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TOWARD A SPACE MATERIALS SYSTEMS PROGRAM

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Program Development

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16. ABSTRACT

A program implementation model is presented which covers the early stages of space material processing and manufacturing. The model includes descriptions of major program elements, development and experiment requirements in space materials processing and manufacturing, and an integration of the model into NASA's long range plans as well as its evolution from present Materials Processing in Space plans.

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PREFACE

This report is the result of the author's activities and contributions as a member of the Steering Committee on Space Materials Systems program development and as a member of the Center's Working Group on the same subject. The goal of these NASA efforts is the establishment of a Space Materials Systems Program for NASA in 1981. The support and encouragement received from Mr. Paul Gordon of the Materials Processing in Space Division, Office of Space and Terrestrial Applications, NASA Headquarters, are greatly appreciated.

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TOWARDS A SPACE MATERIALS SYSTEMS PROGRAM

SUMMARY

A program implementation model is presented which covers the early stages of space material processing and manufacturing. The model includes descriptions of major program elements, development and experiment requirements in space materials processing and manufacturing, and an integration of the model into NASA's long range plans as well as its evolution from present Materials Processing in Space plans.

I. SPACE MATERIALS SYSTEMS PROGRAM OVERVIEW

The following overview deals with a proposed program which may undergo various modifications in time; however, it appears to be sufficiently representative of a direction this program may take if implemented.

A. Program Goal

The goal of the Space Materials Systems Program [1] is the development of systems for the cost effective utilization of space materials resources for both space and terrestrial applications through space missions with the following objectives:

1) Demonstration of the efficacy of advanced autonomous and teleoperated machinery for remote material manufacturing operations which possess a high degree of self-sufficiency and self-replication. Such operations include materials exploration, acquisition, staging, conversion, manufacturing, assembly, and construction.

2) Demonstration of space-adapted techniques for the acquisition and conversion of raw materials occurring in space to useful forms for space system components and for other space and terrestrial applications.

It is understood that the term "space materials" covers lunar, asteroidal, and planetary materials; however, this report covers only the proposed program elements for a lunar materials systems program. Parts of this proposed program could also be applicable to planetary materials utilization. An asteroid material utilization program, however, would have to follow quite different program steps.

B. Program Evolution

Any Space Material Systems (SMS) program has to evolve from and be linked to the present Materials Processing in Space (MPS) program. This can be accomplished in spite of the fact that the MPS objectives are different from those of the SMS.

The MPS objectives cover research in the sciences and technology of processing terrestrial materials under low gravity conditions and the development of new materials and processes in commercial applications. The SMS evolution will begin with experiments with simulated space materials of terrestrial origin and proceed with ground based experiments with simulated space processing techniques (Fig. 1). This will be followed by a Shuttle-based and free-flyer supported experiment program applying the initial steps of automated processing technology. This will be followed by an Orbiting Materials Processing Experiment Station coupled with an associated manufacturing facility as the major prototype stations which will develop the final capabilities required by an automated lunar materials processing and a space manufacturing facility. It is anticipated that a development over a ten year period would provide these capabilities.

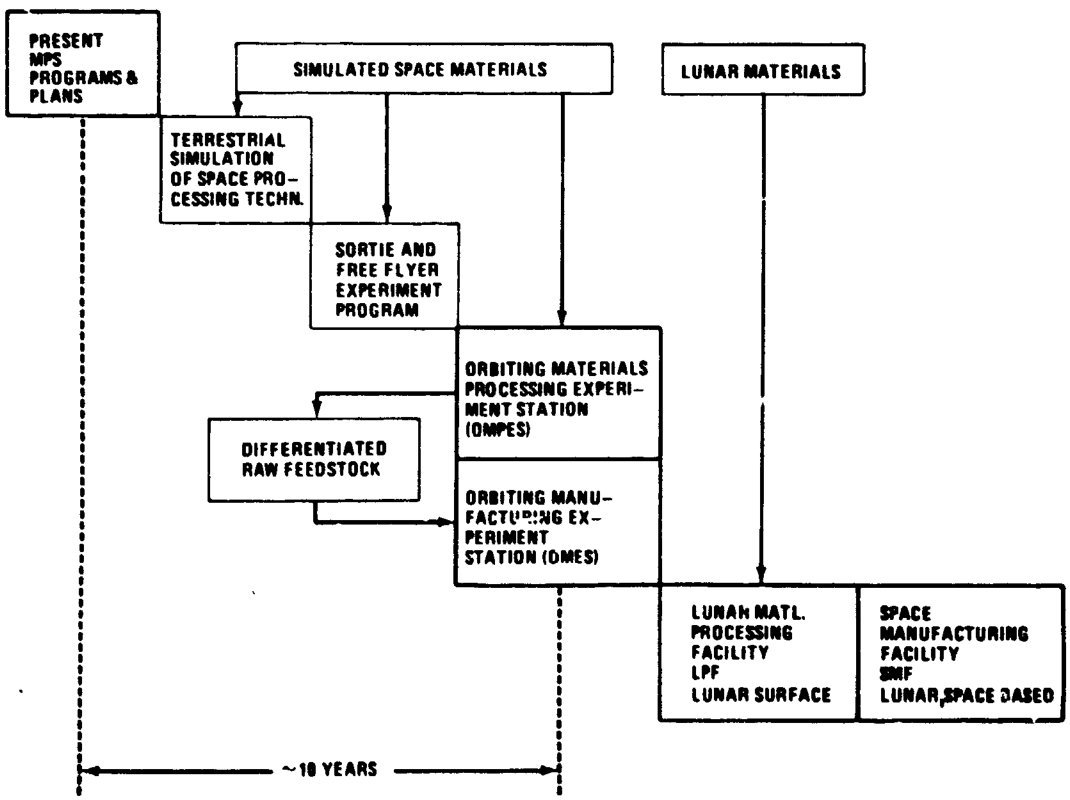

Figure 1. Assumed space materials systems evolution overview.

C. Program Reference System

In order to develop a total SMS Program, a definition of an overall SMS scenario was undertaken. The major building blocks are shown in Figure 2 including the required traffic between them. The overall program structure is outlined in the Work Breakdown Structure (WBS) in Table 1. The planetary and asteroid complexes in Figure 2 are shown for reference only and are not covered by the WBS. It is assumed that the Advanced Lunar Complex will be entirely autonomous and will constitute the point of departure for any planetary or asteroid missions. The Geostationary Complex will be the central focus of the majority of operations and the prime recipient of space materials and products.

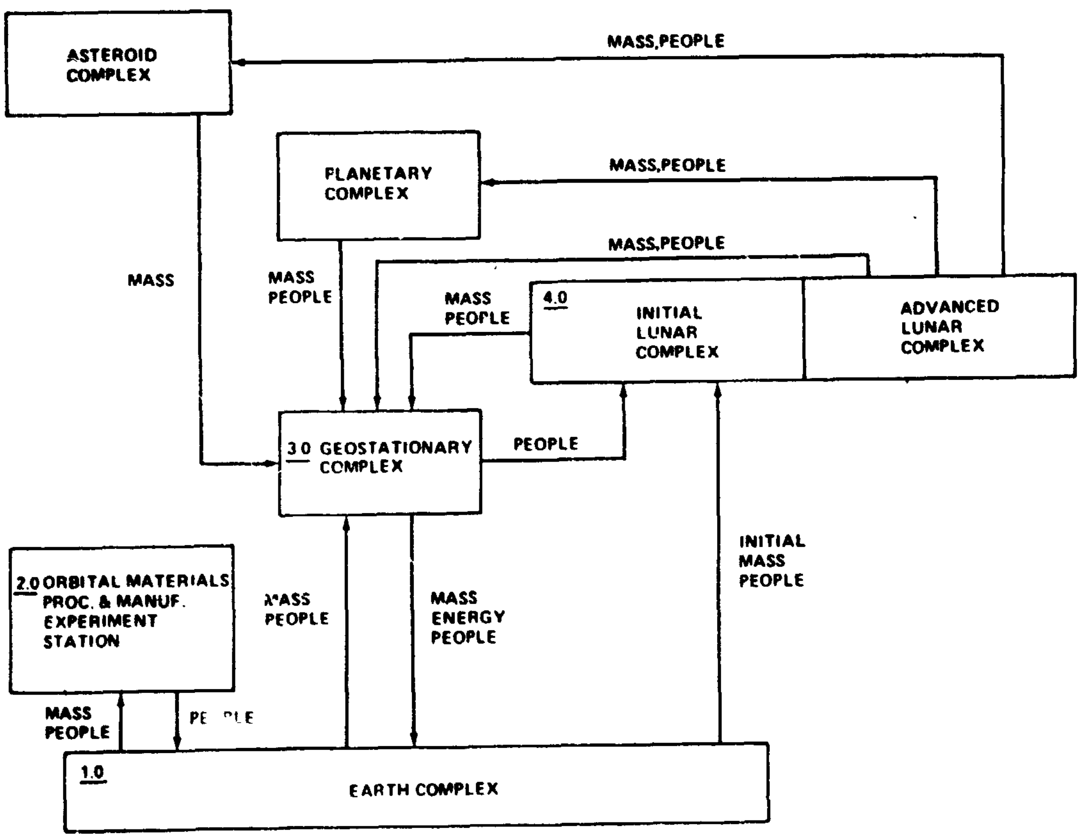

Figure 2. General overall reference SMS definition.

D. Program Development

The program development flow includes four major decision milestones each of which concludes and initiates a key development phase (Fig. 3). The contents of each development phase and their expected goals are given in Table 2.

TABLE 1. WORK BREAKDOWN STRUCTURE FOR SMS (adapted from 2)

1.0	Earth Complex
1.1	Systems Management and Utilization Organization
1.1.1	Legislative body
1.1.2	Development agency
1.1.3	User organization
1.2	Industrial Infrastructure for Development, Test and Fabrication
1.2.1	Aerospace industries
1.2.2	Chemical industries
1.2.3	Electronic industries
1.3	Earth Surface Transport System
1.3.1	Automotive industries
1.3.2	Transport service
1.4	Earth-Space Transport System
1.4.1	Launch vehicles
1.4.2	Payloads
1.4.3	Launch and landing facilities
1.4.4	Payload handling facilities
1.4.5	Launch vehicle operating agency
1.4.6	Propellant storage
1.4.7	Earth STS support facility in LEO
1.4.8	Earth STS support facility in GSO
2.0	LEO Complex
2.1	LEO-Space Transport System
2.1.1	LEO-STS Operating facility
2.1.2	LEO Local personnel transport system
2.1.3	LEO Local cargo transport system
2.1.4	LEO Propellant storage
2.2	Orbital Materials Processing Experimental Station (OMPES)
2.2.1	Material storage module
2.2.2	Beneficiation module
2.2.3	Chemical processing facility
2.2.4	Mechanical processing facility
2.2.5	Power system
2.2.6	Habitat
2.2.7	Storage
2.3	Orbital Manufacturing Experiment Station (OMES)
2.3.1	Structural shop
2.3.2	Electrical shop
2.3.3	Power System
2.3.4	Habitat
2.3.5	Storage
2.3.6	Assembly facility

TABLE 1. (Continued)

3.0 GSO Complex

3.1 GSO-Space Transport System

3.1.1 GSO-STS Operating facility
3.1.2 GSO Local personnel transport
3.1.3 GSO Local cargo transport
3.1.4 GSO Propellant storage

3.2 Space Manufacturing Facility (SMF)

3.2.1 Structural shop
3.2.2 Electrical shop
3.2.3 Electronic shop
3.2.4 Power system
3.2.5 Habitat
3.2.6 Storage
3.2.7 Assembly facility

3.3 Product Maintenance and Repair Facility

3.3.1 Maintenance facility
3.3.2 Repair facility

3.4 Operational Products

4.0 Lunar Complex

4.1 Lunar Base

4.1.1 Lunar Materials Processing Facility (LPF) I

4.1.1.1 Strip mine facility
4.1.1.2 Beneficiation module
4.1.1.3 Chemical processing facility
4.1.1.4 Mechanical processing facility
4.1.1.5 Fabrication shop
4.1.1.6 Assembly facility

4.1.2 Lunar Materials Processing Facility (LPF) II

4.1.2.1 Mine construction site
4.1.2.2 Operating mine
4.1.2.3 Gas processing facility
4.1.2.4 Liquifaction facility

4.1.3 Lunar Infrastructure

4.1.3.1 Power plant system
4.1.3.2 Dump
4.1.3.3 Launching and landing facility
4.1.3.4 Central storage area
4.1.3.5 Central workshop
4.1.3.6 Central surface transport system
4.1.3.7 Lunar complex control center

TABLE 1 (Concluded)

	4.1.4	Lunar Habitat
		4.1.4.1 Housing facilities
		4.1.4.2 Farming facilities
4.2	Lunar Space Transportation System	
	4.2.1	Lunar STS Support Facility in LO and in GSO
		4.2.1.1 Control module
		4.2.1.2 Propellant storage module
		4.2.1.3 Spare and supplies storage
		4.2.1.4 Habitation module
		4.2.1.5 Power module
		4.2.1.6 Payload storage
		4.2.1.7 Maintenance hangar
		4.2.1.8 Docking module
		4.2.1.9 Lunar STS

TABLE 2. SMS DEVELOPMENT PHASES

Development Phase Content	Expected Goal to be Reached
(1) SMS Conceptual Design	Basic Understanding of Problem and Approaches to Solutions
(2) Terrestrial Development Tests	Basic Materials Processing and Manufacturing Capabilities
(3) Early Space Development Tests	Routine Space Materials Processing Capabilities; Increased Manufacturing Capabilities
(4) Space System Development and Element Production	Orbital Materials Processing and Manufacturing Experiment Station Construction and Operations
(5) Start-Up for Full Scale Operations	Lunar Processing Facility and Space Manufacturing Facility Construction and Operations

Figure 3 lists the required parallel developments within each development phase.

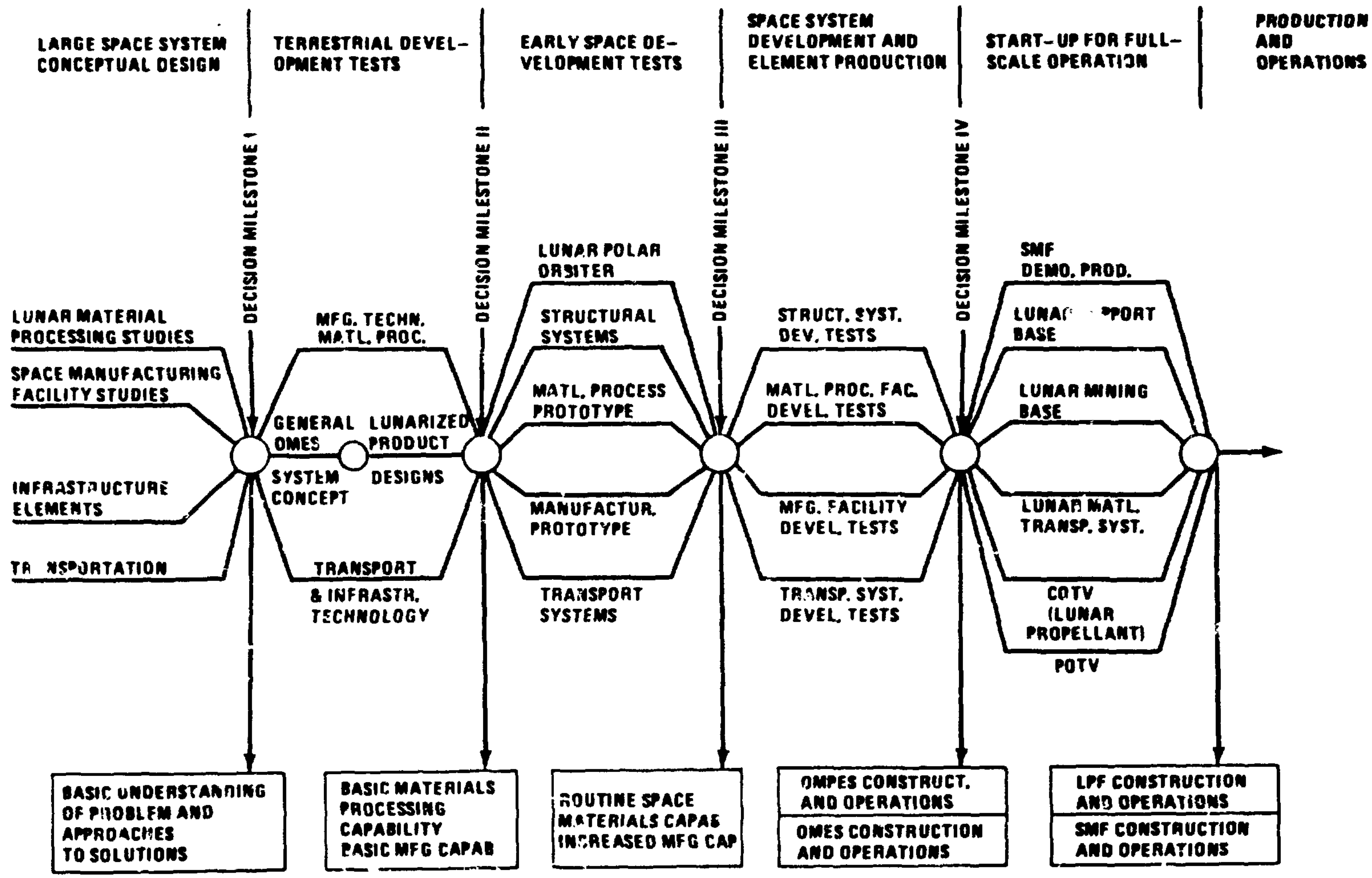

Figure 3. Parallel developments of space material systems.
(adapted from 3)

E. Program Integration

An SMS program cannot be developed separately from and independently of other ongoing and planned programs. Therefore, it has to evolve from both the present Materials Processing in Space Program (MPS) and integrated into NASA's overall long range plans. In addition, ongoing and anticipated technology and mission developments that have key supporting or enabling characteristics must be recognized and considered.

Figure 4 shows a possible evolution from MPS into SMS. Having different background histories and goals, the program can be merged within a Shuttle-based manned and automated experiment program followed by a combined program that could include the Power System supported automated Material Experiment Carrier, manned sortie and automated free-flyer missions. Thus, early and advanced space materials research and process development can be jointly undertaken with future MPS plans. After this phase the two developments will part according to their individual specifid goals.

Figure 5 shows a possible SMS integration into present NASA long range plans. Already mentioned is the combined Shuttle utilization and free-flyer program as well as automated and manned sortie missions. The planned manned, permanent low-earth orbit facility can evolve into both the Orbital Materials Processing (OMPES) and the Orbital Manufacturing Experiment Station (OMES). Furthermore, the envisioned manned, permanent geosynchronous orbit facility could evolve into the Space Manufacturing Facility (SMF), deriving its machinery and operations from the OMES. The extension of the OMPES finally, would be the Lunar Processing Facility (LPF). All facilities will be highly automated.

II. PROGRAM REQUIREMENTS

After having outlined the SMS program reference system within an integrated space program scenario, guidelines must be developed to provide overall direction to the experiment program requirements. Since the overall purpose of the SMS program is to produce "useful forms of space system components...and applications" the type of products must be described together with the required activities and technologies.

A. Products

The following types of feedstock and products have been selected based on an almost universal need for these in space and on the availability of suitable raw material for these products on the lunar surface.

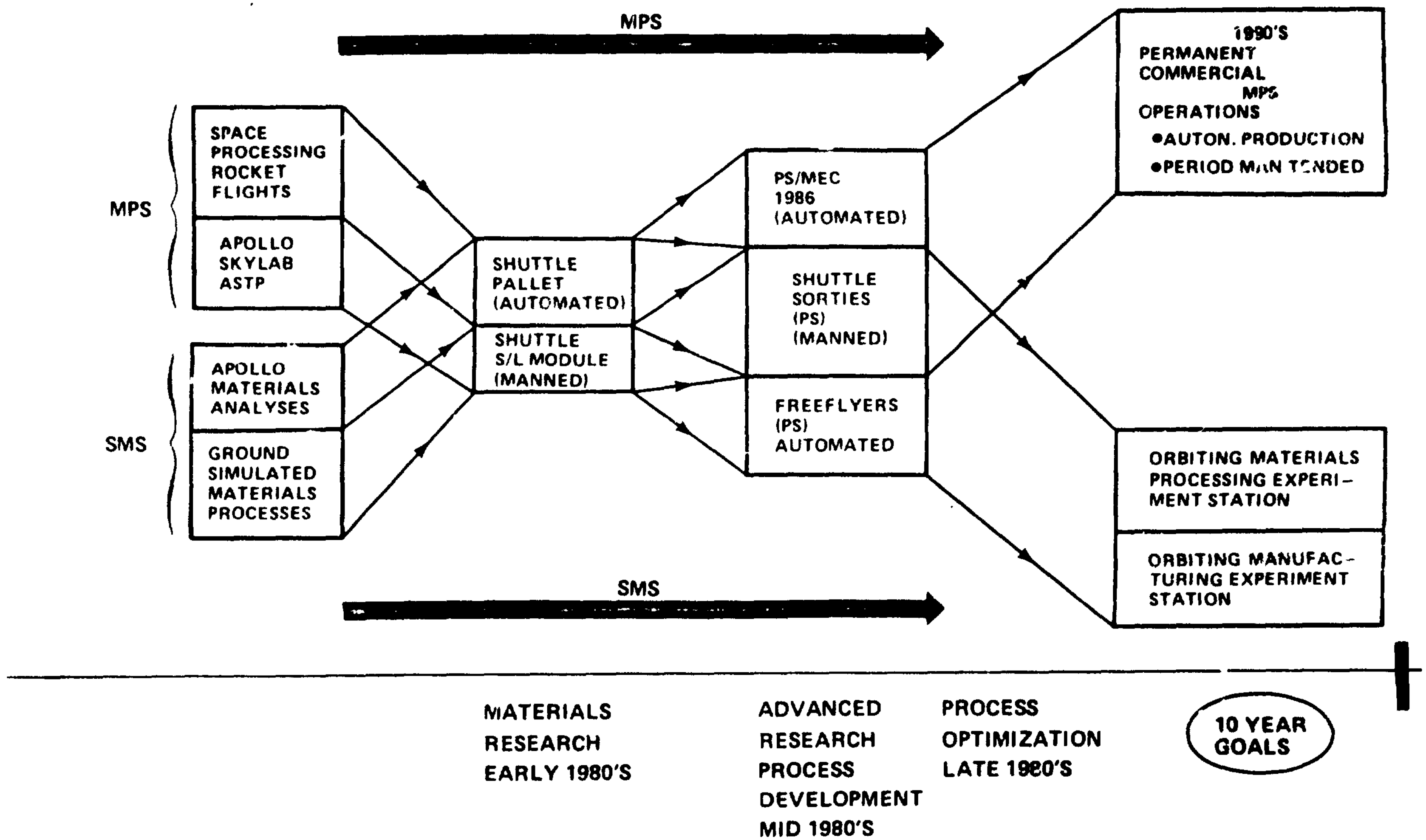

Figure 4. Evolution of MPS into SMS.

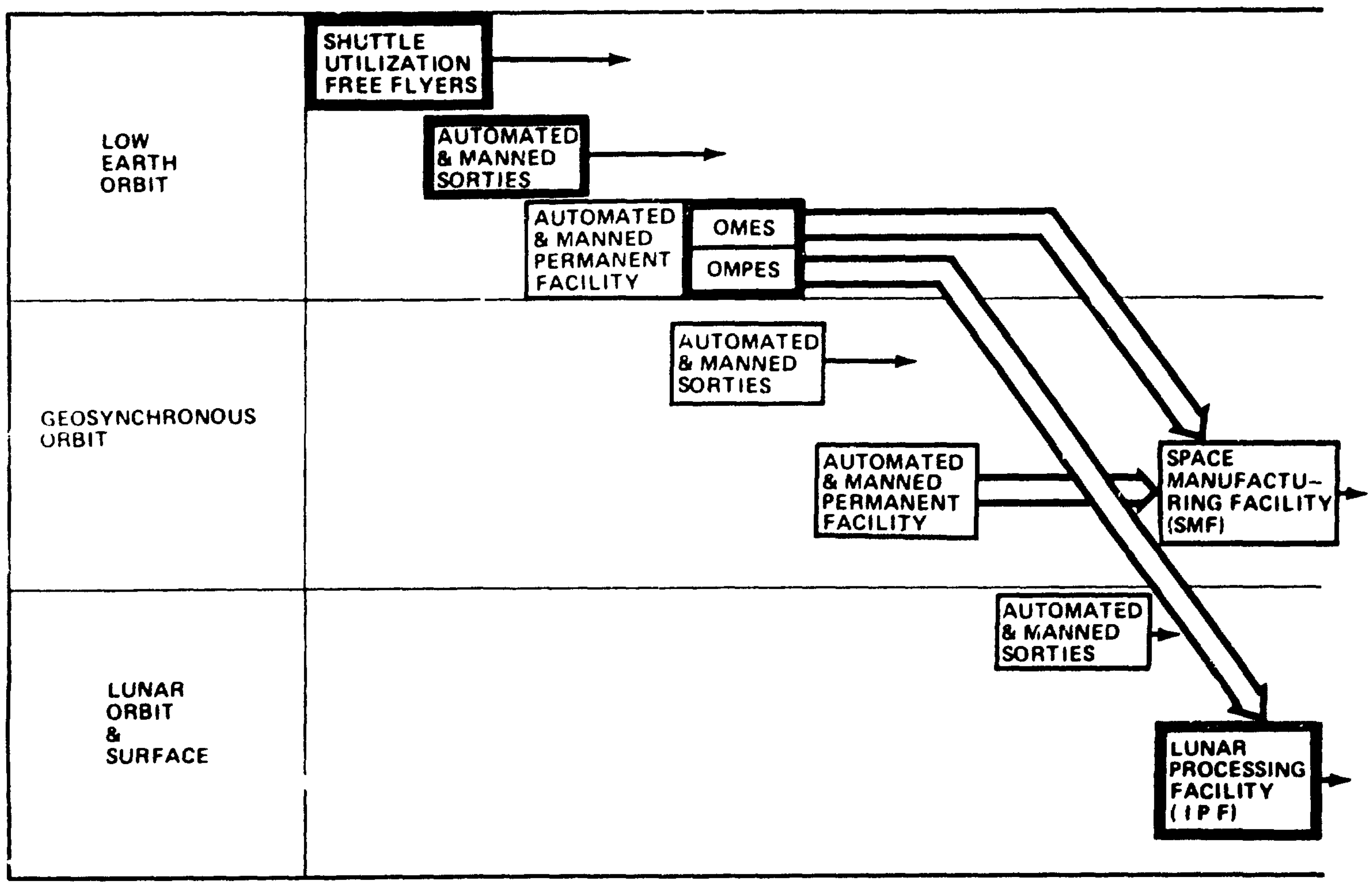

Figure 5. Integration of SMS into NASA long range plans.

The capability to produce specific feedstock from the metallic elements and from Si is required. Typical feedstock would be round and flat bars, sheets, ingots, plates, wire, etc.

The capability to produce the following representative products is required:

1) Structural beams and connectors

2) Insulated wire

3) Silicon photovoltaic cells

4) Solar arrays

5) Space radiators

6) Foamed glass

7) Silicon Fiberglass

8) Silica glass

9) Glass filament containers

In addition the following materials must be produced [4]:

STRUCTURAL MATERIALS

Metals - Steels, aluminum, magnesium, titanium
Reinforced Metals - Aluminum, magnesium
Reinforced with silica, steel or alumina
Glasses, fused silica
Ceramics, alumina, magnesia, silica, compounds

THERMAL MATERIALS

Refractories plus chromia, titania, titanium silicide. Same as ceramics plus incl. castables, ramming cements insulation, fiberglass, fibrous or powdered ceramics

ELECTRICAL MATERIALS

Conductors - Aluminum, magnesium, iron, resistance alloys (FeCrAl)
Electrodes -
Magnetic materials, iron alloys, magnetic ceramics
Insulation, glass, ceramics

FIBROUS MATERIALS

Glass, silica (for paper, filters, etc.)

PLASTICS, ELASTOMERS AND SEALANTS

Soluble silicates, silicone resins

ADHESIVES AND COATINGS

Anodized aluminum, magnesium, titanium, electroplating (Cr)
Sputtered coatings, etc.

LUBRICANTS, HEAT TRANSFER FLUIDS

Sulfides, SO_2, He

B. Space Materials Processing Requirements

Ground and early space-based space materials processing experiments will use simulated lunar materials, particularly simulated Ilmenite ($Fe\,Ti\,O_3$) and simulated Anorthosite ($Ca\,Al_2\,Si_2\,O_8$). Their major components and elemental composition are given in Table 3. The capability to extract the elements shown in the table is required. The extremely small quantities of Cr, Mn, Na, K, S, and P which occur may be useful in the production of certain alloys.

TABLE 3. CONSTITUENTS OF LUNAR ORE

	Compound \ Element	Fe	Mg	Ti	O_2	%
Ilmenite	Fe O	35.5			10.1	45.6
	Ti O			31.4	21.0	52.4
	Mg O		1.2		0.8	2.0
	%	35.5	1.2	31.4	31.9	100
	Compound \ Element	Al	Ca	Si	O_2	%
Anorthosite	$Al_2\,O_3$	17.9			15.9	33.8
	Ca O		13.6		5.4	19.0
	$Si\,O_2$			22.0	25.2	47.2
	%	17.9	13.6	22.0	46.5	100

The required processing capability involves three separation processes:

1) Mechanical (including magnetic)

2) Thermal

3) Chemical

The applications for these processes are shown in Figure 6.

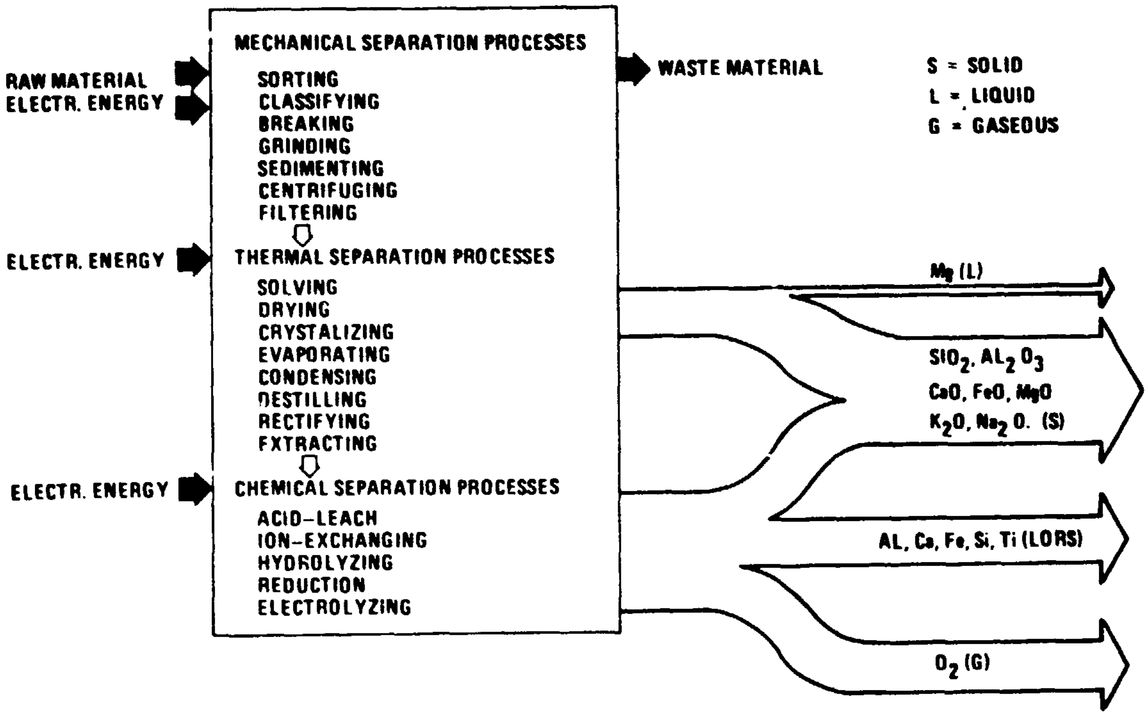

Figure 6. Lunar materials processing[2].

The automated equipment for these processes must be developed and their ultimate installation into an Orbital Materials Processing Experiment Station (OMPES) must be planned and integrated. An example of six typical modules of such a facility is shown in Figure 7. It is understood that ultimately an optimum level of automation must be applied here.

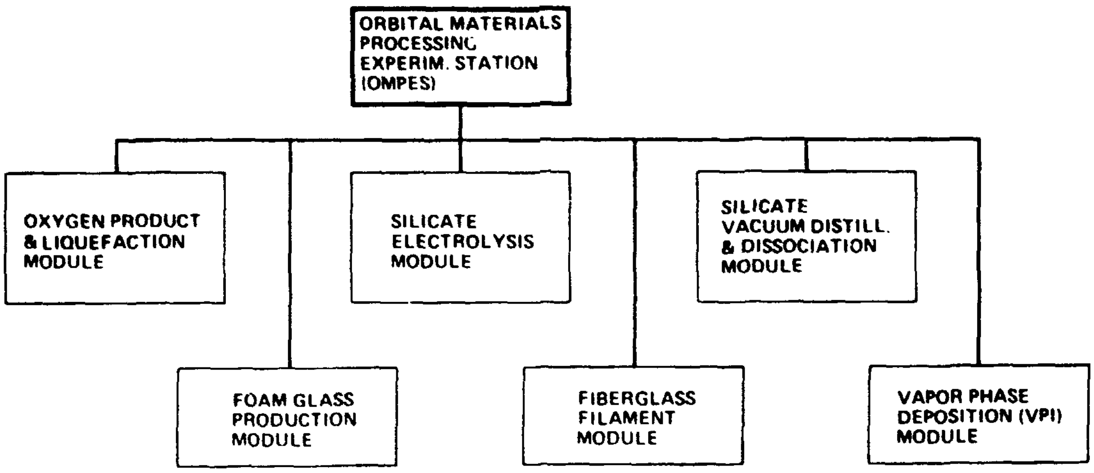

Figure 7. Orbital materials processing experiment station modules.

C. Space Materials Manufacturing Requirements

Ground and early space-based space materials manufacturing experiments will be based on the available processed material and feedstock produced. It seems quite possible and beneficial to integrate the processing and manufacturing activities into one coordinated work flow.

Since aluminum may become a major space material, part of the experimental work could include the utilization of fractionated External Tank (ET) material. Figure 8 shows a facility schematic for the experimental production of solar arrays using fractionated ET material for supporting structures.

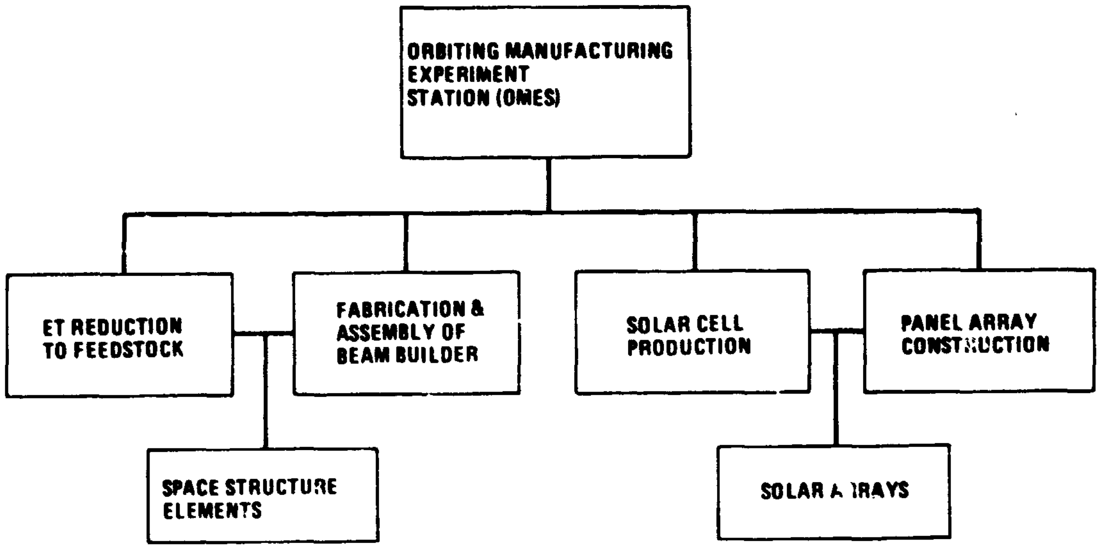

Figure 8. Example of orbiting manufacturing experiment station activities.

The main requirements placed on an Orbital Manufacturing Experiment Station are (Table 4):

1) Product Formation. To avoid machining as much as possible (heavy masses, time consumming, waste material) casting and metal powder processing may be a preferred means of formation

2) Assembly and intelligent robots/teleoperators

3) Information System including machine intelligence

4) Materials Handling with optimum automation again.

III. RECOMMENDED PROGRAM TECHNOLOGY DEVELOPMENTS

The recommended technology requirements are closely related to the representative products discussed before; therefore the technology achievements will have the broadest possible applications throughout a multitude of space systems.

A. General Research and Development

This effort concentrates on fundamental equipment, processes, new materials and automation and control technology (Table 5).

TABLE 4. GENERAL AND SPECIFIC OMES REQUIREMENTS

Product Formation (derived from MPS)

- **Primary shaping (casting, powder processing)**
- **Finishing**

Assembly (to evolve from near term MPS automation)

- **Robots/teleoperator (high capacity arms, multi-arm coordination)**
  - **Vision**
  - End-effectors (smart, self-preserving, dexterous)
- Fastening devices (cold welding, mechanical, welding, adhesives)

Information System

- Distributed
- Hierarchical
- Machine-intelligence

Materials Handling

- Automated
- Mobile robots/teleoperators

Inventory Control

- Automated storage and retrieval system
- Quality control (automated inspection, general purpose machine-intelligent, high resolution vision module)

Specific Capabilities

- ET Reduction to feedstock
  - Milling, grinding, or melting system
  - Experimentation in:
    - Material Separation
    - Processing
  - Verification of:
    - Extraction
    - Manipulation and control mechanizations
  - Provides pure metal powders for research
- Beam builder
  - Fabrication (using feedstock from ET)
  - Assembly
  - Experimentation in
    - Materials handling
    - Storage problems

TABLE 5. GENERAL RESEARCH AND DEVELOPMENT [3]

Conceptual and experimental work on furnace designs, including Shuttle prototypes of zero-g-specific designs, and development of refractory materials resistant to molten-material/vacuum corrosion.

Experimental research on zero-g solidification processes, specifically requirements for casting processes and resultant material properties.

Conceptual and experimental research on the use of foamed materials (e.g. glass, metals) in large space structures, including tests of production methods and resulting material properties.

Research on beam welding and cutting equipment (e.g. electron beams, lasers) including equipment requirements and characteristics of output.

Development of automated control hardware and software structures, including space-rated automatic equipment, sensors, computers, teleoperators. Software options should include centralized control, distributed control, human/computer decision loops, adaptive programming, and learning ability.

B. Metals Furnaces and Casters

Research in this area (Table 6) covers the following items:

Conceptual Studies
Refractory Material Tests
Metal Solidification – Containerless Processing
Continuous Casters
Die-Casters
Prototype Furnaces
Prototype Casters — Ground and Space
Prototype Slab Cutters.

C. Ribbon and Sheet Operations

This covers (Table 7):

Rolling Mill (Ground and Space)
Electron Beam Cutters
Electron Beam Welders
Ribbon Slices (Ground and Space)
Striated Heat Pipes and Heat Pipe Fluids
Prototype Form Roller
Radiator Assembly Device
Ribbon and Sheet Integration (Ground and Space).

TABLE 6. METALS FURNACES AND CASTERS [3]

Research Item	Objective	Concept Definition	Ground Experiment	Shuttle Experiment
Conceptual studies of furnace options	To produce preliminary designs of magnetic induction, solar trough, solar paraboloid, and rotating furnaces. Includes geometric design and sizing, static and dynamic load predictions heating systems and temperature profiles, power and mass requirements, input/output systems design, estimation of maintenance, repair, and logistics, evaluation of technical uncertainty and required experiments, evaluation of operational safety, control requirements and systems, cost estimates, and comparisons of furnace options.	X		
Refractory material tests	To establish experimentally the tolerance of candidate refractory materials to molten metals and vacuum, and their thermal and magnetic properties. These materials are for casings and molds in furnaces, pipelines, continuous casters, and large piece casters. Emphasis on long-life structural materials.	X	X	
Metal solidification experiments	To investigate the material microstructure and properties resulting from solidification in zero-g, specifically for metals and alloys in various casters. Development of relationships between casting parameters (mold shapes, thermal profiles, injection pressures, thermal conductivity of mold, mold material, alloy composition) and properties (structural, thermal, magnetic, electric) of cast output. Probably requires several sets of experiments.			X

TABLE 6. (Continued)

Research Item	Objective	Concept Definition	Ground Experiment	Shuttle Experiment
Continuous caster design	To produce a preliminary design of a space-specific continuous caster for Al and Al alloy, based on earth designs, the metal solidification experiments, and the refractory material tests. Includes geometric design and sizing, structural design, choice of materials, cooling system design, thermal profiles, output handling systems, automatic monitoring and control equipment, estimation of maintenance, repair, logistics, and costs evaluation of operational safety and technical uncertainty.	X		
Die caster and large-piece caster design	To produce preliminary designs of space-specific die casters and large-piece casters, based on earth designs, the metal solidification experiments, and the refractory material tests. Casters receive molten Al, Al alloy, Fe, Fe alloy. Design includes structural design, choice of materials, estimation of injection pressures, thermal profiles, load histories, input/output systems, cooling systems, automatic monitoring and control, design of pipes, valves, and pumps, estimation of power, mass (reduced by zero-g). maintenance, repair, logistics, and costs evaluation of technical uncertainty and operational safety.	X		
Prototype furnaces	To develop useful ground prototypes of selected furnace options, if the zero-g effects can be adequately modeled or accounted for (otherwise space prototypes are required).		X	?

TABLE 6. (Continued)

Research	Objective	Concept Definition	Ground Experiment	Shuttle Experiment
Prototype casters	To develop useful ground prototypes of the continuous caster, die casters, and large-piece caster, if the zero-g effects can be adequately modeled or accounted for (otherwise space prototypes are required).		X	?
Space prototypes of furnaces and casters	To develop and integrate space-rated furnaces, pipelines, pumps, continuous casters, die casters, and large-piece caster (casters can be integrated to furnaces and pipes one at a time). This effort may require stepwise verification of furnaces, then casters, with furnaces flown several times or parked in space. Includes development of automatic control systems, human maintenance and repair techniques in space, and long-term exposure to space environment. Output returned to Earth for analysis.			X
Prototype slab cutter	To develop a ground (but space-rated) prototype of a 128 kW electron beam cutter including automatic filament replacement, cooling systems, automatic control, mechanical tracking. Tests on 2-cm-thick Al slab. Development of maintenance and repair techniques. Emphasis on reliability.		X	

TABLE 7. RIBBON AND SHEET OPERATIONS [3]

Research Item	Objective	Concept Definition	Ground Experiment	Shuttle Experiment
Prototype rolling mill	To produce design of space-specific reversing rolling mill for Al and Al alloy and to develop a ground prototype (which may be somewhat different than the design, due to its large mass). Includes structural design, estimation of power, mass, maintenance, repair, logistics, and costs, load predictions, operational safety, control requirements and systems. Prototype includes active vibration-damping, automatic control, in-space repair features, input/output systems. If possible, tests on space-cast slabs.	X	X	
Prototype electron beam cutters	To develop ground (but space-rated) prototypes of ribbon-cutting EB guns (research can benefit from development of slab cutter). Prototypes include automatic filament replacement, cooling systems, automatic control, tracking systems. Tests on Al and Al alloy ribbon. Development of maintenance and repair techniques. Emphasis on reliability and accuracy.		X	
Prototype electron beam welders	To develop ground (but space-rated) prototypes of sheet-welding guns. Prototypes include same features as EB cutters. Tests include verification of weld properties. Development of maintenance and repair techniques. Emphasis on reliability, and on accuracy of control and tracking systems and techniques.		X	

TABLE 7. (Continued)

Research Item	Objectives	Concept Definition	Ground Experiment	Shuttle Experiment
Prototype ribbon slicer	To produce space-specific design of slicing-rollers device for Al and Al alloy ribbon, and to develop ground prototype (possibly different from design, due to high mass). This is a modification of the rolling mill design and rolling mill prototype, without reversing action. Tests of longevity, reliability. Development of techniques to vary output specifications.	X	X	
Development of striated heat pipes and heat pipe fluids	To verify the feasibility and assess the requirements of striated heat pipes for radiators, including development of a heat pipe fluid compatible with aluminum and with suitable boiling temperature. Modifications to the heat pipe design should be made as needed. Effects of zero-g on heat pipe operation should be assessed (this may require space experiments).		X	?
Prototype striator	To produce space-specific design of striation-rollers device for Al ribbon, and to develop ground prototype (possibly different from design, due to high mass). This is a modification of the rolling mill and ribbon slicer prototypes. Tests of longevity, reliability, output quality.	X	X	
Prototype form roller	To develop a ground (but space-rated) prototype of the form roller to produce heat pipes and radiator pipes from Al ribbon. This design is a modification of the Grumman beam-builder form roller. Tests of reliability, output quality, ease of repair.		X	

TABLE 7. (Continued)

Research Item	Objectives	Component Definition	Ground Experiment	Shuttle Experiment
Design of radiator assembly device	To produce a preliminary design of a fully automated device to produce large radiators, including radiator pipes and manifolds. Design work uses commonality of some features with radiator assembly station, and develops similar parameters;	X		
Prototype radiator assembly device	To develop ground (but space-rated) prototype of large-radiator assembly device, including automatic control, active vibration damping, in-space repair features. Tests of reliability and output quality. Assessment of accuracy of ground simulation (high mass of radiator leads to different structural requirements on equipment).		X	
Integration of ribbon and sheet operations ground prototypes	To integrade the ground prototypes of rolling mill, EB cutters and welders, ribbon slicer, striator, form roller, and radiator assembly devices into a working, fully automated prototype sheet and ribbon operations section. Includes development of handling systems (space-rated) and automatic control devices. Tests of system, including maintenance and repair.		X	
Space prototypes of rolling mill, ribbon slicer, and striator	To develop and test space prototypes of the related rolling devices. Includes tests of active damping systems, reliability, versatility, in-space repair. Due to mass of the prototypes these devices are candidates for orbital parking. Output returned to Earth for analysis.			X

TABLE 7. (Concluded)

Research Item	Objective	Component Definition	Ground Experiment	Shuttle Experiment
Space prototypes of integrated sheet and ribbon devices	To develop space prototypes of the remaining devices in the sheet and ribbon operations section (many of the ground prototypes are already space rated) and to test these together with the space prototypes of rolling equipment. Includes tests of reliability, output quality, in-space maintenance and repair. Despite their number, these devices are not expected to mass more than one Shuttle payload; they may require additional power, however.			X

D. Insulated Wire Production

This covers (Table 8):

Glass Fiber Producer (Ground and Space)
Insulation Winder.

E. Solar Cell Production

This covers (Table 9):

State of the Art Review
Production System Studies
Zone Refining (Space)
Direct Vaporization
Ion Implantation Devices (Ground and Space)
Study and Experiments on Recrystallization (Ground and Space)
Prototype Ion Implantation Damage Annealer
Front Contact Sintering (Space)
Solar Cell Deposition
Laser Cutting of Solar Cells
Interconnect Vaporizer
Optical Cover and Substrate Production

F. Support Equipment

This covers (Table 10):

Input/Output Station
Internal Transport and Storage
Production Control System
Free-Flying Teleoperator.

G. Automation, Robotics and Machine Intelligence Systems (ARAMIS) in the SMS Program

The use of space materials will require development of highly automated processing systems. Ideally, if replication technology could be perfected to the point that systems with self-replication capability are developed, an extraterrestrial base could be established. The SMS program is an ideal area to start this work [6].

In the Orbital Materials Processing Experiment Station (OMPES), we will perform materials processing on long duration, multi-payload, multi-discipline and multi-mode missions. Dynamic behavior of complex SMS subsystems must be accounted for and controlled by smart sensors and mechanisms, operating remotely and automatically.

TABLE 8. INSULATED WIRE PRODUCTION [3]

Research Item	Objective	Concept Definition	Ground Experiment	Shuttle Experiment
Design of glass fiber producer	To produce a space-specific design of an automatic glass fiber producer. Includes investigation of suitable glass compositions available from lunar materials, alloys resistant to corrosion by molten glass and vacuum, heating systems, temperature and viscosity profiles, estimation of piston and tube loads, sizing and structural design, estimation of maintenance, repair, and costs, evaluation of technical uncertainty and operational safety, design of automatic spool threaders and control systems.	X		
Space experiment on fiber production	To investigate experimentally the effect of zero-g on the drawing of glass fibers through dies. Includes relationships between glass composition, molten glass pressure, die geometry, glass fiber diameter, drawing speed, and fiber quality. This is a small experiment; the output is returned to Earth for analysis. It may be advantageous to repeat the experiment after initial evaluation.			X
Prototype glass fiber producer	To develop ground (but space-rated) prototype of glass-fiber producer, based on preliminary design and Shuttle experiment results. Tests of equipment reliability, and of output quality (provided zero-g effects can be accounted for-otherwise in-space testing may be necessary).		X	?

TABLE 8. (Concluded)

Research Item	Objective	Concept Definition	Ground Experiment	Shuttle Experiment
Prototype insulation winder	To develop a ground (but space-rated) prototype of an insulation winder. This is a modification of an earth wire wrapper, adapted to vacuum operations and use of spools of glass fibers. Prototype includes automatic loading systems for spools. Tests of equipment reliability, ease of in-space repair.		X	

TABLE 9. SOLAR CELL PRODUCTION [3]

Research Item	Objective	Concept Definition	Ground Experiment	Shuttle Experiment
Continuous review of developments in solar cell production techniques	To review the large number of current research findings on solar cell production alternatives (published by many research teams), and to assess the applicability of these developments to space operations.	X		
Conceptual studies of solar cell production systems	To investigate alternative processes and production sequence for the manufacture of solar cells. Includes preliminary operations layouts and designs, estimation of mass, power, maintenance, repair, logistics and costs, evaluation of technical uncertainty and operational safety, ease of automation and repair, output quality, and comparison of options. Definition of technology evolution programs for alternatives.	X		
Conceptual study and space experiments on zone refining	To investigate, theoretically and experimentally, the effect of zero-g on the zone refining process. Includes determination of optimum zone refining parameters to maximize zone travel rate and minimize number of passes required for purification, and study of effects of types and concentrations of impurities on refining requirements. Output returned to Earth for analysis. Equipment is expected to be small.	X		X
Prototype zone refiner	To develop a prototype zone refiner to purify metallurgical grade Si from the Moon to semiconductor grade. This is a ground device, if the zero-g effects can be accurately modeled or		X	?

TABLE 9. (Continued)

Research Item	Objective	Concept Definition	Ground Experiment	Shuttle Experiment
	accounted for (otherwise, a space prototype is required). Prototype includes feed and handling systems, heating and cooling systems, quality control sensors and automatic control systems. Tests of effects of operating parameters on output quality. Emphasis on maximum automation ease of in-space repair.			
Space prototype of zone refiner	To develop and test a space-rated prototype zone refiner. This device may require a power source beyond the Shuttle's, and may benefit from in-orbit parking between test runs. Output is returned to Earth for analysis.			X
Conceptual study and space experiments on direct vaporization	To investigate, theoretically and experimentally, the effects of zero-g on direct vaporization of Al, Si, SiO_2, and to produce preliminary designs of direct vaporization devices. Includes evaluation of effects of deposition parameters (e.g. pressure of vapor, deposition surface temperature and morphology, thermal profiles) on properties of deposited output.	X		X
Prototype direct vaporization devices	To develop ground prototypes of DV devices for Al, Si, SiO_2, if zero-g effects can be accurately modeled or accounted for (otherwise space prototypes are required). Includes development of thermal belt, EB tracking control, slab feeding mechanisms, quality control systems, maintenance and repair techniques, cooling systems. Tests of equipment reliability and output properties.		X	?

TABLE 9. (Continued)

Research Item	Objective	Concept Definition	Ground Experiment	Shuttle Experiment
Prototype ion implantation devices	To develop a ground (but space-rated) ion implantation device for boron and phosphorus, from existing equipment. Emphasis on deeper penetration (2-5 microns), full automation, longevity of equipment. Tests of equipment reliability, doping profiles, implantation damage. Assessment of compatibility with DV of silicon.		X	
Conceptual studies and experiments on recrystallization	To investigate, theoretically and experimentally on the ground, the feasibility and requirements for recrystallization of direct-vaporized layers of silicon. Includes studies of pulse and scan recrystallization, effects of silicon morphology, pulsing/scanning parameters, and environmental factors on recrystallized output. Production of preliminary designs for recrystallization devices, and of designs for space experiments.	X	X	
Space experiments on recrystallization	To investigate the effects of zero-g on recrystallization of silicon layers. Equipment is expected to be small. Output returned to Earth for analysis.			X
Prototype recrystallization devices	To develop ground prototypes of recrystallizers if zero-g effects can be accurately modeled or accounted for (otherwise space prototypes are required). Emphasis on automation, reliability, ease of repair. Tests of output quality.		X	?

TABLE 9. (Continued)

Research Item	Objective	Concept Definition	Ground Experiment	Shuttle Experiment
Space experiments on ion implantation damage anneal	To assess the effect of zero-g on pulsed-beam annealing of ion implantation damage. Equipment is expected to be small. Output is returned to Earth for analysis.			X
Prototype ion implantation damage annealer	To develop a ground prototype of an ion implantation damage annealer, based on existing designs, if the zero-g effects can be accurately modeled or accounted for (otherwise a space prototype is required). Emphasis on automation, reliability, ease of repair. Tests of output quality.		X	?
Prototype of direct vaporizer with mask and mask cleanup device	To modify ground prototype of direct vaporizer for Al to operate through a shadow mask (to deposit top contact pattern). Includes development of space-rated mask with long life, and of device to brush deposited Al from mask automatically. Tests of output quality, equipment reliability.		X	
Space experiment on front contact sintering	To investigate the effect of zero-g on pulsed-beam sintering of solar cell front contacts. Equipment is expected to be small. Output is returned to Earth for analysis. Includes variation of sintering parameters.			X
Prototype front contact sintering device	To develop ground (or space, if needed) prototype of top contact sintering device, including tracking systems, in-space repair features, quality control systems, automatic control. Tests of equipment reliability and output quality.		X	?

TABLE 9. (Continued)

Research Item	Objective	Concept Definition	Ground Experiment	Shuttle Experiment
Integrated space prototypes of solar cell deposition	To develop integrated, space-rated prototypes of thermal belt, direct vaporizers for Al and Si, ion implanters for boron and phosphorus, masking of front contact, recrystallizers and ion implantation damage anneal, and front contact sintering. Includes automated control, quality control, input/output and handling systems, tests of in-space maintenance and repair techniques. Output (operational solar cells without glass layers) is returned to earth for analysis. Equipment estimated at less than one Shuttle payload, not including power and heat waste systems.			X
Conceptual study and experiments on laser cutting of solar cells	To investigate, theoretically and experimentally on the ground, the use of lasers to cut solar cell material. Includes effects of cutting parameters (wavelength, focusing, tracking speed, power) on resulting degradation of cell near cut.	X	X	
Prototype solar cell crosscutter and longitudinal cutter	To develop ground prototypes of laser cutting systems for solar cells, including automatic control, tracking systems, quality control. Tests on space-produced solar cell material or equivalent. Emphasis on equipment accuracy and reliability.		X	

TABLE 9. (Continued)

Research Item	Objective	Concept Definition	Ground Experiment	Shuttle Experiment
Prototype direct vaporizer for interconnects	To develop a ground (but space-rated) prototype of a direct vaporizer to produce 50-micron thick Al sheet, including systems to roll up the output, automatic controls, cooling systems for EB guns. This device is a modification of other DV prototypes. Emphasis on reliability, ease of repair, automation.		X	
Prototype solar cell interconnection device	To develop ground prototype of solar cell interconnection device (same as panel interconnection device). This is a sophisticated mechanical device, with tight tolerances. Emphasis on automation, reliability. Includes interconnect feed systems, sensor and alignment systems, electrostatic bonders. Tests on simulated solar cells and panels. Possible applications on Earth.		X	
Conceptual studies of optical cover and substrate production options	To review existing literature and to produce preliminary designs of production options for SiO_2 layers, including direct vaporization and separate sheet production followed by electrostatic or laser bonding. Includes assessment of feasibility and operational requirements. Preliminary designs include thermal profiles, load histories, power and mass requirements, estimates of maintenance, repair, logistics, and costs, assessment of reliability and output quality.	X		

TABLE 9. (Continued)

Research Item	Objective	Concept Definition	Ground Experiment	Shuttle Experiment
Prototype panel alignment and insertion device	To develop a ground (but space-rated) prototype of the panel alignment and spare panel insertion device. Includes full automation including sensing and control, in-space maintenance and repair feature, maintenance and repair estimates. Tests of accuracy and reliability of equipment, and assessment of modifications required for zero-g use.		X	
Prototype kapton tape applicator	To develop a ground prototype of a kapton tape applicator to produce structurally connected solar array segments. Includes automatic sensing and control, tracking and loading systems, in-space repair features. Tests of reliability of equipment, using simulated solar cell panels. Assessment of modifications required for zero-g.		X	
Prototype array segment packager	To develop a ground prototype of the array segment packager. Includes full automation (sensing, control, tracking), in-space repair features. Tests on simulated arrays, assessing equipment reliability, output quality, modifications required for zero-g.		X	
Integration of cell inter onnection and panel/array buildup prototypes	To integrate the ground prototypes of devices to produce complete array segments for deposited solar cell material. Includes continuous processes, automated control, quality control, input/output and handling systems, maintenance and repair features. Tests on simulated or		X	

TABLE 9. (Concluded)

Research Item	Objective	Concept Definition	Ground Experiment	Shuttle Experiment
	actual deposited solar cell material. Emphasis on reliability, ease of repair, integrated control. Possible applications on earth.			
Integrated space prototypes of cell interconnections and panel/array buildup devices	To space-rate and test the integrated prototypes for production of array segments. Equipment is expected to fill less than a Shuttle payload, not including power and heat waste systems. Output returned to Earth for analysis.			X
Space prototype of complete solar cell production strip	To develop and test full-scale prototype of 104 m-long solar cell production strip. Includes structural integration of components, full automation, tests of in-space repair and maintenance, return of output to Earth for analysis. Equipment requires more than one Shuttle payload, in-space assembly and checkout. Can be used to produce solar arrays for space use.			X

TABLE 10. SUPPORT EQUIPMENT [3]

Research Item	Objective	Concept Definition	Ground Experiment	Shuttle Experiment
Design & ground tests of input/ output station	To produce a design of the cargo and personnel docking facilities, including structural design of damped impact-resistant structure, docking latches, manipulator cranes (with life-support pads, control computers, end effectors), androgyne docking rings, airlocks, and pressurized tunnel. Also ground tests on equipment components, stressing reliability, longevity, ease of repair.	X	X	
Design & Ground Tests of internal transport & storage devices	To produce a design for magnetic cart internal transport system and for the internal storage device. Internal transport includes track, carts, magnetic drive components, control actuators, sensors, routing control hardware & software, & cart/cargo interfaces. Internal storage device includes holding racks, drive systems, input/output devices, labeling systems control hardware & software. Design work includes load predictions, geometric design & sizing, estimates of maintenance & repair, evaluation of operational safety. Tests of component longevity, reliability, ease of repair. Evaluation of modifications required for zero-g use.	X	X	
Design & ground tests of crawlers	To produce & ground test designs for solar cell factory crawlers, including structural design, drive systems, tracks & support structure, sensors, computer hardware and	X	X	

TABLE 10. (Continued)

Research Item	Objective	Concept Definition	Ground Experiment	Shuttle Experiment
	software, communications, manipulators, end effectors. Crawlers are specialized to the sections they service, & therefore require variations on a basic design. Tests of component accuracy and reliability, & development of ground prototypes. Design of control software, crawler/internal transport interface, maintenance & repair techniques. Evaluation of modifications needed for zero-g use.			
Design & ground tests of production control systems	To investigate production control options and to produce preliminary designs of space-rated computers, monitoring sensors, data transmission systems, status display systems, routing control software, inventory control software, maintenance & repair scheduling software, computer hierarchies, damage-tolerance techniques (e.g. redundancy, distributed controls with self-reconfiguration), management structures. Simulations of various software options & ground tests of hardware, leading to full-scale simulation operations, including failures & changes in production objectives.	X	X	
Design & ground tests of free-flying teleoperators	To produce a design for a versatile free-flying hybrid teleoperator for repair & maintenance operations in the solarcell factory. Based on the Shuttle Teleoperator Retrieval System, this design includes multipurpose manipulators & end effectors, navigation systems, thrusters.	X	X	

TABLE 10. (Concluded)

Research Item	Objective	Concept Definition	Ground Experiment	Shuttle Experiment
	communications hardware, sensors, computers, power supplies, propellant tanks, & a remote control station. Design work includes definition of specific tasks & requirements, component design, system integration, development of complex software structures (including telemetry links to remote computers). Tests of components (emphasis on reliability) & simulations of integrated functions. Development of multi-media control station & communications links (video, audio, tactile). Assessment of modifications required for space use. May have some earth applications.			
Space prototype of free-flying hybrid teleoperator	To develop & test a space-rated prototype of the free-flying hybrid teleoperator. Tests of all six command modes, device versatility and accuracy, operating range (time, distance, physical environment), operator learning curves. Tests can include teleoperator operations on structure/transport systems/ etc. prototypes developed earlier, & should include tests in simulated thermal & radiation environment of the solar cell factory. Teleoperator has potential uses in near-term space operations.			X

Automation is required to reduce size and mass of the materials handling and storage system. New technology for this requires modeling of the search and recognition function, development of special sensors (visual and tactile) and development of flexible gripping and transporting mechanisms.

New technology is also required for detection of higher probability failure modes and provisions for appropriate responses in the handling system.

Replacement of the human operator's monitoring and remote control functions by fully automated control will depend on the degree to which the system will incorporate ARAMIS and fault-tolerant design techniques.

A general schematic of an SMS remote control and automated operation is shown in Figures 9 and 10. A work breakdown structure for autonomous system research and development is shown in Figure 11 and a systems hierarchy is given in Figure 12. Using ARAMIS in the SMS program to optimize the overall systems and subsystems operations is complex because of the large number of levels in the decision hierarchy.

The objective of ARAMIS development would be to:

1) Increase productivity

2) Reduce program cost by:

   a. Eliminating excessive telemetry/stored image data.

   b. Reducing the quantity of manpower/equipment for ground control.

ARAMIS will provide alternatives to ground-based intervention and control of automated SMS, even under anomalous operating conditions and contingencies.

Areas of ARAMIS application include:

1) Automatic failure detection, isolation and repair of SMS subsystems and components.

2) Automatic verification and validation of system status and functioning after initial deployment, in-space servicing or fault correction.

3) Recognition and correction of anomalous processing phenomena.

Further development is needed to apply techniques of ARAMIS to these tasks thereby reducing dependence on ground-based monitoring and control by a human control operator.

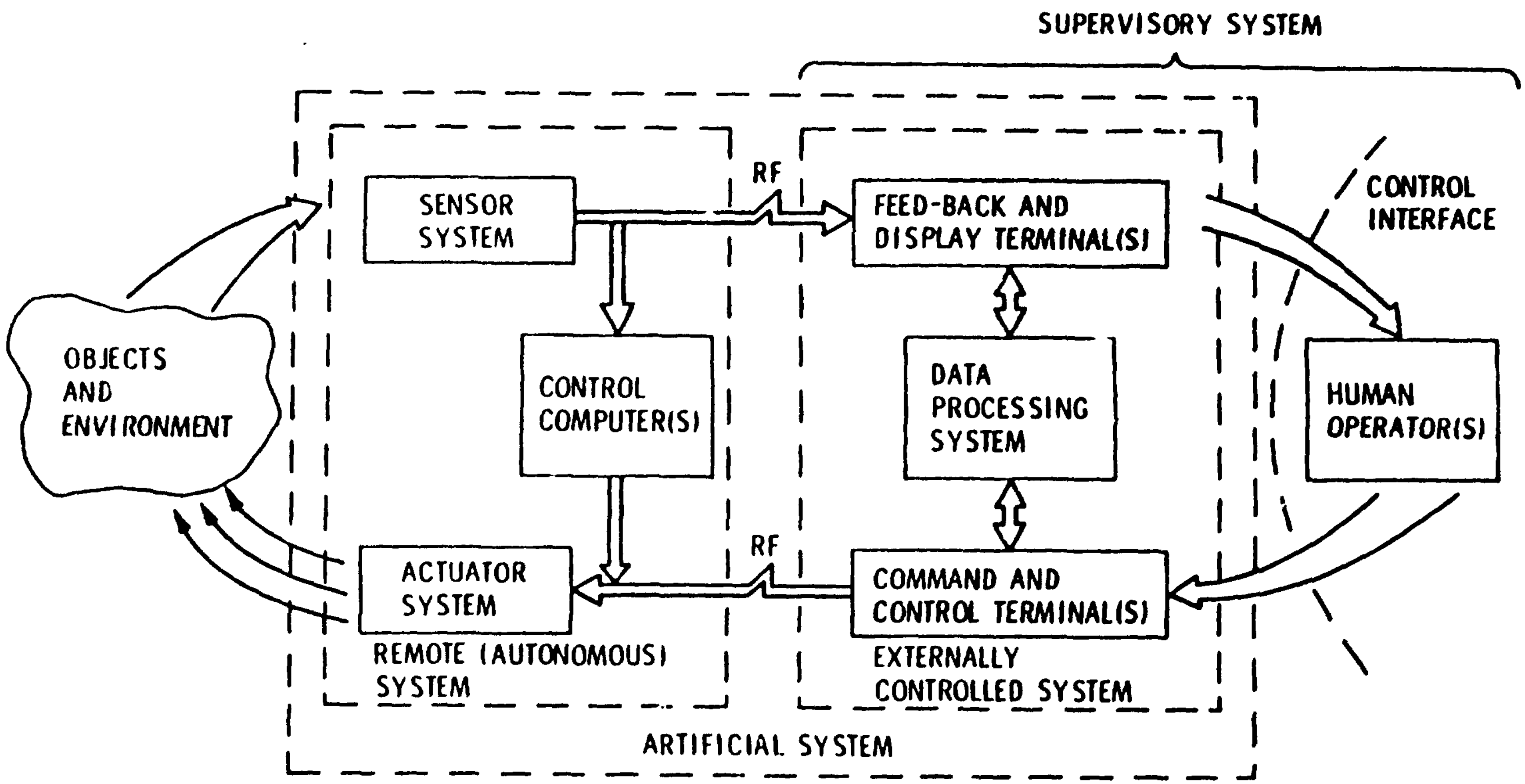

Figure 9. Automation model (5).

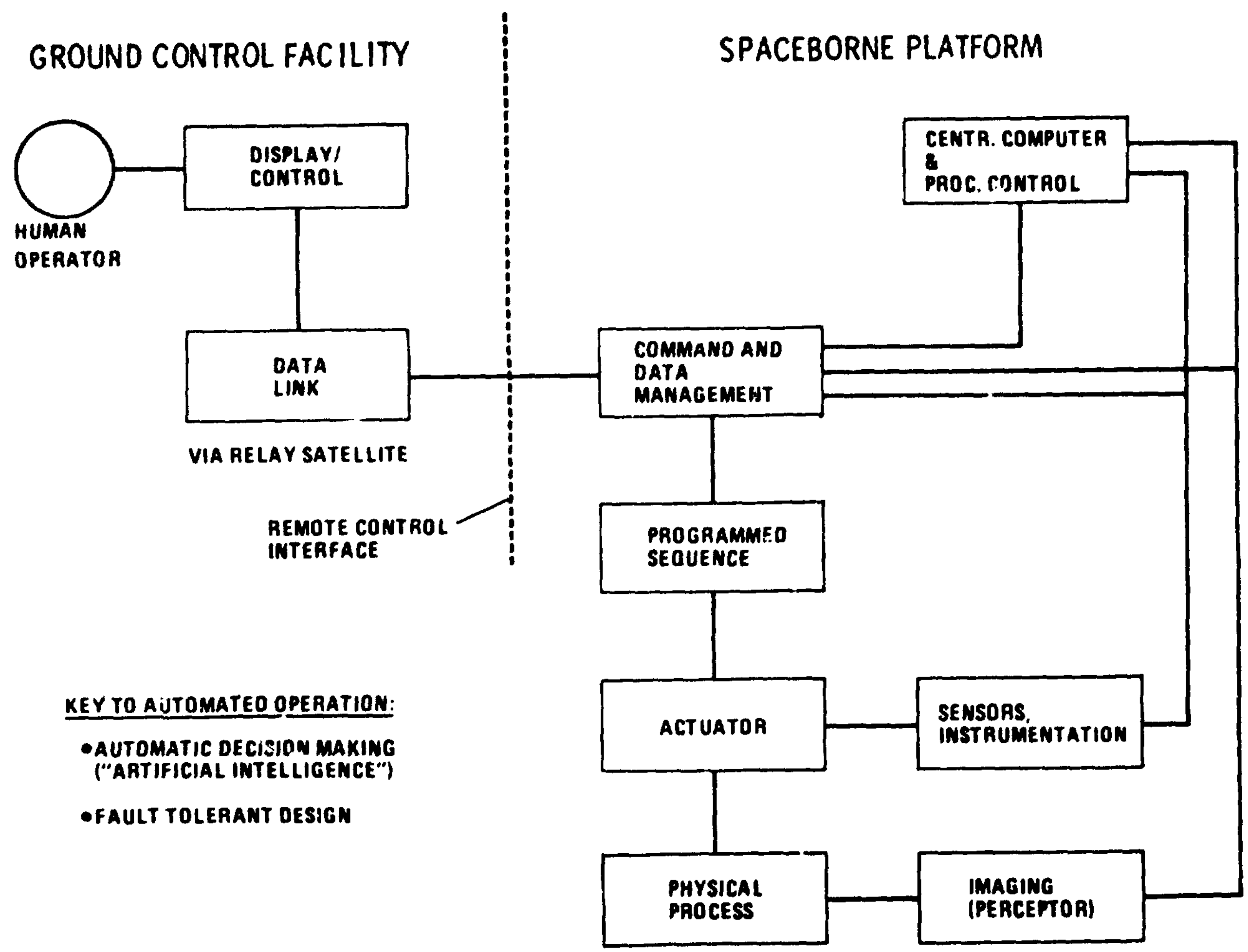

Figure 10. Schematic of SMS remote control and automated operation.

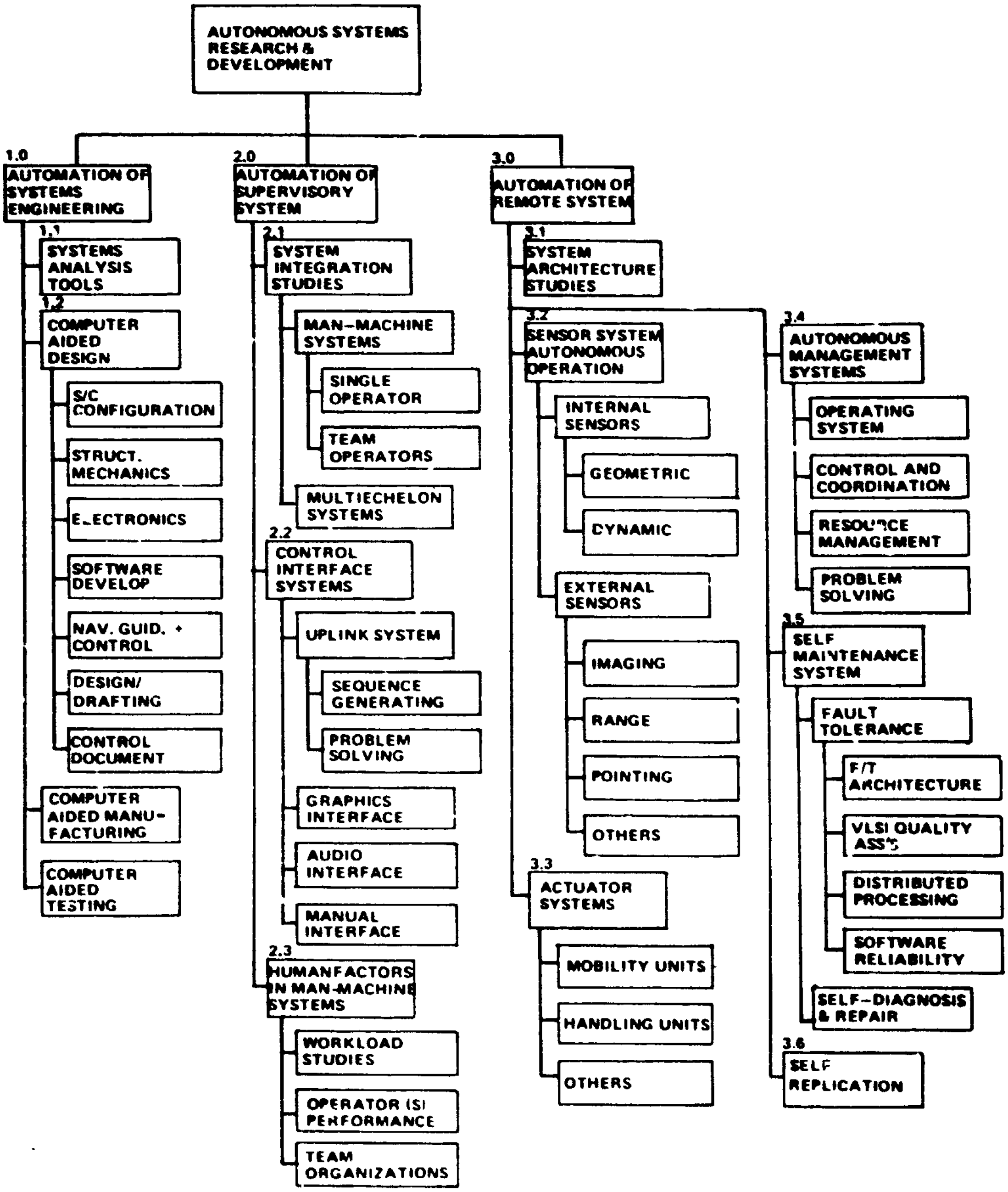

Figure 11. Work breakdown structure for autonomous systems R & D.

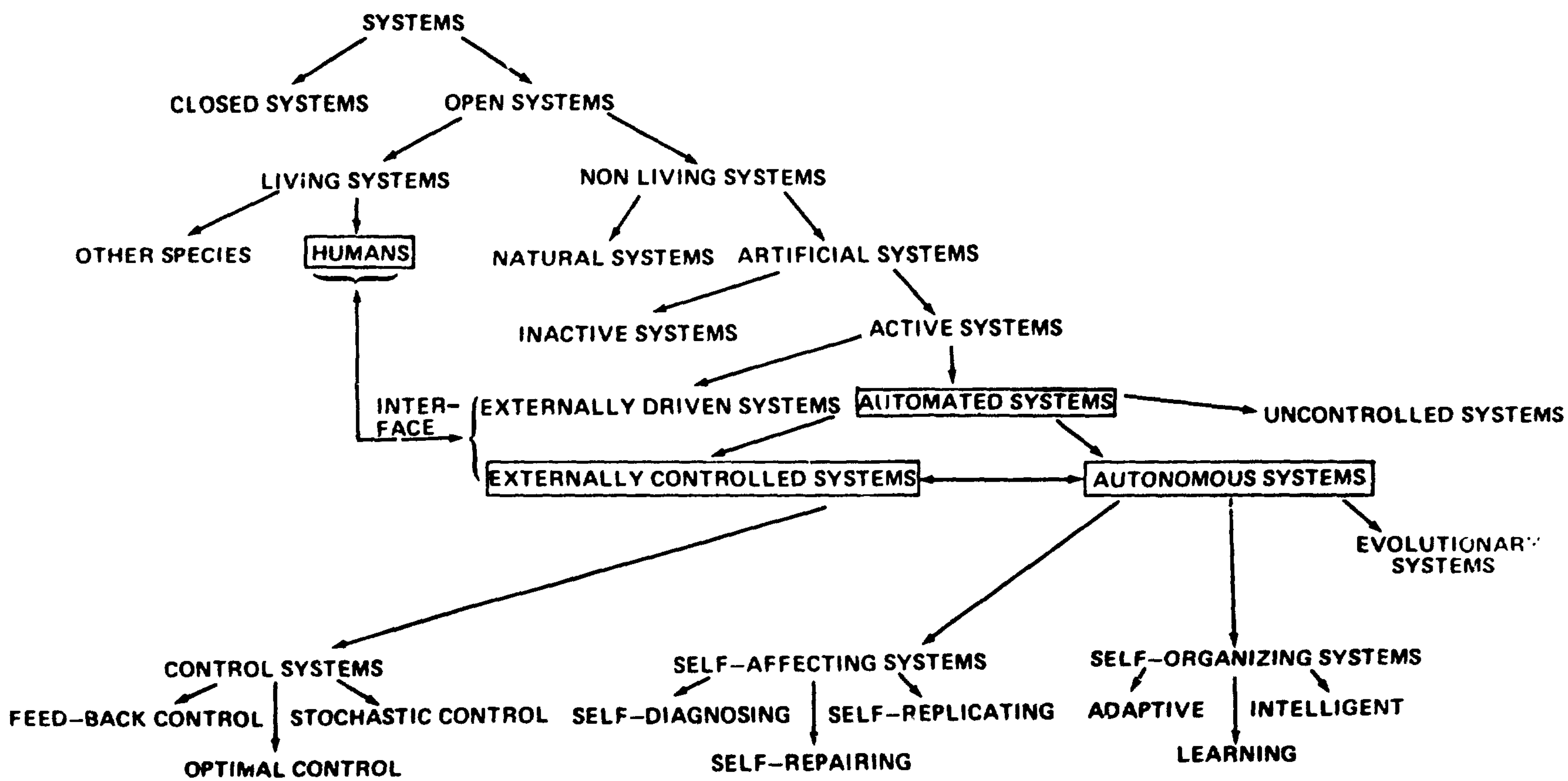

Figure 12. A hierarchy of systems (5).

Tasks involved in implementing recognition and correction of anomalous processing phenomena include:

1) Detailed definition and modeling of the human operator's response functions in monitoring, interpreting, and correcting processing phenomena (including visual perception).

2) Development of instrumentation and computer vision techniques.

3) Synthesis of automatic control based on feedback signals from process instrumentation and sensors.

4) Verification of automated operation by laboratory simulation of the process.

It is appropriate to look at SMS ARAMIS requirements in context with present NASA ARAMIS plans covering a variety of program requirements. A first-cut at goals for broad system capabilities to be achieved by the end of the 1980's can be derived from the overall NASA Mission Model and the NASA Technology Development Model.

Other applicable programmatic information can be derived from the list of Selected Applicable Documents.

A list of capability goals by the end of the 1980's is given in Table 11.

H. Early Studies and Development Tasks

This covers the following program activities:

1) Study Tasks (Table 12)

   a. Systems Studies

   b. Material Processing and Trade Studies

   c. Technology Studies.

2) Technology Development Tasks (Table 13)

3) Shuttle Technology Experiments (Table 14).

TABLE 11. BROAD AUTOMATION SYSTEM CAPABILITY GOALS BY THE END OF THE 1980's

(1) Remote System Capabilities include by 1990 the system integrated capability of the subsystems:

- (1a) Autonomous pointing and navigation (1986);
- (1b) Autonomous on-board resource management (1986);
- (1c) Autonomous self-test and maintenance for extended time duration (1986); and
- (1d) Multi-remote system coordination (1988)

(2) Supervisory System Capabilities include by 1990 the system integrated capability of:

- (2a) An Uplink Process Control System; and
- (2b) High level control interface systems for real time interactive, remote operations and monitoring including graphics, audio, and manual interface.

(3) Systems Engineering Capabilities include by 1990:

- (3a) Automated techniques for systems analysis and evaluation
- (3b) Computer aided design for all disciplines with a common control documentation base
- (3c) Computer aided testing with tie-in to control documentation base.

TABLE 12. PROPOSED STUDY TASKS

A. System Study Tasks

OMPES Concept definition
OMPES Materials program definition
OMES Concept definition
OMES Production program definition

B. Materials Processing and Trade Study Tasks

Oxygen production options
Silicon refining options

C. Technology Study Tasks

Oxygen ion electric thrusters	Electrolysis of silicates
In-space oxygen liquefiers	Foamed glass production
Mass driver accelerator	VAC Distillation of silicates
Mass catcher	Fiberglass production from silicates
Large space radiators	Vapor deposition of metals
Space Manufacturing robotics	Vapor deposition of glass
MBE Production of solar cells	

TABLE 13. PROPOSED TECHNOLOGY DEVELOPMENT TASKS

Technology Development	Proposed Tasks
Earth processing & mfg technology development	Electrolysis of silicates Foamed glass production Fiberglass prod from silicates Vapor deposition of metals
Oxygen ion electric thruster development	Oxygen ion electric thrusters
Propellant production technology development	In-space oxygen liquefiers Large space radiators
Subsequent process & mfg technology development	MBE production of solar cells Vac distillation of silicates Vapor deposition of glass
Automated processes development	Space mfg robotics

TABLE 14. SHUTTLE TECHNOLOGY EXPERIMENTS

Vapor deposition of aluminum & iron on a molybdenum strip

Perform vacuum deposition in zero-g
Demonstrate metal separation from Mo sheet following deposition

Melting & casting of aluminum, iron & sendust (85% Fe-10% Si-5% Al)

Perform casting at zero-g & low controlled g
Demonstrate both permanent metal mold & sand-plaster mold casting

Reacting SiO_2 to form high-purity silica glass

Manufacture of thin silica sheet & glass filaments

Manufacturing of foamed glass elements from simulated native lunar glass, including structural shapes & waveguide sections

Electroplating aluminum with copper in zero-g

Vapor depositions of aluminum on silicon wafers through maskant

Liquefaction of oxygen in zero-g & 1/6 g

Development of ion-electric thrusters using oxygen propellant

Research on large space (and lunar surface) radiators

Research on robotics suitable for general purpose space industrialization

Production of solar cells by molecular beam epitaxy (MBE)

Production of foam glass from lunar type silicates

Vacuum distillation and dissociation of lunar type silicates

Production of fiberglass filaments from lunar type silicates

Vapor phase deposition of thick sheet and plate of iron and aluminum alloys

Vapor deposition of thin silica glass for solar cell substrates and covers

TABLE 15. IMMEDIATE RESEARCH NEEDS FOR UTILIZATION PLANNING OF LUNAR MATERIALS [4]

1. Physical Separations:

   Verify degrees and rates of physical separabilities of distinctive components (major minerals, free-iron grains, amorphous combinations) by direct and combined means (magnetic, electrostatic, sieving, crushing, vibration, others). Use analog materials and very limited quantities of lunar samples.

2. Glass and Ceramics:

   Apply the extensively developed technologies and basic materials knowledge of terrestrial glasses and ceramics to determine the products and production characteristics for the direct and early use on the moon and in space of bulk lunar soils, physical separates (mineral, vitreous and metallic), and chemical separates of the soils.

   Verify the indicated degree and rate of recovery of gasses from lunar soils which will be released by heating in melting operations and by means of low energy desorption processes (extreme oxidizing and reducing conditions at low gas pressures).

3. Chemical Processing:

   Demonstrate the electrorefining and alloying of metallic "free" iron.

   Demonstrate with simulated lunar soils on the bench-scale level the HF acid leach, ammonium salt fusion and mixed acid leaching based on adaptations of well known terrestrial industrial and laboratory procedures for extracting the major oxides and elements (O, Si, Al, Mg, Ti, Ca Fe) from a wide range of bulk lunar soils. Rates of throughputs, recycle efficiencies, and separability data will be determined in these demonstration experiments. Implications of reagent make-up from native lunar materials will be determined.

   Investigation of sodium or electrochemical reduction of a) raw or beneficiated lunar soil fractions, or b) chemical intermediates from hydrochemical processing of lunar soils

   Literature studies of methods to recover minor and trace element fractions obtainable from immiscible liquid extraction of magmas (molten fluids) such as would occur in glass production.

4. Systems Analyses and Operations Tests:

   Examine economic attractiveness of the manufacturing of machines of production (including materials processing devices) and products by a minimal mass facility from native lunar iron, glass and ceramics and

TABLE 15. (Concluded)

derived products. Facility should be based on current state-of-the art of semi-automatic numerical production and remote monitoring.

Theoretically examine the use of silane based fuels for use in moon-earth liquid rockets. Determine whether or not lunar hydrogen can be obtained in adequate quantities to transport lunar materials back to low earth orbit, significantly reduce earth-life requirements of propellants, and provide feedstock in low earth orbit for materials industries

Examine construction by large volume living and manufacturing chambers under the lunar surface by melting of the lunar soil into self-sealed lava tubes.

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APPENDIX A.

ORGANIZATION OF SPACE MATERIAL SYSTEMS PROGRAM

The program was organized by the previous NASA administrator to be presented to the present administrator late in 1981. This appendix shows the organization and participating members of the two planning working groups.

National Aeronautics and
Space Administration

Washington, D.C.
20546

Office of the Administrator

NOV 24 1980

TO: R/Associate Administrator for Aeronautics and Space Technology
E/Associate Administrator for Space and Terrestrial Applications

FROM: A/Administrator

SUBJECT: Organization of a Space Materials Systems Program

It has become increasingly clear that space materials may be an important resource for future U.S. terrestrial needs as well as for NASA's future space missions. Therefore, it is appropriate to focus on those capabilities required for establishing and carrying out the missions, as defined in the enclosed goal and program description, which will generate and evaluate the necessary technologies. Such a program plan, Space Materials Systems, should be formulated by the Materials Processing in Space Division of OSTA in cooperation with the Space Systems and Research and Technology Divisions of OAST. The plan should also be coordinated with the other NASA program offices.

The new Space Materials Systems program should be supported by ongoing activities in program offices as described in the enclosure.

Overall space mission responsibilities will be assigned shortly.

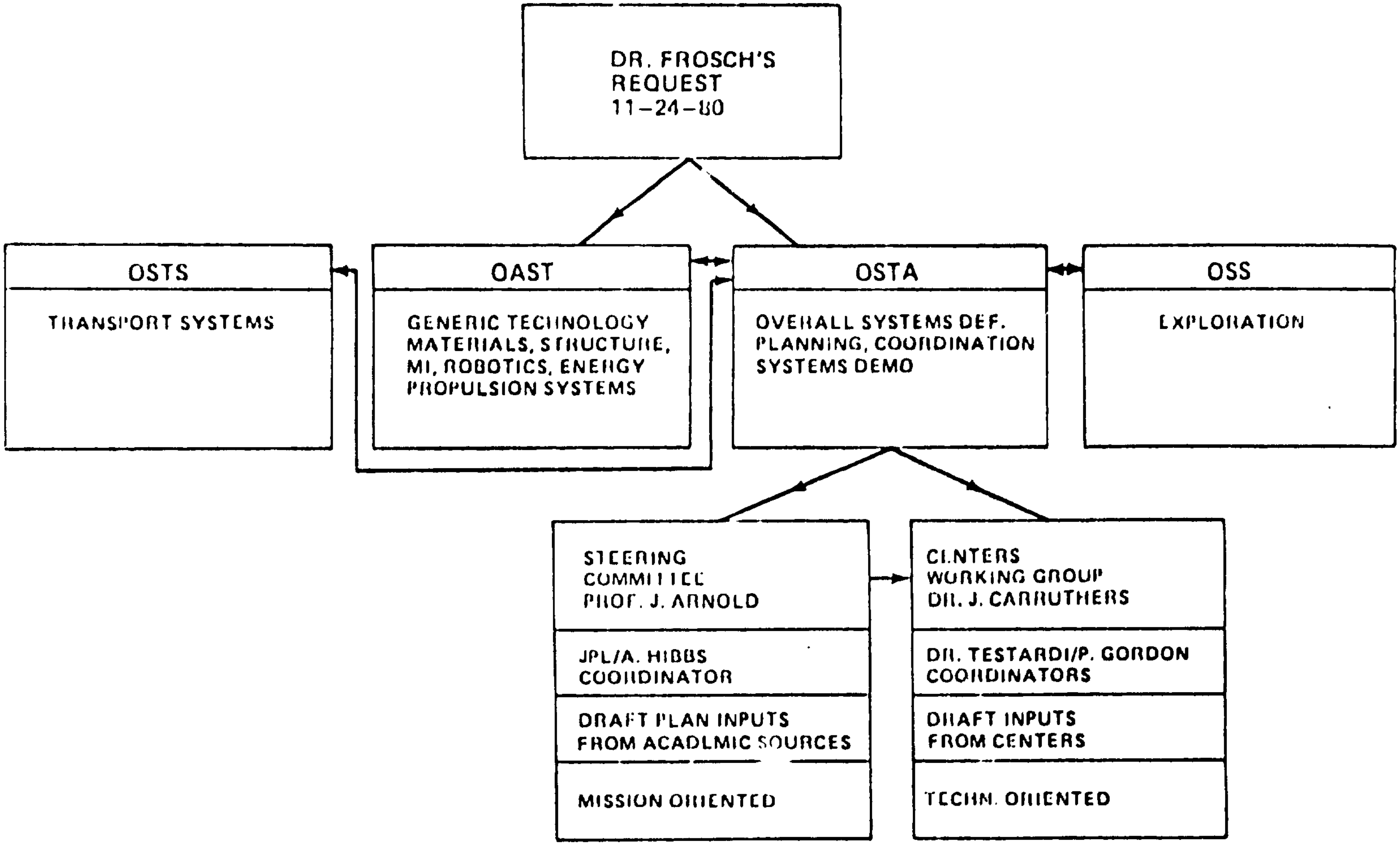
Please prepare a program plan for approval of the NASA Administrator by August 1, 1981. The plan should include technical background and rationale, organizational structure of the program with responsibilities and manpower requirements, implementation strategy for technology and space missions, organizational interfaces with other program offices, NASA Centers and external programs and constituencies, and an assessment of funding requirements from estimated costs and schedules.

The new program in Space Materials Systems could be a vital component of our future space missions; it may also provide important alternate sources for our limited terrestrial resources in the future.

Robert A. Frosch

Enclosure:
Space Materials Systems: Goal and Program Description

cc:
Officials-in-Charge of Headquarters Program and Staff Offices
Directors, NASA Field Installations
Director, Jet Propulsion Laboratory



ORGANIZATION OF SPACE MATERIALS SYSTEMS PROGRAM PLANNING

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OAST	RS-5/MR. S. R. SADIN RTM-6/MR. L. HARRIS
OSTS	MTC-3/MR. I. BEKEY
OSS	SL-4/MR. B. FRENCH

CENTER REPRESENTATIVES

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GSFC	DR. A. TIMOTHY (8-344-5677)

Attendees at the First Meeting of the
SPACE MATERIALS SYSTEMS PROGRAM

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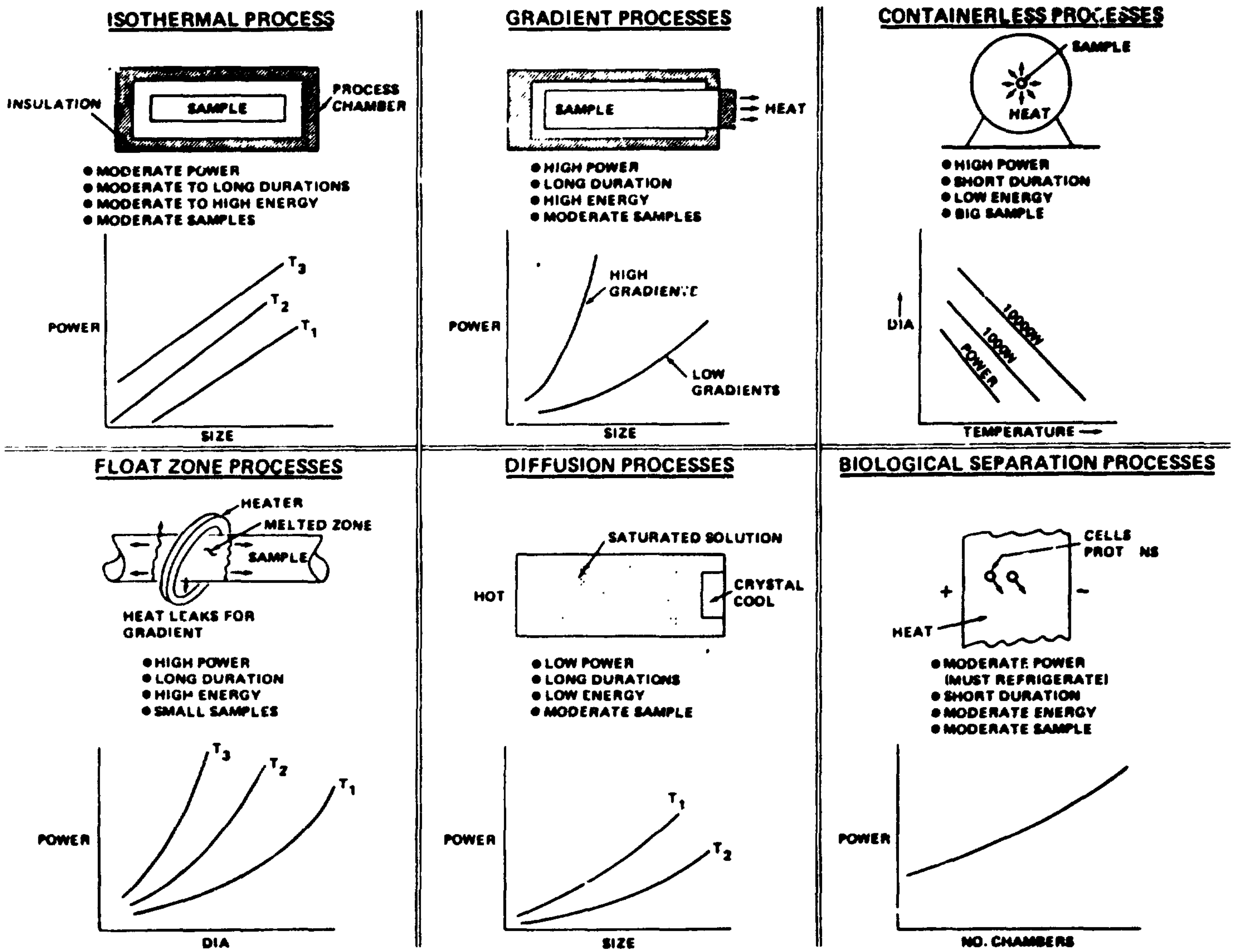
APPENDIX B.

PRESENT MPS PROGRAM

The figures and listings which constitute this Appendix show the present MPS program.



MPS REQUIREMENTS ENGINEERING OVERVIEW

MPS-PRESENT MSFC MANAGED ACTIVITIES

A. Crystal Growth

Growth of Solid Solution Crystals (Davidson)

Semiconductor Material Growth in Low-G Environment (Crouch)

Epitaxial Growth of Single Crystal Films (Lind)

Advanced Methods for Preparation and Characterization of Infrared-Detector Materials (Lehoczky)

Characterization of Semiconductor Materials (Gillies)

Marangoni Effect in Crystal Processing (Fowle)

Defect Chemistry and Characterization of (Hg, Cd) Te (Vydyanath)

Direct Observation of Interface Stability (Tiller)

Vapor Growth of Alloy-Type Semiconductor Crystals (Wiedemeier)

Fluid Dynamics and Thermodynamics of Vapor Phase Crystal Growth (Wiedemeier)

HgI_2 Crystal Growth for Nuclear Detectors (Schnepple)

Vapor Phase of PbSnTe (Zoutendyk)

Ultrahigh Vacuum Semiconductor Thin-Film Technology (Grunthaner)

Ultravacuum Vapor Epitaxial Growth of Silicon (Neugebauer)

Efficient Solar Cells by Space Processing (Schmidt)

Solution Growth of Crystals in Zero-Gravity (Lal)

Crystal Growth in a Spaceflight Environment (Shlichta)

Float Zone Experiments in Space (Verhoeven)

Surface Tension-Driven Convection Phenomena (Ostrach, Mann)

Thermocapillary Flows and Their Stability: Effects of Surface Layers and Contamination (Davis)

Analytical Float Zone Experiments Systems (AFZES) Phase B Study (Fowle)

MPS-PRESENT MSFC MANAGED ACTIVITIES (Continued)

B. Metals, Alloys, and Composites

Aligned Magnetic Composites (Larson)

Directional Solidification of Magnetic Composites (Pirich)

Ultimate Intrinsic Coercivity $SmCo_5$ Magnet (Das)

The Growth of Metastable Peritectic Compounds (Larson)

Undercooling Studies in Metastable Peritectic Compounds (Lacy)

Liquid Phase Miscibility Gap Materials (Gelles)

Directional Solidification of Monotectic and Hypermonotectic Aluminum-Indium Alloys Under μ-g (Potard)

Studies of Model Immiscible Systems (Lacy)

Comparative Alloy Solidification (Johnston)

Directional Solidification of Monotectic Alloys (Johnston)

The Influence of Gravity on the Solidification of Monotectic Alloys (Hellawell)

Liquid Metal Diffusion in Solubility Gap Materials (Pond)

Ultrapure Metals Preparation in Space (Bunshah)

Measurement of the Properties of Tungsten at High Temperatures (Margrave)

Electrotransport of Solutes in Refractory Metals (Schmidt)

Crystal Nucleation in Glass-Forming Alloy and Pure Metal Melts Under Containerless and Vibrationless Conditions (Turnbull)

A Proposal to Measure the Viscosity of Molten $Pd_{78}Si_{16}Cu_6$ (Lord)

Science Requirements Definiton Study for the Electromagnetic Containerless Processing Module (Frost)

Containerless Processing Technology (Oran)

Uniform Dispersions by Crystallization Processing (Uhlmann)

MPS-PRESENT MSFC MANAGED ACTIVITIES (Continued)

Solid Electrolytes Containing Dispersed Particles: The Effect of a Dispersed Second Phase on the Ionic Conductivity of Solid State Electrolytes (Wagner)

Foam Copper (Pond)

Dendritic Solidification at Small Supercoolings (Glicksman)

Solidification Processes Involving Solutes (Glicksman)

Direct Observation of Interface Stability (Tiller)

C. Glasses, Ceramics, and Refractories

Containerless Processing of Optical Glass in Space (Happe)

Fining of Glasses in Space (Weinberg)

Physical Phenomena in Containerless Glass Processing (Subramanian)

Glass Fining Experiments in Zero Gravity (Wilcox)

Crystal Nucleation in Glass-Forming Alloy and Pure Metal Melts Under Containerless and Vibrationless Conditions (Turnbull)

A Proposal to Measure the Viscosity of Molten $Pd_{78}Si_{16}Cu_6$ (Lord)

Containerless Processing Technology (Oran)

Science Requirements Definition Study for the Electromagnetic Containerless Processing Module (Frost)

Fusion Target Technology (Wang)

Glass Shell Manufacturing in Space (Nolen)

The Upgrading of Glass Microballoons (Dunn)

Advanced Containerless Processing Technology (Wang)

D. Fluids, Transports, and Chemical Processes

Production of Large-Particle-Size Monodisperse Latexes in Microgravity (Vanderhoff)

Fluid Dynamics and Thermodynamics of Vapor Phase Crystal Growth (Wiedemeier)

MPS-PRESENT MSFC MANAGED ACTIVITIES (Continued)

Physical Phenomena in Containerless Glass Processing (Subramanian)

Fining of Glasses in Space (Weinberg)

Glass Fining Experiments in Zero Gravity (Wilcox)

Contact and Coalescence of Viscous and Viscoelastic Bodies (Uhlmann)

Uniform Dispersions by Crystallization Processing (Uhlmann)

Marangoni Effect in Crystal Processing (Fowle)

Mass Transfer in Electrolytic Systems Under Low Gravity Conditions (Riley)

Surface Tension-Driven Convection Phenomena (Ostrach, Mann)

Thermocapillary Flows and Their Stability: Effects of Surface Layers and Contamination (Davis)

Investigation of the Free Flow Electrophoresis Process (Weiss)

Electrophoresis Technology (Snyder)

Mathematical Models of Continuous Flow Electrophoresis (Saville)

E. Ultrahigh Vacuum and Containerless Processing Technologies

Ultrapure Metals Preparation in Space (Bunshah)

Electrotransport of Solutes in Refractory Metals (Schmidt)

Ultrahigh-Vacuum Semiconductor Thin-Film Technology (Grunthaner)

Ultravacuum Vapor Epitaxial Growth of Silicon (Neugebauer)

Efficient Solar Cells by Space Processing (Schmidt)

Crystal Nucleation in Glass-Forming Alloys and Pure Metal Melts Under Containerless and Vibrationless Conditions (Turnbull)

A Proposal to Measure the Viscosity of Molten $Pd_{78}Si_{16}Cu_6$ (Lord)

Fusion Target Technology (Wang)

The Upgrading of Glass Microballoons (Dunn)

Glass Shell Manufacturing in Space (Nolen)

MPS-PRESENT MSFC MANAGED ACTIVITIES (Continued)

Measurement of the Properties of Tungsten at High Temperatures (Margrave)

Ultimate Intrinsic Coercivity $SmCo_5$ Magnet (Das)

Undercooling Studies in Metastable Peritectic Compounds (Lacy)

Containerless Processing Technology (Oran)

Advanced Containerless Processing Technology (Wang)

Mass Spectrometer Development (Melfi)

Technology Demonstration Measurement for Molecular Wake Shield (Hoffman)

System Feasibility of a Space Vacuum Research Facility - Wake Shield Demonstration (Moore)

Analysis of Degassing Techniques to Support Vacuum Research Facility (Moore)

F. Bioprocessing

Electrophoresis Technology (Snyder)

Mathematical Models of Continuous Flow Electrophoresis (Saville)

Automated Analytical Electrophoresis Apparatus (Bartels)

Hormone Purification by Isoelectric Focusing in Space (Bier)

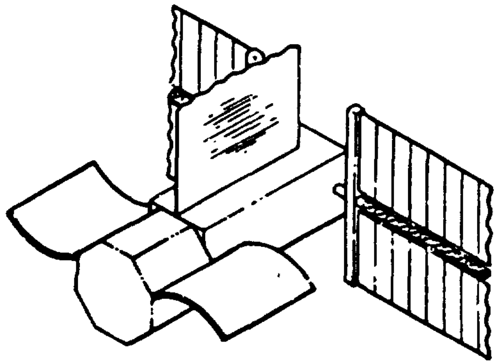
Countercurrent Distribution of Biological Cells (Brooks)

PROJECT SUMMARY

MEC – AN UNMANNED SPACECRAFT THAT FLIES ATTACHED TO THE POWER SYSTEM WITH BOTH R & D AND COMMERCIAL PAYLOADS FOR MATERIALS PROCESSING ON LONG DURATION, HIGH POWER, LOW-g MISSIONS

NASA ORGANIZATIONS – OSTA AND OSTS, NASA HEADQUARTERS
– MATERIALS R&D INDUSTRY
– MARSHALL SPACE FLIGHT CENTER

STATUS – PHASE A STUDY IN PROGRESS. PLANNING UNDERWAY FOR FUTURE PHASES



MEC ATTACHED TO POWER SYSTEM

POTENTIAL MEC PAYLOADS

1. CONTAINERIZED
   - ISOTHERMAL
   - HIGH GRADIENT
2. CONTAINERLESS
   - ACOUSTIC
   - ELECTROMAGNETIC
   - ELECTROSTATIC
3. SOLUTION CRYSTAL GROWTH
4. FLOAT ZONE
5. FLUIDS/CHEMICAL
6. VACUUM
7. BIOLOGICAL
8. PRINCIPAL INVESTIGATOR UNIQUE
9. COMMERCIAL

MATERIALS EXPERIMENT CARRIER (MEC) PROJECT

APPROVAL

TOWARD A SPACE MATERIAL SYSTEMS PROGRAM

By Georg F. von Tiesenhausen

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

Herman P. Gierow

H. P. GIEROW
Director, Advanced Systems Office

William R. Marshall

W. R. MARSHALL
Director, Program Development