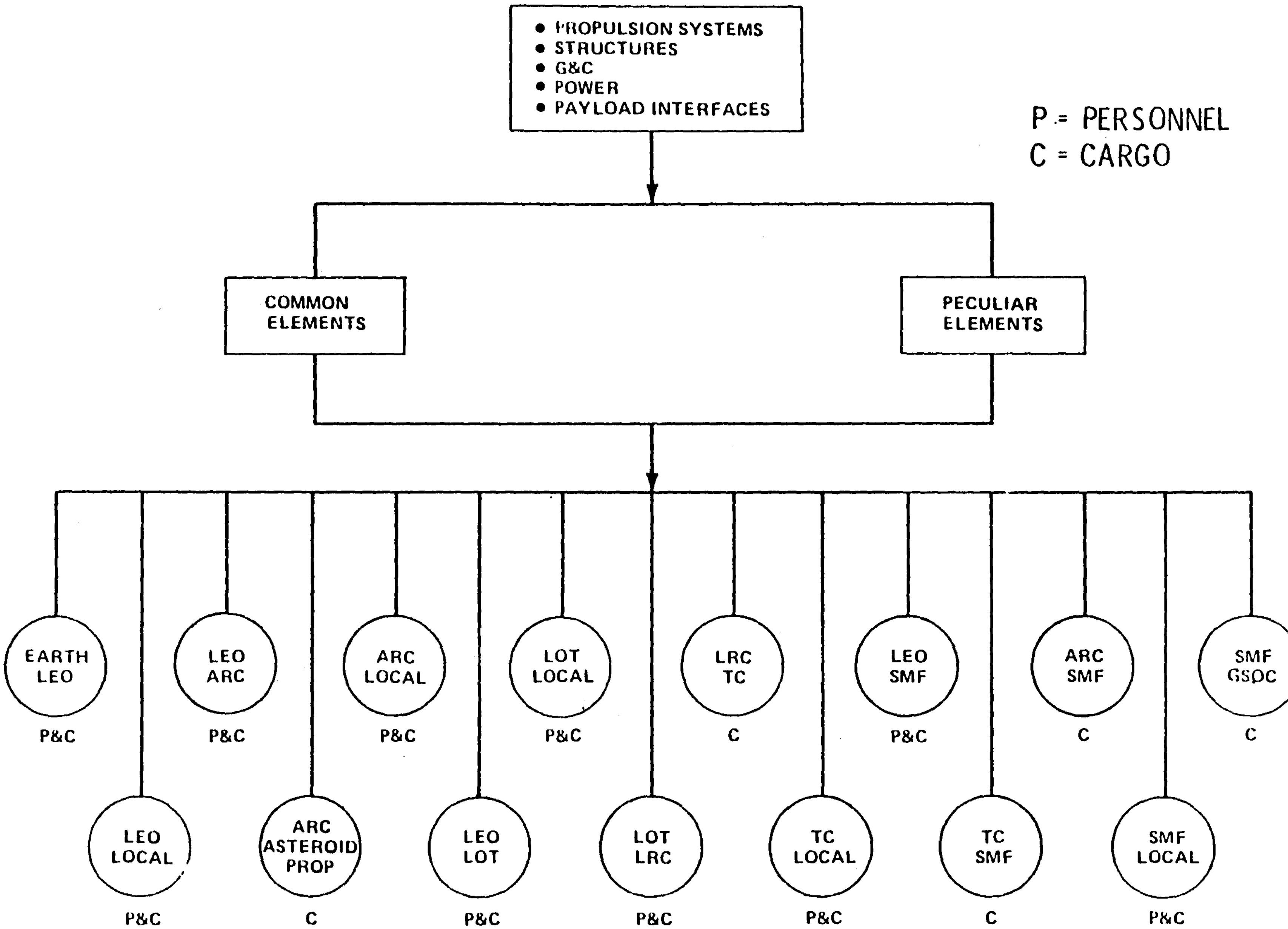

Figure 6-5. Transportation Systems Technology Requirements

TABLE 6-10

GENERAL REQUIREMENTS

Transportation

SPACE TRANSPORTATION	CARGO PER FLIGHT	ANNUAL CARGO	ANNUAL PERSONNEL
Earth-EOT	220 tons	26,400 tons	1650
EOT-LOT	175 tons	175 tons	48
LOT-LRC	TBD	175 tons	48
LRC-TC	Continuous	1,500,000 tons	15 Flights @ 5 per flight
EOT-SMF	Continuous	TBD	1500
TC-SMF	3000 tons	1,500,000 tons	
SMF-GSOC	100,000 tons	500,000 tons	

LOCAL	CARGO	PERSONNEL	RANGE
EOT	TBD (EOT through SMF)	2 (EOT through SMF)	10^3 km (EOT, LOT)
LOT			
LRC			10^2 km
TC			10^3 km (TC, SMF)
SMF			
GSOC	See References		

All quantities are rough order of magnitude and scenario dependent.

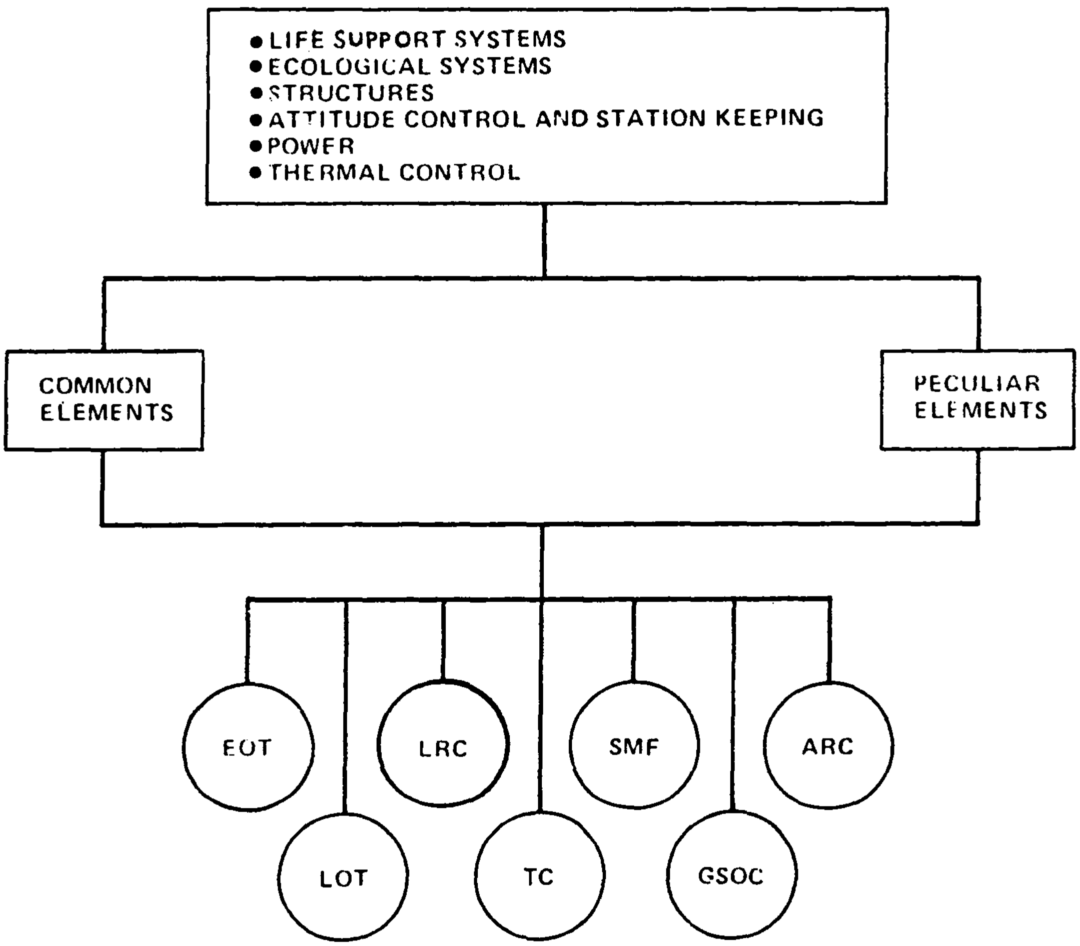

Figure 6-6. Habitat Systems Technology Requirements

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TABLE 6-11

GENERAL REQUIREMENTS
Habitats

HABITAT SYSTEMS	POPULATION	FUNCTION
EOT	50-100	Main Traffic Control Terminal
LOT	5-10	Transit Control Earth-Moon
LRC	50-100	Mining; Material Processing
TC	5 (temporary)	TC Maintenance and Control
SMF	6500	SPS Production
GSOC	See References	

All quantities are rough order of magnitude and scenario dependent.

support and ecological systems, structures, attitude control and station keeping, power and thermal control. An overall habitat analysis and design study must be undertaken to optimize this total space habitation system. While the specific study group on "closed ecological systems" decided that this development could not be accomplished within the development time frame of the program and is not requried for technical feasibility, it would be rather timely to develop a closed ecosystem model for potentially improved systems economy. A stepwide approach is recommended through various levels of details where subprograms covering both biological and physico-chemical systems can be considered.

The building blocks of such a model would encompass management systems for:

- Atmosphere
- Water
- Food
- Waste
- Energy
- Space environment

This model then can be used to perform parametric analyses and optimizations if coupled to an appropriate experimental program which by definition is required to be of a long duration, covering several generations of biological samples.

6.4.2.3 Power Systems

The ultimate selection and sizing of the required power systems and stations must be the result of extensive system analyses studies. Preliminary requirements regardless of the power system options are listed in Fig. 6-7 and Table 6-12.

Again, an attempt needs to be made for maximum commonality among the various power system elements in order to stay within reasonable economic boundaries.

6.4.3 Specific Requirements

6.4.3.1 Lunar Resources Complex (Table 6-13)

A detailed lunar materials survey is required that will show specific selenographical materials, distributions, and characteristics from the surface to as much depth below the surface as possible. This is necessary for lunar operational site selection and for operational planning (strip mining versus deep excavation material extraction). The required equipment for moving more than 10^9 kg mass of lunar raw material per year must provide for all applicable operations like excavation, drilling, grading, screening, mucking, and loading. Auxiliary equipment for lunar ground stabilization, material conveyance, continued ground material analysis, and mass flow measurements is required.

6.4.3.2 Transition Complex

This is the least defined major program element. The requirement of intercepting a steady mass stream of about 50 $kg \cdot s^{-1}$ appears even unresolved in the conceptual

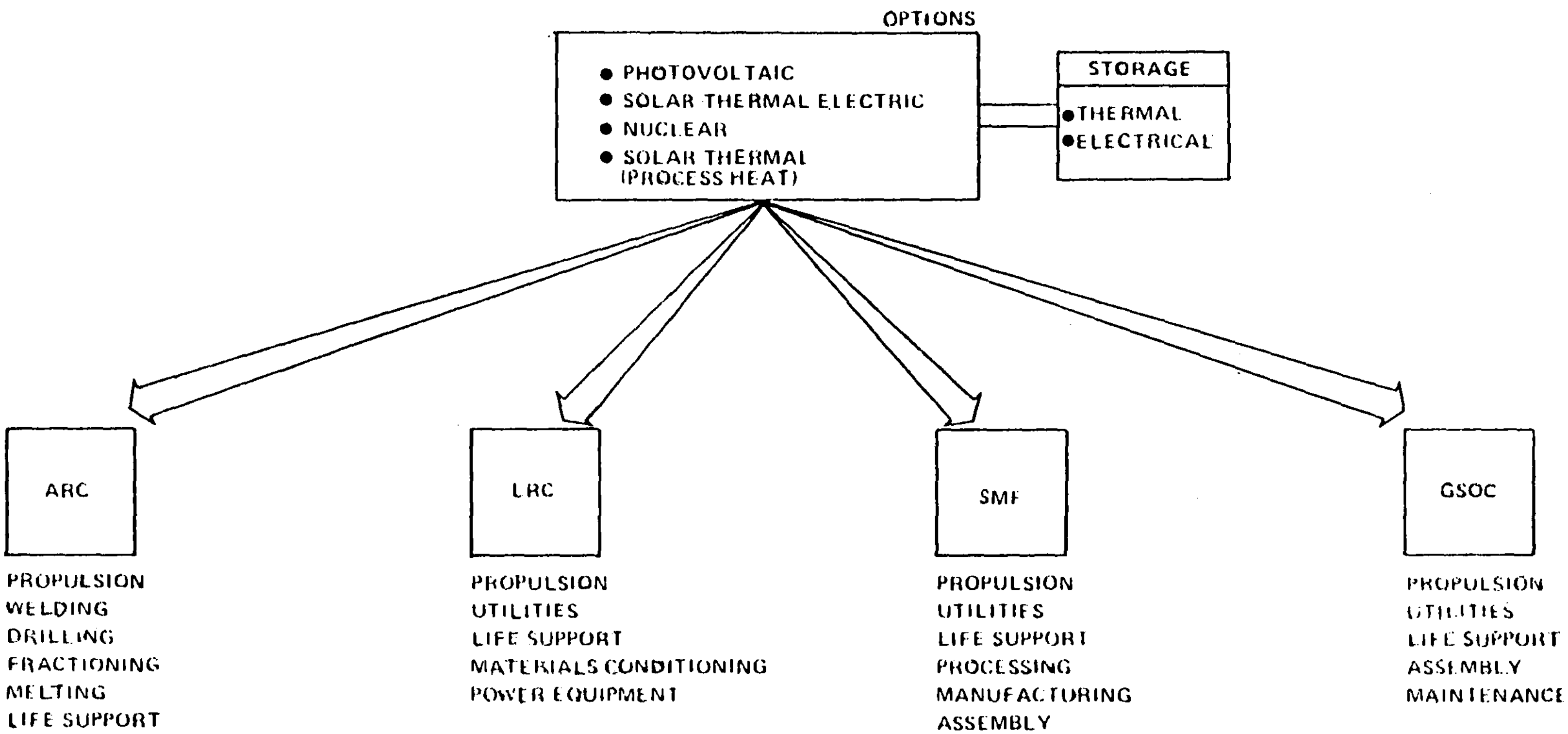

Figure 6-7. Power Systems Technology Requirements

1925-77

TABLE 6-12

GENERAL REQUIREMENTS

Power Systems

POWER SYSTEMS	DEMONSTRATION CAPACITY (kW)	OPERATIONAL CAPACITY (kW)
EOT	50-100	100-200
LOT	10-20	10-50
LRC (with mass driver)	30,000-60,000	200,000-250,000
TC	1000-2000	3000-5000
SMF	300,000-500,000	1,500,000-3,000,000
Transport		
• Chemical	Insufficient Data	Insufficient Data
• Mass Driver	3000-5000	3000-5000
• Other	Insufficient Data	Insufficient Data

All quantities are rough order of magnitude and scenario dependent.

TABLE 6-13

LRC TECHNOLOGY REQUIREMENTS

EXPLORATION

CONSTRUCTION OF

- LANDING & LAUNCH SITES
- ROADS & BRIDGES

OPERATION OF

- MINING AREAS
- MATERIAL DELIVERY AREAS
- SPOIL AREAS

ACTIVITIES REQUIRED	EQUIPMENT LINE-UP (SPREAD)
GRADING	POWER SHOVELS
SCRAPING	MOTOR SCRAPERS
SHOVELING	BULLDOZERS
CRUSHING	MOTOR GRADERS
SCREENING	CONVEYORS
DRILLING	BIG, FAST, LIGHTWEIGHT, POWERFUL AUTOMATED WITH QUALITY CONTROL
MUCKING	

phase. Part of this deficiency is based on the postulated required lunar launch accuracy which is within millimeters per second of velocity and seconds of arc in its vectors. Thus, the requirements for solving the problems of the payload interceptor ("mass catcher") lie in its physical concept, its guidance, control, station keeping, and changing, and in its dynamic stability. An exhaustive design and operational analysis is required before any technology work can be initiated. This should include the number and sequencing of interceptors and safety aspects of maintenance personnel.

6.5 ASTEROID RESOURCES UTILIZATION FOR THE CONSTRUCTION OF SATELLITE POWER SYSTEMS

6.5.1 Asteroid Resources Complex (ARC) (Table 6-14)

This complex is envisioned to be a long-duration manned spacecraft flying formation with a selected asteroid in order to prepare it for a transfer trajectory which would insert it into a desired Earth orbit for utilization at the SMF. The propulsive energy is expected to be derived from solar electric energy used to consume a portion of the asteroid mass.

The activities involve asteroid despinning and docking of propulsion and guidance and control systems.

The program subelements of the ARC are:

- LEO-ARC transportation of personnel and cargo
- Habitat spacecraft
- Various equipment to be determined by system studies

TABLE 6-14

ASTEROID RESOURCE COMPLEX

REQUIRED ACTIVITIES

- Personnel and cargo reception from EOT
- Personnel habitation
- Asteroid despinning
- Asteroid propulsion system docking
- Asteroid G&C systems docking
- Local movements

PROGRAM SUBELEMENTS

- LEO-ARC transportation (P&C)
- ARC habitat base
- ARC equipment and operations
- ARC asteroid docking and propulsion
- ARC local transportation

- Asteroid docking and propulsion system
- Local transportation

6.5.2 Specific Program Requirements (Table 6-15)

A systematic search and ephemeris acquisition efort is required prior to any detailed techology planning. This search would concentrate on Earth orbit intercepting asteroids. Measurements on the physical characteristics and the chemical composition are required.

Principal methods and concepts of asteroid despin, capture, docking, propulsion, and control must be developed and major principles and guidelines for technically and economically accomplishing this task must be established.

The fractionalization of asteroid material for propulsion purposes (40% of asteroid) needs to be carefully explored.

Typical candidate asteroid sizes are:

- Mass 10^9 kg
- Diameter 100 m

6.5.3 Program Schedule

No program schedule for asteroid resources utilization has been gathered within the Technical Planning Group.

TABLE 6-15

SPECIFIC PROGRAM REQUIREMENTS

ASTEROID RESOURCES COMPLEX (ARC)

- Survey and ephemeris acquisition of near-Earth-approaching asteroids
- Establishment of physical and chemical characteristics
- Asteroid capture, retrieval, and relocation
- Asteroid fractionalization
- Ability to capture a 10^9-kg mass of 150-m diameter
- Ability of conversion of asteroid mass into propellant for insertion into SMF area

6.6 REFERENCES FOR SECTION 6

1. Satellite Power System, Engineering and Economic Analysis, NASA TMX-73344, November 1976, NASA-MSFC.

2. Satellite Power System Study Status, NASA-MSFC, June 1977.

3. Solar Power Satellite, System Definition Study, Final Briefing, NASA-JSC, Contract No. NAS9-15196, May 1977.

4. System Definition Space-Based Power Conversion Systems, Final Review, NASA-MSFC, Boeing Contract No. NAS8-31628, December 1976.

5. Space-Based Solar Power Conversion and Delivery Study, NASA-MSFC, ECON, Inc. Contract No. NAS8-31308.

6. Space Settlements, A Design Study, NASA SP-413, 1975, Publishing Date 1977.

7. A System Design for a Prototype Space Colony, a student project in system engineering, M.I.T. and W. Fellarlar Foundation, Inc., 1976.

8. "Mining the Apollo and Amor Asteroids," Brian O'Leary, Science, 197, 363-366, 22 July 1977.

9. Space Manufacturing from Nonterrestrial Materials, NASA-Ames, OAST Study, 1976.

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11. 1977 Ames Space Settlements and Industrialization Study, preliminary papers and discussions.

APPENDIX

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FORM NO. I

PAGE 1 OF 2

1. TITLE LOCATION OF LUNAR ORE BODIES

NO. ______ THEME / W.G. / TASK

DATE 7 / 25 / 77

2. OBJECTIVE Establish criteria for selection of lunar ore bodies and locate candidate sites from photogeology and remote sensing techniques

3. NEED ANALYSIS

a) LEVEL NOW [1], WILL BE LEVEL [1] UNDER EXISTING PLANS.

b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL [3] FOR OPERATIONAL SYSTEM USE BY [DATE: 1980]

c) RISK IN ACHIEVING ADVANCEMENT:
HIGH [ ] MEDIUM [ ] LOW [X]

d) CRITICALITY TO THE ACCOMPLISHMENTS: ENABLING [ ] OR
ENHANCING: HIGH [X] MEDIUM [ ] LOW [ ]

e) TASKS NEEDED: STUDY [X] ANALYSIS [X] RESEARCH [X]
GRD TEST [ ] AIR CRAFT TEST [ ] SPACE FLIGHT TEST [ ]
OTHER (Specify) [ ] ______ (Check one or more)

f) R&T BASE CANDIDATE FY 78 100K

4. COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED

1. Determine the parameters which describe an economically valuable lunar ore body

2. Locate candidate sites using photo geology and spectral mapping from earth-based telescopes

LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED

FORM NO. I
PAGE 2 OF 2

TITLE Location of Lunar Ore Bodies

NO. ____ THEME / W.G. / TASK

DATE 7 / 25 / 77

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

Fund study and research program

7. ALTERNATIVE APPROACHES/OPTIONS

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
(1)			—	—																
(2)				—	—															
MANPOWER (M-Y) INHOUSE																				
CONTRACT																				
FUNDING (10^6 $) INHOUSE																				
CONTRACT																				

SPACE TECHNOLOGY NEED

FORM NO. I

PAGE 1 OF ________

1. TITLE PROPERTIES OF LUNAR ORES

NO. ________
THEME / W.G. / TASK

DATE 7 / 25 / 77

2. OBJECTIVE DETERMINE THE PHYSICAL, CHEMICAL AND MINERALOGIC PROPERTIES OF LUNAR SOILS AS A FUNCTION OF THE ORE GRADE OF THE CONTAINED ORE.

3. NEED ANALYSIS

a) LEVEL NOW [1], WILL BE LEVEL [1] UNDER EXISTING PLANS.

b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL [3] FOR OPERATIONAL SYSTEM USE BY [DATE: 1980]

c) RISK IN ACHIEVING ADVANCEMENT:
HIGH [ ] MEDIUM [ ] LOW [X]

d) CRITICALITY TO THE ACCOMPLISHMENTS: ENABLING [ ] OR
ENHANCING: HIGH [X] MEDIUM [ ] LOW [ ]

e) TASKS NEEDED: STUDY [X] ANALYSIS [X] RESEARCH [X]
GRD TEST [ ] AIR CRAFT TEST [ ] SPACE FLIGHT TEST [ ]
OTHER (Specify) [ ] ________ (Check one or more)

f) R&T BASE CANDIDATE FY 78 100 K

4. COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY ________

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED

1. DETERMINE THE ORE GRADE IN A SERIES OF RETURNED APOLLO SOILS. RELATE THE ORE GRADE TO SPECIFIC PROPERTIES OF THE SOIL INCLUDING MINEROLOGY, CHEMISTRY, GRAIN SIZE, SOIL MATURITY, AND SPECTRAL PROPERTIES.

LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED

FORM NO. I

PAGE 2 OF ____

TITLE PROPERTIES OF LUNAR ORES

NO. ____

THEME / W.G. / TASK

DATE 7 / 25/ 77

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

FUND RESEARCH AND STUDY PROGRAM

7. ALTERNATIVE APPROACHES/OPTIONS

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
(1)			—																	
MANPOWER (M-Y) INHOUSE																				
CONTRACT																				
FUNDING (10^6 $) INHOUSE																				
CONTRACT																				

SPACE TECHNOLOGY NEED — FORM NO. I — PAGE 1 OF 2

1. TITLE: Volatiles in fine-grained lunar minerals
NO.: V 03 (THEME / W.G. / TASK)
DATE: V / 22 / 77

2. OBJECTIVE: to determine the enrichment in volatile fine-grained lunar minerals and define reported selective enrichment.

3. NEED ANALYSIS
a) LEVEL NOW [1], WILL BE LEVEL [2] UNDER EXISTING PLANS.
b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL [3] FOR OPERATIONAL SYSTEM USE BY DATE: 1990
c) RISK IN ACHIEVING ADVANCEMENT: HIGH [ ] MEDIUM [✓] LOW [ ]
d) CRITICALITY TO THE ACCOMPLISHMENTS: ENABLING [ ] OR ENHANCING: HIGH [ ] MEDIUM [✓] LOW [ ]
e) TASKS NEEDED: STUDY [✓] ANALYSIS [✓] RESEARCH [✓] GRD TEST [ ] AIR CRAFT TEST [ ] SPACE FLIGHT TEST [ ] OTHER (Specify) [ ] (Check one or more)
f) R&T BASE CANDIDATE: FY 78 100 k

4. COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED
(1) Determine if ilmenite selectively enriches H_2 in lunar soil.
(2) Determine the grain size versus enrichment for ilmenites from lunar soil.

LEVEL OF STATE OF ART
1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED — FORM NO. I

PAGE 2 OF 2

TITLE: *Volatiles in fine-grained lunar materials*

NO. V 03 — THEME / W.G. / TASK

DATE 7/22/77

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

Fund research program

7. ALTERNATIVE APPROACHES/OPTIONS

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
(1)			—	—																
(2)			—	—																
MANPOWER (M-Y) INHOUSE			.1	.1																
CONTRACT																				
FUNDING (10^6 $) INHOUSE																				
CONTRACT			50	50																

LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED — FORM NO. I — PAGE 1 OF 2

1. TITLE *Parametric Analysis of lunar mining and ore beneficiation*

NO. *V 02* THEME / W.G. / TASK

DATE *7/22/77*

2. OBJECTIVE *to develop models and criteria for evaluating various mining and beneficiation option*

3. NEED ANALYSIS

a) LEVEL NOW [2], WILL BE LEVEL [3] UNDER EXISTING PLANS.

b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL [ ] FOR OPERATIONAL SYSTEM USE BY DATE: [illegible]

c) RISK IN ACHIEVING ADVANCEMENT: HIGH [ ] MEDIUM [ ] LOW [✓]

d) CRITICALITY TO THE ACCOMPLISHMENTS: ENABLING [ ] OR ENHANCING: HIGH [✓] MEDIUM [ ] LOW [ ]

e) TASKS NEEDED: STUDY [✓] ANALYSIS [✓] RESEARCH [ ] GRD TEST [ ] AIR CRAFT TEST [ ] SPACE FLIGHT TEST [ ] OTHER (Specify) [ ] (Check one or more)

f) R&T BASE CANDIDATE *FY'78 Requirement 50K*

4. COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY *Measurement of mineral separation efficiencies for lunar materials*

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED

(1) Develop a parametric model for Lunar mining, shipping, ore beneficiation.
(2) Determine best parameters for model
(3) Optimize model for various models.

SPACE TECHNOLOGY NEED

FORM NO. I
PAGE 2 OF 2

TITLE Parametric Analysis of lunar Mining and beneficiation

NO. V 02
THEME / W.G. / TASK

DATE 2 / 22/77

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

Initiate research program

7. ALTERNATIVE APPROACHES/OPTIONS

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
(1)			—																	
(2)				—																
(3)					—															
MANPOWER (M-Y) INHOUSE			.1	.1	.1															
CONTRACT			.5	.5	1															
FUNDING (10^6 $) INHOUSE			50	50	75															
CONTRACT																				

SPACE TECHNOLOGY NEED — **FORM NO. I**

PAGE 1 OF ______

1. TITLE Extraction Processes for the Production of Structural Materials from Non-Terrestrial Sources

NO. ______ THEME / W.G. / TASK

DATE ___ / ___ / ______

2. OBJECTIVE To develop suitable process for the extraction of oxygen from the effluent gases of metal extraction processes.

3. NEED ANALYSIS

a) LEVEL NOW ☐, WILL BE LEVEL ☐ UNDER EXISTING PLANS.

b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL ☐ FOR OPERATIONAL SYSTEM USE BY [DATE ______]

c) RISK IN ACHIEVING ADVANCEMENT: HIGH ☐ MEDIUM ☐ LOW ☒

d) CRITICALITY TO THE ACCOMPLISHMENTS: ENABLING ☐ OR ENHANCING: HIGH ☒ MEDIUM ☐ LOW ☐

e) TASKS NEEDED: STUDY ☒ ANALYSIS ☐ RESEARCH ☒ GRD TEST ☐ AIR CRAFT TEST ☐ SPACE FLIGHT TEST ☐ OTHER (Specify) ☐ ______ (Check one or more)

f) R&T BASE CANDIDATE YES FY 79 Requirement $200K.

4 COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY ______

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED

To test the feasibility of $CeO_2 - Y_2O_3$ electrolyte.

To establish the optimum conditions vis. long life of the cells.

To improve the existing design of the metal-ceramic seals for high temperature operations.

To select an optimum temperature - the lowest temperature of cell operation consistent with acceptable IR loss in the electrolyte.

LEVEL OF STATE OF ART

1 BASIC PHENOMENA OBSERVED AND REPORTED

2 THEORY FORMULATED TO DESCRIBE PHENOMENA

3 THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL

4 PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED

5 COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY

6 MODEL TESTED IN AIRCRAFT ENVIRONMENT

7 MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED

FORM NO. I

PAGE 2 OF ____

TITLE EXTRACTION PROCESSES FOR THE PRODUCTION OF STRUCTURAL MATERIALS FROM NON TERRESTRIAL RESOURCES

NO. ______

THEME / W.G. / TASK

DATE ___ / ___ / ___

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

Initial efforts involve the ~~optimizing~~ ~~[illegible]~~ design of solid state electrolyte cells for the generation of CO from CO_2, CO_2 and H_2O gas mixtures. To identify the optimum conditions for long term operations and to circumvent the ~~[illegible]~~ [illegible] with respect to the electrolyte [illegible]

7. ALTERNATIVE APPROACHES/OPTIONS

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
			———	———	———	———	———	———	———											
MANPOWER (M-Y) INHOUSE			2	2	3															
CONTRACT			4	8	8															
FUNDING (10^6 $) INHOUSE																				
CONTRACT																				

SPACE TECHNOLOGY NEED

FORM NO. I

PAGE 1 OF ____

1. TITLE EXTRACTION PROCESSES FOR THE PRODUCTION OF STRUCTURAL MATERIALS FROM NON-TERRESTRIAL RESOURCES

NO. ____

THEME / W.G. / TASK

DATE ___ / ___ / ___

2. OBJECTIVE TO DEVELOP SUITABLE PROCESS FOR THE EXTRACTION OF MAGNESIUM FROM OLIVINE (ASTEROIDAL SOURCE).

3. NEED ANALYSIS

a) LEVEL NOW ☐, WILL BE LEVEL ☐ UNDER EXISTING PLANS.

b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL ☐ FOR OPERATIONAL SYSTEM USE BY [DATE ____]

c) RISK IN ACHIEVING ADVANCEMENT:
HIGH ☐ MEDIUM ☐ LOW ☒

d) CRITICALITY TO THE ACCOMPLISHMENTS: ENABLING ☐ OR
ENHANCING: HIGH ☒ MEDIUM ☐ LOW ☐

e) TASKS NEEDED: STUDY ☒ ANALYSIS ☒ RESEARCH ☒
GRD TEST ☐ AIR CRAFT TEST ☐ SPACE FLIGHT TEST ☐
OTHER (Specify) ☐ KINETIC STUDIES (Check one or more)

f) R&T BASE CANDIDATE YES FY 75 REQUIREMENT # 50K.

4 COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY MODELING OF OLIVINE TO SIMULATE THE COMPOSITIONS OF ~~[illegible]~~ ASTEROIDAL OLIVINE.

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED

Kinetics of olivine reduction ~~by~~ with calcium carbide and silicon.

Production of calcium carbide from calcium chloride obtained as a by-product in the carbo-chlorination of anorthite.

Role of calcium silicide ~~and~~ as an intermediate in the overall reduction process.

LEVEL OF STATE OF ART

1 BASIC PHENOMENA OBSERVED AND REPORTED
2 THEORY FORMULATED TO DESCRIBE PHENOMENA
3 THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED
5 COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6 MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED

FORM NO. I

PAGE 2 OF ____

TITLE ____________________

NO. ____________
THEME / W.G. / TASK

DATE ___ / ___ / ___

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

To study the kinetics of [illegible] and to determine the [illegible].

7. ALTERNATIVE APPROACHES/OPTIONS

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
			—	—	—	—	—	—	—											
MANPOWER (M-Y) INHOUSE	[illegible]	[illegible]	1	1	1															
CONTRACT	2	4	[illegible]	1	2															
FUNDING (10^6 $) INHOUSE																				
CONTRACT																				

SPACE TECHNOLOGY NEED

FORM NO. I

PAGE 1 OF ______

1. TITLE EXTRACTION PROCESSES FOR THE PRODUCTION OF STRUCTURAL MATERIALS FROM NON-TERRESTRIAL SOURCES

NO. ______

THEME / W.G. / TASK

DATE ___ / ___ / ______

2. OBJECTIVE TO DEVELOP SUITABLE PROCESSES FOR THE EXTRACTION OF Fe AND TITANIUM FROM ILMENITE CONCENTRATES.

3. NEED ANALYSIS

a) LEVEL NOW ☐ WILL BE LEVEL ☐ UNDER EXISTING PLANS.

b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL ☐ FOR OPERATIONAL SYSTEM USE BY [DATE ______]

c) RISK IN ACHIEVING ADVANCEMENT:
HIGH ☐ MEDIUM ☐ LOW ☒

d) CRITICALITY TO THE ACCOMPLISHMENTS: ENABLING ☐ OR
ENHANCING: HIGH ☒ MEDIUM ☐ LOW ☐

e) TASKS NEEDED: STUDY ☒ ANALYSIS ☒ RESEARCH ☒
GRD TEST ☐ AIR CRAFT TEST ☐ SPACE FLIGHT TEST ☐
OTHER (Specify) ☐ PILOT PLANT OPERATIONS (Check one or more)

f) R&T BASE CANDIDATE YES. FY 75 REQUIREMENT $100K

4. COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY MODELING OF MINERALS TO SIMULATE THE COMPOSITIONS OF LUNAR ILMENITE CONCENTRATE.

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED

Laboratory scale experiments are already worked out. The processes have to be tested on a commercial scale. Efficiency of the recycling of the secondary products need to be evaluated.

LEVEL OF STATE OF ART
1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED

FORM NO. I

TITLE ______________________

NO. ______ THEME / W.G. / TASK

DATE ___ / ___ / ___

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

To study the efficiency of the extraction of Ti and Fe by [illegible] ilmenite. Advanced experiments include the study of engineering aspects for the pilot plant operation

7. ALTERNATIVE APPROACHES/OPTIONS

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
			———	———	———	———	———	———	———											
MANPOWER (M-Y) INHOUSE			1	1	1															
CONTRACT			2	3	4															
FUNDING (10^6 $) INHOUSE																				
CONTRACT																				

SPACE TECHNOLOGY NEED | **FORM NO. I**

PAGE 1 OF ______

1. TITLE EXTRACTION PROCESSES FOR THE PRODUCTION OF STRUCTURAL MATERIALS FROM NON-TERRESTRIAL RESOURCES

NO. ______

THEME / W.G. / TASK

DATE ___ / ___ / ___

2. OBJECTIVE TO DEVELOP SUITABLE PROCESSES FOR THE EXTRACTION OF ~~TO EXTRACT~~ ALUMINUM, ~~SILICON, IRON, MAGNESIUM, TITANIUM AND OXYGEN FROM NON-TERRESTRIAL RESOURCES~~ (A PLAGIOCLASE CONCENTRATE)

3. NEED ANALYSIS

a) LEVEL NOW [ ], WILL BE LEVEL [ ] UNDER EXISTING PLANS.

b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL [ ] FOR OPERATIONAL SYSTEM USE BY [DATE:]

c) RISK IN ACHIEVING ADVANCEMENT: HIGH [ ] MEDIUM [ ] LOW [X]

d) CRITICALITY TO THE ACCOMPLISHMENTS: ENABLING [ ] OR ENHANCING: HIGH [X] MEDIUM [ ] LOW [ ]

e) TASKS NEEDED: STUDY [X] ANALYSIS [X] RESEARCH [X] GRD TEST [ ] AIR CRAFT TEST [ ] SPACE FLIGHT TEST [ ] OTHER (Specify) [ ] PILOT PLANT OPERATIONS (Check one or more)

f) R&T BASE CANDIDATE YES FY 78 REQUIREMENT 150K

4. COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY MODELING OF MINERALS ~~SIMULATED~~ TO SIMULATE THE COMPOSITIONS OF LUNAR ~~AND ASTEROIDAL RESOURCES~~. Plagioclase concentrate (anorthite)

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED

Theoretical analysis of stability field diagrams for required ternary systems ($M_1-M_2-X_1$) and ($M-X_1-X_2$) and quaternary ($M_1-M_2-X_1-X_2$)($M-X_1-X_2-X_3$). Thermodynamic and kinetic studies on the carbo-chlorination of anorthite. Analysis of the [illegible] residue. ~~[illegible]~~. Separation of desired chlorides from the [illegible] residue. Chemical Engineering aspects of the process as related to the lunar environment. Terrestrial conditions. Follow up of initial bench scale investigation with the pilot plant studies.

LEVEL OF STATE OF ART

1 BASIC PHENOMENA OBSERVED AND REPORTED
2 THEORY FORMULATED TO DESCRIBE PHENOMENA
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED
5 COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6 MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED

FORM NO. I

PAGE 2 OF ____

TITLE ______________________

NO. ____________ THEME / W.G. / TASK

DATE ___ / ___ / ___

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

Initial efforts involve the bench scale operations to optimize on the optimal process conditions. Advanced experiments will include Pilot Plant operations.

7. ALTERNATIVE APPROACHES/OPTIONS

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
			—	—	—	—	—	—	—											
MANPOWER (M-Y) INHOUSE			1	1	1															
CONTRACT			2	2	3															
FUNDING (10^6 $) INHOUSE																				
CONTRACT																				

SPACE TECHNOLOGY NEED

FORM NO. I

PAGE 3 OF ______

1. TITLE ______

NO. ______ THEME / W.G. / TASK

DATE ___ / __ / ____

(5) CONTINUATION (If Needed)
Block No.

· Modification of the Alcca electrolyte composition ~~to be~~ compatible ~~with~~ with the products of [illegible] [illegible]

LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED — FORM NO. I

PAGE 1 OF 3

1. TITLE LUNAR MATERIAL PROCESSING BY DIRECT CONC. SOLAR ENERGY

NO. III DDSurk (1)
THEME / W.G. / TASK

DATE 7/20/77

2. OBJECTIVE To analyze & demonstrate what can be done with raw lunar soil and focused solar energy (no major elec. conversion)

3. NEED ANALYSIS

a) LEVEL NOW [2], WILL BE LEVEL [2] UNDER EXISTING PLANS.

b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL [7] FOR OPERATIONAL SYSTEM USE BY [DATE: 1987]

c) RISK IN ACHIEVING ADVANCEMENT:
HIGH [ ] MEDIUM [✓] LOW [ ]

d) CRITICALITY TO THE ACCOMPLISHMENTS: ENABLING [✓] OR
ENHANCING: HIGH [ ] MEDIUM [ ] LOW [ ]

e) TASKS NEEDED: STUDY [✓] ANALYSIS [✓] RESEARCH [✓]
GRD TEST [✓] AIR CRAFT TEST [ ] SPACE FLIGHT TEST [ ]
OTHER (Specify) [ ] (Check one or more)

f) R&T BASE CANDIDATE Yes FY79 150K

4. COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY LUNAR HELIOSTAT

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED

(1) Theory & design of small continuous processor

(2) Small-scale test of process efficiency, flow control, mirror contamination, aux. syst. e.g. ionizer/driver/collector, cryogenic storage of products

(3) Scale-up to dimensions & flow rate compatible with lunar lander, test in Earth vacuum simulator -

SPACE TECHNOLOGY NEED

FORM NO. I

PAGE 2 OF 3

TITLE LUNAR MATERIAL PROCESSING BY DIRECT CONC. SOLAR ENERGY

NO. VI J.D.Burke (1)

THEME / W.G. / TASK

DATE 7/20/77

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

1. Paper study of 4-6000°K extraction schemes
2. Build small model using existing equipment - combine solar furnace and arc-jet - process simulated lunar fines
3. Scale up and run long duration test in vacuum - process lunar fines if desired

7. ALTERNATIVE APPROACHES/OPTIONS Use solar energy to drive plasma jet processor via electrical conversion - see tech need JDBurke (2)

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)

None

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
Paper Study				—																
Sm. Scale Test					—															
Comparison & design lunar						—	—													
Full scale								—												
Demo									—											
Flight sys												—								
MANPOWER (M-Y) INHOUSE				2	3	1	1	5	5	10	10	10								
CONTRACT				1	1	1	1	2	2	10	10	10								
FUNDING (10^6 $) INHOUSE				.05	.15	.05	.05	.2	.2	1	1	1								
CONTRACT				.05	.05	.15	.15	.3	.3	1	1	1								

SPACE TECHNOLOGY NEED

FORM NO. I

PAGE 3 OF 3

1. TITLE LUNAR MATERIAL PROCESSING BY DIRECT CONC. SOLAR ENERGY

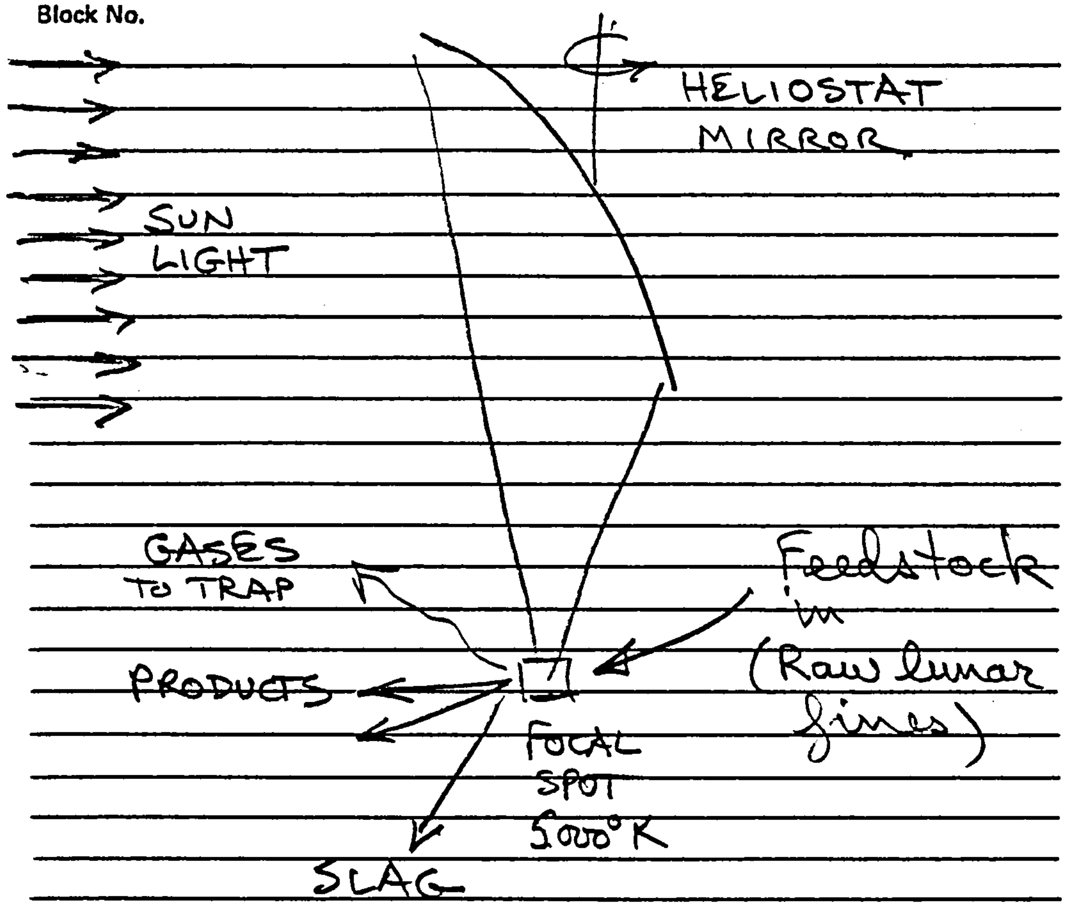
NO.

THEME / W.G. / TASK

DATE ___ / __ / ______

(1)

(   ) CONTINUATION (If Needed)
Block No.



LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED — FORM NO. I — PAGE 1 OF 3

1. TITLE LUNAR MATERIAL PROCESSING BY SOLAR/ELECT. ENERGY

NO. VI SD Burke (2) THEME / W.G. / TASK

DATE 7 / 20 / 77

2. OBJECTIVE To analyze & demo. what can be done extracting useful products from lunar soil with solar-powered arc or plasma jet

3. NEED ANALYSIS

a) LEVEL NOW [3], WILL BE LEVEL [3] UNDER EXISTING PLANS.

b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL [7] FOR OPERATIONAL SYSTEM USE BY [DATE: 1987]

c) RISK IN ACHIEVING ADVANCEMENT:
HIGH [ ] MEDIUM [ ] LOW [✓]

d) CRITICALITY TO THE ACCOMPLISHMENTS: ENABLING [ ] OR ENHANCING: HIGH [ ] MEDIUM [✓] LOW [ ]

e) TASKS NEEDED: STUDY [✓] ANALYSIS [✓] RESEARCH [ ]
GRD TEST [✓] AIR CRAFT TEST [ ] SPACE FLIGHT TEST [ ]
OTHER (Specify) [ ] (Check one or more)

f) R&T BASE CANDIDATE Yes FY79 150K

4. COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY SOLAR/ELECT CONVERTER FOR LUNAR SURFACE USE

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED

(1) Theory & design of small continuous processor

(2) Small-scale test using elec. power source, demo. recovery of products

(3) High voltage solar array for lunar polar application

(4) Scale up to dims. & flow rate compatible w/lunar lander, test in Earth vac. simul.

SPACE TECHNOLOGY NEED

FORM NO. I
PAGE 2 OF 3

TITLE LUNAR MATERIAL PROCESSING BY SOLAR/ELECT. ENERGY

NO. VI J D Burke ②
THEME / W.G. / TASK

DATE 7/20/77

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

1. Paper study arc/plasma jet extraction schemes incl. laser separation of species
2. Build several small models using various principles & compare
3. Scale up & run long-duration test

7. ALTERNATIVE APPROACHES/OPTIONS Use direct solar heat — see J D Burke ①

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)

None; related work is going on in Hi volt, low cost solar arrays, SEP, and laser/molecular beam technology —

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
Paper Study				—																
Sm Scale Tests					—	—														
Design Lunar							—	—												
Full scale test									—	—										
Flight Sys												—	—							
MANPOWER (M-Y) INHOUSE				1	3	2	3	3	5	5	10	10	10							
MANPOWER (M-Y) CONTRACT				1	1	3	3	3	5	5	10	10	10							
FUNDING (10^6 $) INHOUSE				.1	.2	.1	.1	.1	.5	.5	1	1	1							
FUNDING (10^6 $) CONTRACT				.1	.1	.2	.2	.2	.5	.5	1	1	1							

SPACE TECHNOLOGY NEED

FORM NO. I

PAGE 3 OF 3

1. TITLE Lunar Material Processing by Solar/Elect. Energy

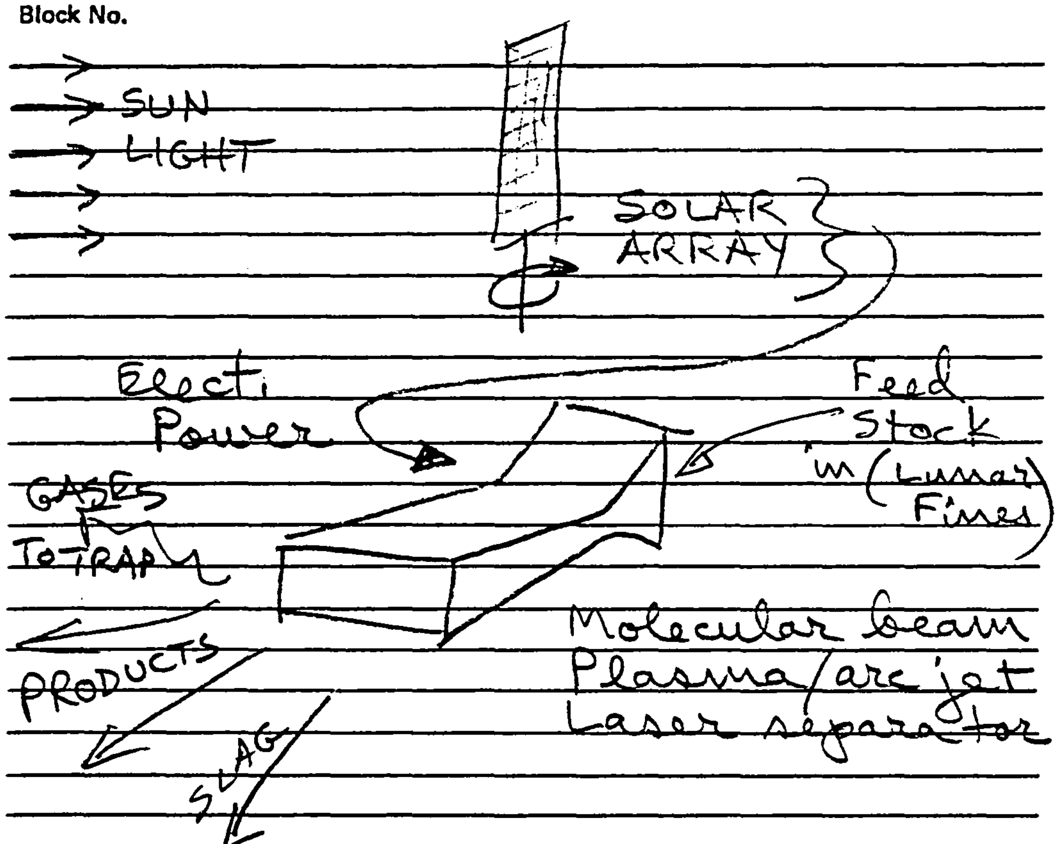
NO. VI S.D. Burke (2)

THEME / W.G. / TASK

DATE 7/29/77

( ) CONTINUATION (If Needed)

Block No.



LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED — FORM NO. I — PAGE 1 OF 2

1. TITLE *Physical Properties of Lunar Materials*
NO. V 01 — THEME / W.G. / TASK
DATE 7/21/77

2. OBJECTIVE *To determine the electrical and magnetic properties of lunar minerals so that extraction and beneficiation techniques can be developed.*

3. NEED ANALYSIS

a) LEVEL NOW [1], WILL BE LEVEL [4] UNDER EXISTING PLANS.

b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL [7] FOR OPERATIONAL SYSTEM USE BY [DATE: 1987]

c) RISK IN ACHIEVING ADVANCEMENT: HIGH [ ] MEDIUM [✓] LOW [ ]

d) CRITICALITY TO THE ACCOMPLISHMENTS: ENABLING [✓] OR ENHANCING: HIGH [ ] MEDIUM [ ] LOW [ ]

e) TASKS NEEDED: STUDY [ ] ANALYSIS [✓] RESEARCH [✓] GRD TEST [✓] AIR CRAFT TEST [ ] SPACE FLIGHT TEST [✓] OTHER (Specify) [ ] (Check one or more)

f) R&T BASE CANDIDATE *Yes. FY 78 Requirement 50K*

4. COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY *Development of high efficiency electrostatic and magnetic separator which are operational at low gravity and in vacuum.*

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED.

(1) • Determine the magnetic and electrostatic properties of lunar minerals.
(2) • Demonstrate phenomena of mineral separation on bench scale. Quantity phenoma.
(3) • Develop criteria for simulants and test simulants
(4) • Do pilot or large bench test
(5) • Develop space systems.
(6) • Define empirical operating conditions

SPACE TECHNOLOGY NEED

FORM NO. I
PAGE 2 OF 2

TITLE Physical properties of lunar minerals

NO. I 01
THEME / W.G. / TASK

DATE 7/22/77

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

Initial research using lunar samples to study electrostatic and magnetic separation of minerals.

7. ALTERNATIVE APPROACHES/OPTIONS

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
1			—																	
2			—	—																
3				—	—	—														
4						—	—	—												
5								—	—											
6										—	—									
MANPOWER (M-Y) INHOUSE			1	1																
MANPOWER (M-Y) CONTRACT			1	1																
FUNDING (10^6 \$) INHOUSE			50	75																
FUNDING (10^6 \$) CONTRACT																				

#5 B...k

SPACE TECHNOLOGY NEED

FORM NO. I

PAGE 1 OF ______

1. TITLE USE OF HIGH STRENGTH GLASSY METALS

NO. ______ THEME / W.G. / TASK

DATE ___ / ___ / ___

2. OBJECTIVE Lunar Fabrication of Strong Light Weight Material For USE ~~IN SPACE~~

3. NEED ANALYSIS

a) LEVEL NOW ☐, WILL BE LEVEL ☐ UNDER EXISTING PLANS.

b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL ☐ FOR OPERATIONAL SYSTEM USE BY [DATE]

data base not available at this time

c) RISK IN ACHIEVING ADVANCEMENT: HIGH ☐ MEDIUM ☐ LOW ☐

d) CRITICALITY TO THE ACCOMPLISHMENTS: ENABLING ☐ OR ENHANCING: HIGH ☐ MEDIUM ☐ LOW ☐

e) TASKS NEEDED: STUDY ☐ ANALYSIS ☐ RESEARCH ☐ GRD TEST ☐ AIR CRAFT TEST ☐ SPACE FLIGHT TEST ☐ OTHER (Specify) ☐ ______ (Check one or more)

f) R&T BASE CANDIDATE FY'78 60-120K

4. COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED

An ingenious system for producing continuous ribbons of metallic glasses ("met glasses") has been developed. The hot metal in liquid form is injected between counter rotating drums which are continuously cooled. Long lengths of thread like ribbon having an unusual combination of strength and plasticity are produced. A five component alloy with a tensile fracture strength approximately 3 times greater than stainless steel has been produced with a local plastic shear strength in excess of 50% vs glass (1%)

LEVEL OF STATE OF ART

1 BASIC PHENOMENA OBSERVED AND REPORTED
2 THEORY FORMULATED TO DESCRIBE PHENOMENA
3 THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4 PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED
5 COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6 MODEL TESTED IN AIRCRAFT ENVIRONMENT
7 MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED

FORM NO. 1

PAGE 2 OF ____

TITLE USE of High Strength Glossy Metals

NO. ____
THEME / W.G. / TASK

DATE ___ / ___ / ___

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

7. ALTERNATIVE APPROACHES/OPTIONS

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
MANPOWER (M-Y) INHOUSE																				
CONTRACT																				
FUNDING (10^6 $) INHOUSE																				
CONTRACT																				

LEVEL OF STATE OF ART

1 BASIC PHENOMENA OBSERVED AND REPORTED
2 THEORY FORMULATED TO DESCRIBE PHENOMENA
3 THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4 PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED
5 COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6 MODEL TESTED IN AIRCRAFT ENVIRONMENT
7 MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED

FORM NO. I

PAGE 1 OF ______

1. TITLE Inorganic Network Polymers For Lunar USE

NO. ______ THEME / W.G. / TASK

DATE 7/25/77

2. OBJECTIVE Synthesis of New types of inorganic polymers for use as lunar binders and adhesives.

3. NEED ANALYSIS

a) LEVEL NOW ☐, WILL BE LEVEL ☐ UNDER EXISTING PLANS.

b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL ☐ FOR OPERATIONAL SYSTEM USE BY DATE: ______

c) RISK IN ACHIEVING ADVANCEMENT: HIGH ☐ MEDIUM ☐ LOW ☐

d) CRITICALITY TO THE ACCOMPLISHMENTS. ENABLING ☐ OR ENHANCING: HIGH ☐ MEDIUM ☐ LOW ☐

e) TASKS NEEDED: STUDY ☐ ANALYSIS ☐ RESEARCH ☐ GRD TEST ☐ AIR CRAFT TEST ☐ SPACE FLIGHT TEST ☐ OTHER (Specify) ☐ ______ (Check one or more)

f) R&T BASE CANDIDATE FY'78 60-120K

data [illegible] not available at this time

4. COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY ______

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED

Many inorganic substances are polymers. Glass technology deals with highly crosslinked network polymers yet inorganic polymer chemistry is concerned almost entirely with linear polymers. approach toward synthesis of inorganic polymers based on belief that it was essential to link the structural units together into a long chain. In a basic paper N. H. Ray, Endeavour, V. 34, N 121 pg-12, 1975 sets forth some basic guidelines. Outside Silicones no useful new inorganic polymers have appeared

SPACE TECHNOLOGY NEED

FORM NO. I

PAGE 2 OF ____

TITLE Inorganic Network Polymers For Lunar Use.

NO. ____ THEME / W.G. / TASK

DATE ___ / ___ / ___

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

7. ALTERNATIVE APPROACHES/OPTIONS

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
MANPOWER (M-Y) INHOUSE																				
CONTRACT																				
FUNDING (10^6 $) INHOUSE																				
CONTRACT																				

SPACE TECHNOLOGY NEED — FORM NO. I

PAGE 1 OF ____

1. TITLE Lunar Fabrication of Building Materials From available Rock and Soil

NO. ____ THEME / W.G. / TASK

DATE ___ / ___ / ___

2. OBJECTIVE [illegible]

3. NEED ANALYSIS

a) LEVEL NOW ☐, WILL BE LEVEL ☐ UNDER EXISTING PLANS.

b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL ☐ FOR OPERATIONAL SYSTEM USE BY DATE:

c) RISK IN ACHIEVING ADVANCEMENT: HIGH ☐ MEDIUM ☐ LOW ☐

d) CRITICALITY TO THE ACCOMPLISHMENTS: ENABLING ☐ OR ENHANCING: HIGH ☐ MEDIUM ☐ LOW ☐

e) TASKS NEEDED: STUDY ☐ ANALYSIS ☐ RESEARCH ☐ GRD TEST ☐ AIR CRAFT TEST ☐ SPACE FLIGHT TEST ☐ OTHER (Specify) ☐ (Check one or more)

f) R&T BASE CANDIDATE FY 78 60K

Data base not available at this time

4. COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED

Use of available soil and rock for make up of cold mold composition such as typical cement asbestos product which can be volumetrically loaded in a compression mold, pressed to shape in a punch press like operation and cured in an oven. Calcium aluminum silicate is a common material and similar materials are available on lunar surface. Also concerned with sintering of lunar rocks and soil for building materials

LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED

FORM NO. I

PAGE 2 OF ____

TITLE Lunar Fabrication of Building Materials From available Rock & Soil

NO. ____ THEME / W.G. / TASK

DATE ___/___/___

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

7. ALTERNATIVE APPROACHES/OPTIONS

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
MANPOWER (M-Y) INHOUSE																				
CONTRACT																				
FUNDING (10^6 $) INHOUSE																				
CONTRACT																				

LEVEL OF STATE OF ART

1 BASIC PHENOMENA OBSERVED AND REPORTED
2 THEORY FORMULATED TO DESCRIBE PHENOMENA
3 THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4 PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED
5 COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6 MODEL TESTED IN AIRCRAFT ENVIRONMENT
7 MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED

FORM NO. I

PAGE 1 OF ______

1. TITLE SYNTHESIS OF LUNAR BINDERS & ADHESIVES

NO. ______ THEME / W.G. / TASK

DATE ___ / ___ / ______

2. OBJECTIVE [illegible]

3. NEED ANALYSIS

a) LEVEL NOW ☐, WILL BE LEVEL ☐ UNDER EXISTING PLANS.

b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL ☐ FOR OPERATIONAL SYSTEM USE BY DATE: ______

data base Not available at this time

c) RISK IN ACHIEVING ADVANCEMENT:
HIGH ☐ MEDIUM ☐ LOW ☐

d) CRITICALITY TO THE ACCOMPLISHMENTS: ENABLING ☐ OR ENHANCING: HIGH ☐ MEDIUM ☐ LOW ☐

e) TASKS NEEDED: STUDY ☐ ANALYSIS ☐ RESEARCH ☐
GRD TEST ☐ AIR CRAFT TEST ☐ SPACE FLIGHT TEST ☐
OTHER (Specify) ☐ ______ (Check one or more)

f) R&T BASE CANDIDATE FY'78 75K

4. COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY N/A

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED

Need exists for adhesive and binders for uses in filament ~~and~~ glass structures, sealants, adhesives, use on road bed material to compact dust

SPACE TECHNOLOGY NEED

FORM NO. I

PAGE 2 OF ____

TITLE *Synthesis of Lunar Binders and Adhesives*

NO. ____

THEME / W.G. / TASK

DATE ___/___/___

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

7. ALTERNATIVE APPROACHES/OPTIONS

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
MANPOWER (M-Y) INHOUSE																				
CONTRACT																				
FUNDING (10^6 $) INHOUSE																				
CONTRACT																				

SPACE TECHNOLOGY NEED — FORM NO. I — PAGE 1 OF 2

1. TITLE Integral Base design — NO. 2 (THEME / W.G. / TASK)

DATE __ / __ / __

2. OBJECTIVE Determine Results on the configuring of the elements of the lunar base to facilitate emplacement of the base in minimum time

3. NEED ANALYSIS

a) LEVEL NOW ☐, WILL BE LEVEL ☐ UNDER EXISTING PLANS.

b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL ☐ FOR OPERATIONAL SYSTEM USE BY DATE: 1985

c) RISK IN ACHIEVING ADVANCEMENT: HIGH ☐ MEDIUM ☐ LOW ☑

d) CRITICALITY TO THE ACCOMPLISHMENTS: ENABLING ☐ OR ENHANCING: HIGH ☑ MEDIUM ☐ LOW ☐

e) TASKS NEEDED: STUDY ☑ ANALYSIS ☑ RESEARCH ☐ GRD TEST ☐ AIR CRAFT TEST ☐ SPACE FLIGHT TEST ☐ OTHER (Specify) ☐ (Check one or more)

f) R&T BASE CANDIDATE Yes FY 75 2,000,000 $

4. COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY Remote monitoring of assemble integrety

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED

(1) Soft landing of large unit sections on the moon
(2) System study of packaging, ~~and~~ removing and deploying large units on the lunar surface
(3) Machines (trucks & cranes) to assist in deployment.

LEVEL OF STATE OF ART
1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED

FORM NO. I
PAGE 2 OF 2

TITLE Unitized base design

NO. ______
THEME / W.G. / TASK

DATE ___/ /___

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

Systems study of limits to this approach and ~~major~~ impact of ~~[illegible]~~ # of [illegible] buildings vs ease of deployment

7. ALTERNATIVE APPROACHES/OPTIONS

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
Study			←—	—→																
MANPOWER (M-Y) INHOUSE			10	10																
CONTRACT			20	20																
FUNDING (10^6 $) INHOUSE			.5	.5																
CONTRACT			1.0	1.0																

SPACE TECHNOLOGY NEED

FORM NO. I

PAGE 1 OF 2

1. TITLE Remote site preparation

NO. 2

THEME / W.G. / TASK

DATE ___ / ___ / ___

2. OBJECTIVE Determine limits & costs of techniques for major site preparation of the lunar base using grading equipment operating from earth.

3. NEED ANALYSIS

a) LEVEL NOW ☐, WILL BE LEVEL ☐ UNDER EXISTING PLANS.

b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL ☐ FOR OPERATIONAL SYSTEM USE BY DATE: 1986

c) RISK IN ACHIEVING ADVANCEMENT:
HIGH ☐ MEDIUM ☐ LOW ☒

d) CRITICALITY TO THE ACCOMPLISHMENTS. ENABLING ☐ OR ENHANCING: HIGH ☒ MEDIUM ☐ LOW ☐

e) TASKS NEEDED: STUDY ☒ ANALYSIS ☒ RESEARCH ☐
GRD TEST ☐ AIR CRAFT TEST ☐ SPACE FLIGHT TEST ☐
OTHER (Specify) ☐ (Check one or more)

f) R&T BASE CANDIDATE Yes 1975, 1.5M$

4. COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY Robotics, remote monitors

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED

(1) Advances in self-controlled monitors of earth moving elements on the moon to prevent accidents due to 1½ second time delay between the earth and the moon.
(2) Automatic deployment of large scale solar arrays to power the earth moving equip.
(3) High reliability of heavy equipment units – must be designed for no maintenance for 10 years
(4)

LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED

FORM NO. I
PAGE 2 OF 2

TITLE Same

NO. 2
THEME / W.G. / TASK

DATE / /

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

(1) Design study of earth moving equipment needed
(2) Prototypes build and operated extensively on earth
(3) Development of flight units

7. ALTERNATIVE APPROACHES/OPTIONS Manned operation on the moon of the equipment

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)

~~[illegible]~~
Asteroid mining for reaction mass for mass drivers

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
(1) Design			←—	—→																
(2) Prototype				←—	——	——	—→													
(3) Deploy										←—	—→									
MANPOWER (M-Y) INHOUSE			10	10																
MANPOWER (M-Y) CONTRACT			20	20																
FUNDING (10^6 $) INHOUSE			.5	.5																
FUNDING (10^6 $) CONTRACT			1.0	1.0																

LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED — FORM NO. I — PAGE 1 OF 2

1. TITLE ~~Materials Packaging~~ Slug Packaging Materials

NO. 4

THEME / W.G. / TASK

DATE __ / __ / __

2. OBJECTIVE Develope "film" to be used to package slugs of lunar material to be ejected from the moon by the mass driver

3. NEED ANALYSIS

a) LEVEL NOW ☐, WILL BE LEVEL ☐ UNDER EXISTING PLANS.

b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL ☐ FOR OPERATIONAL SYSTEM USE BY DATE: 1985

c) RISK IN ACHIEVING ADVANCEMENT: HIGH ☐ MEDIUM ☐ LOW ☒

d) CRITICALITY TO THE ACCOMPLISHMENTS. ENABLING ☒ OR ENHANCING: HIGH ☐ MEDIUM ☐ LOW ☐

e) TASKS NEEDED: STUDY ☐ ANALYSIS ☐ RESEARCH ☒ GRD TEST ☒ AIR CRAFT TEST ☐ SPACE FLIGHT TEST ☐ OTHER (Specify) ☐ (Check one or more)

f) R&T BASE CANDIDATE Yes FY 78 $ 600,000 $.

4. COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY (1) Fiberglass/Aluminum Composite Film

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED

(1) 0.5 micron thick Kelvar film reinforced by internal threads - Factor of 10 thinner than now available (need 500,000 psi yielding stress)

(2) Sealing techniques not using air

SPACE TECHNOLOGY NEED

FORM NO. I
PAGE 2 OF 2

TITLE Slug Packaging material

NO. ______
THEME / W.G. / TASK

DATE ___ / ___ / ___

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

~~[illegible]~~ (1) Development & research on production of the films
(2) Test for stability in containing powdered slugs over a range of slug mass (1 Kg to 100 Kg), thermal conditions of Terran storage and flight to deep space

7. ALTERNATIVE APPROACHES/OPTIONS Binder which could be applied to the outside of each slug

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)

—

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
Dev.			—																	
Test				—																
MANPOWER (M-Y) INHOUSE			2	5																
CONTRACT			1	5																
FUNDING (10^6 $) INHOUSE			.1	.25																
CONTRACT			.1	.25																

SPACE TECHNOLOGY NEED FORM NO. I

PAGE 1 OF 1

1. TITLE Slug maker

NO. 6
THEME / W.G. / TASK

DATE __/__/__

2. OBJECTIVE Device to pelletize slugs of lunar soil (1Kg – 100Kg) and seal with high strength film

3. NEED ANALYSIS

a) LEVEL NOW ☐, WILL BE LEVEL ☐ UNDER EXISTING PLANS.

b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL ☐ FOR OPERATIONAL SYSTEM USE BY DATE: 1987

c) RISK IN ACHIEVING ADVANCEMENT:
HIGH ☐ MEDIUM ☒ LOW ☒

d) CRITICALITY TO THE ACCOMPLISHMENTS. ENABLING ☒ OR
ENHANCING: HIGH ☐ MEDIUM ☐ LOW ☐

e) TASKS NEEDED: STUDY ☐ ANALYSIS ☒ RESEARCH ☒
GRD TEST ☒ AIR CRAFT TEST ☐ SPACE FLIGHT TEST ☐
OTHER (Specify) ☐ ______ (Check one or more)

f) R&T BASE CANDIDATE 1975 200K$

4. COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY ~~Auto~~ Automatic monitoring of the status of the machine

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED

(1) Probably very few if any basic design advances

(2) Emphasis on extremely high reliability and remote control and monitoring

LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED

FORM NO. I
PAGE 2 OF 2

TITLE [illegible]

NO. ____
THEME / W.G. / TASK

DATE __/__/__

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

(1) Review of existing pelletizer and packaging designs
(2) Modify designs for high reliability, remote operation
(3) Build prototype & test

7. ALTERNATIVE APPROACHES/OPTIONS —

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)

None

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
(1) Review			—																	
(2) Design				—	—															
(3) Prototype						—	—	—												
MANPOWER (M-Y) INHOUSE			2	4	4	.2	2													
CONTRACT			2	10	10	30	20													
FUNDING (10^6 $) INHOUSE			.1	.2	.2	.1	.1													
CONTRACT			.1	.5	.5	3.0	3.0													

SPACE TECHNOLOGY NEED — FORM NO. I

PAGE 1 OF 2

1. TITLE Binders for lunar soil

NO. 5

THEME / W.G. / TASK

DATE / /

2. OBJECTIVE Develope binds which can be mixed with lunar soil to form foundations, roads, support platforms, landing pad, etc.

3. NEED ANALYSIS

a) LEVEL NOW ☐, WILL BE LEVEL ☐ UNDER EXISTING PLANS.

b) REQUIRED ADVANCEMENT – SHOULD BE TECHNOLOGY READY AT LEVEL ☐ FOR OPERATIONAL SYSTEM USE BY DATE:

c) RISK IN ACHIEVING ADVANCEMENT: HIGH ☐ MEDIUM ☐ LOW ☒

d) CRITICALITY TO THE ACCOMPLISHMENTS: ENABLING ☐ OR ENHANCING: HIGH ☒ MEDIUM ☐ LOW ☐

e) TASKS NEEDED: STUDY ☒ ANALYSIS ☑ RESEARCH ☒ X GRD TEST ☒ AIR CRAFT TEST ☐ SPACE FLIGHT TEST ☐ OTHER (Specify) ☐ (Check one or more)

f) R&T BASE CANDIDATE yes FY75 [illegible] weeks

4. COMPLEMENTARY TECHNOLOGY ADVANCEMENTS REQUIRED FOR USE OF THIS TECHNOLOGY Fiberglass and glass production on the lunar surface

5. SPECIFY TECHNOLOGY ADVANCEMENT REQUIRED TO ACCOMPLISH NEED

(1) Probably no major advance for binders supplied from earth

(2) Intense work needed on possibility of producing inorganic binders directly from lunar soil

LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED
2. THEORY FORMULATED TO DESCRIBE PHENOMENA
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT
7. MODEL TESTED IN SPACE ENVIRONMENT

SPACE TECHNOLOGY NEED.

FORM NO. I
PAGE 2 OF 2

TITLE Binders for Lunar Soil

NO. 5
THEME / W.G. / TASK

DATE / /

6. RECOMMENDED APPROACH/PROGRAM PLAN TO ACCOMPLISH NEED

(1) Review inorganic binder technology
(2) Conceptual design of binder production on the lunar surface
(3) Prototype plant developed

7. ALTERNATIVE APPROACHES/OPTIONS (1) Import from earth
(2) Fusion of soil to make glass, ceramics and cast basalt

8. CURRENT/PLANNED RELATED ACTIVITIES (RTOP, OTHER)
None

9. TECHNOLOGY SCHEDULES

SCHEDULE ITEM (FY)	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
TASK ITEM																				
Study			—																	
Trial Syst.				—																
Prod. Prototype					—	—														
MANPOWER (M-Y) INHOUSE			2	2	4															
CONTRACT			2	6	20															
FUNDING (10^6 $) INHOUSE			.1	[illegible]	.2															
CONTRACT			.1	.3	3															

LUNAR BASE

Major Technology Development/Study Areas. Assume base implaced in 10 YFS* (R&D start, product needed).

1. Solettas for illumination of lunar bases during the night. (Multipanel solar sails, each panel point separately at target area.) Each sail 625 km^2 in area (78, 87). Note especially ability to maintain orbit which precesses with lunar rotation rate (12-15° day).

2. Identify high strength film materials for packaging of lunar soil (1, 5 YFS).

3. Electrostatic grain size and mineral separation techniques for bulk processing of lunar soils (1, 3 YFS).

4. Production of oxygen from lunar soils with recirculating hydrogen as the reducing element (400 to 1000 tons/yr production rate)(1, 3 YFS).

5. Liquefying oxygen on the lunar surface (500-1000 tons/yr)(1, 3 YFS).

6. Remote (from a lunar or Earth base) control of lunar trucks to be used for detailed exploration, excavation, site preparation, hauling soil, and as hoists and cranes (1, 3 YFS).

7. Binders or binding techniques for stabilizing lunar soil for use in foundations, landing pads, and haul roads (1, 8 YFS).

8. Study of the limits on unitizing the lunar base and mass driver and correction stations (1, 2).

9. Confirm possibility of lunar orbital storage of LOX and transfer to descent vehicles (400-1000 tons/yr quantities)(1, 10 YFS).

10. Production of fiberglass and aluminum composite on the Moon for materials packaging, structural utilization, and as an electrical conductor (1, 6 YFS).

*YFS = years from start.

11. Detailed design studies for extremely reliable pelletizer and packaging unit for lunar soils--produce 2×10^8 packages/yr, each weighing 3.8 g with fixed radii (≃9 cm) and variable density (2.2-5 g/cm^3) (1, 8 YFS).

12. Extremely intensive work on lightweight, reliable, easy to operate spacesuits which provide the maximum possible freedom of movement and dexterity in space and on the Moon (≃10 hr on time) (1, 7 YFS).

HIGH PRIORITY R&D FOR PROCESSING AND BENEFICIATION OF LUNAR MATERIALS - GROUP V

1. Determination of relevant physical and chemical properties of lunar soil (~$250K)

   - Determine empirical parameters for magnetic, electrostatic, and air classifier for the separation of lunar soils with respect to grain size and minerology
   - Determine the distribution and concentration of volatiles (particularly H_2) among the phases in lunar soils as a function of mineralogy and grain size and history--grinding and abrasion

2. Laboratory scale processing (~$300K)

   - Study chlorocarbonization of $FeTiO_3$ and $CaAl_2SiO_8$ to determine kinetics of reaction
   - Study chlorocarbonization of ilmenite and anorthite ores to determine kinetics and check for blocking reaction

3. Prepare chemical and mineralogic simulant (~$100K)

4. Test processes in bench scale (~400K)

   - Study ability to close cycles
   - Determine mass and energy efficiencies

5. Models, parametric (~$150K)

   - Lunar mining and beneficiation
   - Chemical processing
   - Volatile extraction

Phasing (CY)	TOTAL ($K)	TIME 7 YR
1. 78-80	250	
2. 78-81	300	
3. 80-81	100	
4. 81-84	400	
5. 81-85	150	
	1200	

NONTERRESTRIAL MATERIAL PROCESSING
GROUP V

This section reviews key research projects which are needed to demonstrate technology readiness.

I. 1. Stability field diagrams for P_{MCl_y} vs. P_{Cl_2}, and P_{Cl_2} vs. 1/T for the M-C-Cl and M_1-M_2-C-Cl systems M = Al, Ca, Si, Fe, Mg, Ti.

2. Thermodynamics and kinetics of carbo-chloronate of anorthite at temperatures below 1200 K. Identification of various gaseous species and condensed phases formed during the reaction. Separation and purification of products obtaining pure $AlCl_3$ for the electrolysis.

3. The feasibility of the extraction of Al via AlCl in the high temperature reaction of anorthite and $AlCl_3$. Establishment of the minimum temperature for the reaction kinetics of the main reaction and the disproportionation reaction:

$$3AlCl(g) \rightleftarrows AlCl_3 + 2Al$$

Separation of Ca, Al, and Si from the Ca-Al-Si alloy obtained.

4. Modification of Alcoa's electrolysis process to take advantage of the various alkali and alkaline Earth chlorides obtained as by-products.

5. Reactant losses during the recycling of the various reactants need to be established.

II. 6. Kinetics of the reduction of olivine with calcium carbide need to be studied.

7. Production of calicum carbide from the by-product of calcium chloride obtained in the processing of anorthite must be optimized.

8. The role of calicum silicide as an intermediate on the overall reduction process must be established.

III. 9. The scaling up of the chlorination process for the beneficiation of ilmenite need to be considered.

10. The recycling losses of various reactants need to be established.

IV. 11. Further research is needed in the solid-state electrolysis for the recovery of oxygen from the by-products CO, CO_2, etc. Optimum conditions for the extended service life of the cells must be established.

12. Some improvements may be made in the existing design of modal-ceramic seals.

13. Electrolyte with maximum ionic conductivity other than the conventional CaO-stabilized zirconia or jeltria stabilized thoria may be chosen.

14. Optimum temperature with acceptable IR loss in the electrolyte must be established.

15. Further work must be done while choosing a suitable catalyst. Role of impurities in the gas-feed, especially as it relates to the poisoning of the catalyst.

V. 16. All these processes must be demonstrated under conditions simulated to the space conditions.

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15. Supplementary Notes

S.R. Sadin, Chairman

16. Abstract

In June 1977 a one-week planning workshop was held in Palo Alto, California, to examine the utilization of nonterrestrial materials for the construction of large space systems. The purpose of the workshop was to generate recommendations to NASA regarding research and study requirements.

The participants addressed themselves to the development of research and technology programs on the use of nonterrestrial materials for space applications. The space power satellite (SPS) system was chosen as a model because it exemplifies large space systems for which the use of nonterrestrial materials may be economically viable. Sample topics considered included the mining of raw materials and the conversion of raw materials into useful products. These topics were considered against a background of the comparative costs of using terrestrial materials. At what point does the use of nonterrestrial materials become competitive with the cost of terrestrial resources?

The workshop participants also considered exploratory activities involved in the the preparation of a nonterrestrial materials utilization program, and the human factors involved. The recommendations generated by this workshop represent the ideas of the participants only, not official NASA positions. However, several of their recommendations have been already incorporated into NASA activities.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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