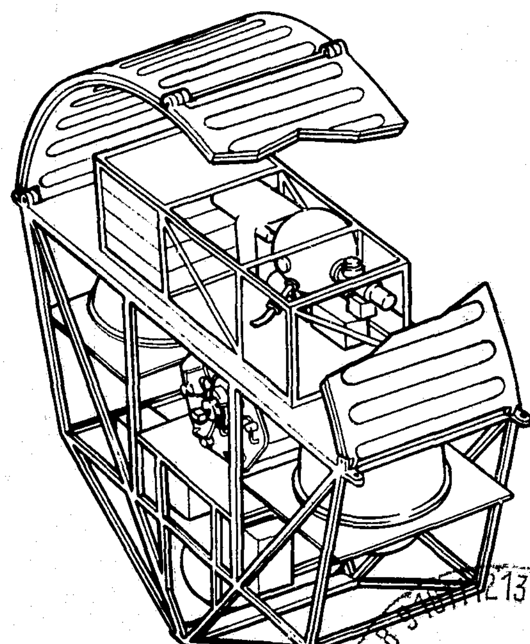
Automated Space Processing Payloads Study
(Contract NAS 8-30741)

Volume I
Executive Summary

Final Report
BSR 4171
January 1975



Bendix Aerospace Systems Division

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Prepared for:

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center, Alabama 35812

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CONTENTS

		Page
FOREWORD		iv
1.	INTRODUCTION	1-1
2.	STUDY APPROACH AND SCOPE	2-1
3.	SIGNIFICANT RESULTS AND CONCLUSIONS	3-1
	3.1 EXPERIMENT REQUIREMENTS AND HARDWARE DATA	3-1
	3.2 CAPABILITIES AND CHARACTERISTICS OF INDUSTRIAL AUTOMATION EQUIPMENT, CONTROLS, AND TECHNIQUES	3-5
	3.3 PAYLOAD GROUPING	3-7
	3.4 AUTOMATED PAYLOAD CONCEPTUAL DESIGN	3-9
	3.5 SPACE PROCESSING PAYLOAD PRELIMINARY DESIGN	3-10
	3.6 AUTOMATED SPACE PROCESSING PAYLOADS FOR EARLY SHUTTLE MISSIONS	3-12
	3.7 COST, SCHEDULE, AND SR&T	3-16
4.	SUGGESTED ADDITIONAL EFFORT	4-1

ILLUSTRATIONS

Figure	Title	Page
2-1	Study Logic	2-1
2-2	Study Schedule	2-2
3-1	Automated Space Processing Facility Concepts	3-11
3-2	Payload Configurations	3-15
3-3	Single Facility Typical Development Schedule	3-16
3-4	Automated Space Processing Facilities Development Schedule	3-17
3-5	Work Breakdown Structure	3-19

TABLES

Table	Title	Page
3-1	Experiment Designation G-8	3-2
3-2	Selected Experiments	3-3
3-3	Experiment Hardware Status Summary	3-4
3-4	Commercial Item Survey Data	3-5
3-5	Automation Hardware Availability Summary	3-6
3-6	Levitation Experiment Groups	3-8
3-7	Furnace Experiments Groups	3-8
3-8	Concept Summary	3-9
3-9	Processing Facilities Design Summary	3-10
3-10	Space Processing Payloads; Strawman Program for Early Missions	3-13
3-11	Automated Space Processing Payloads for Early Missions	3-14
3-12	Program Costs for Separate Development	3-20
3-13	SR&T for Automated Space Processing Equipment Development	3-21

FOREWORD

The Automated Space Processing Payloads Study was performed by the Aerospace Systems Division of The Bendix Corporation under Contract NAS 8-30741 for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The study was managed by Lynn Lewis and was administered under the technical direction of Jim Poe and Ken Taylor in the Payload Studies Group of Program Development at the Marshall Space Flight Center. Key contributors to the study included Walter Crosmer, Oakley Neau, Derek Perkins, Donald Ebert, Eric Granholm, and Ronald Wludyka of the Aerospace Systems Division and Jim Edmond of the Bendix Research Laboratories Division. Significant contributions to the study were also made by personnel under the direction of Dr. R. T. Frost of the Space Science Laboratory of the General Electric Company and by personnel under the direction of Dr. Robert Mazelsky of the Research and Development Center of the Westinghouse Electric Corporation.

Bendix wishes to especially acknowledge the extensive support provided throughout the study by the two Marshall Space Flight Center Contracting Officer's Representatives, Mr. James Poe and Mr. Kenneth Taylor.

SECTION 1

INTRODUCTION

To date, the Space Processing Applications (SPA) Program has identified six major areas of material science research and technology that can be exploited in a weightless or low-gravity environment. These are metallurgy, electronic materials, glass technology, biological preparations, and physical and chemical processes in fluids. Work was performed by this and previous studies in system analyses and engineering areas to define an inventory of equipment to conduct the experiment program. Plans call for the pursuit of an aggressive program, taking advantage of a large number of potential Space Shuttle flight opportunities following the completion of a series of rocket experiments. Addition of automated space processing payload equipment will enable the SPA Program to participate in those Space Shuttle missions on which the only available resource is weight and volume capability, and to increase productivity on flights providing more extensive resources.

This study addresses the automated space processing payload equipment by examining the extent to which the experiment hardware and operational requirements can be met by automatic control and material handling devices and defines payload and system concepts that make extensive use of automation technology.

Specific objectives satisfied by the study are to:

- Identify SPA experiments amenable to automation.
- Identify operations which may be more efficiently or economically performed by the flight crew.
- Define automated functions and equipment for space processing payloads.
- Determine the feasibility of automating SPA experiments for operation under STS mission conditions.
- Determine the extent to which existing commercial automation hardware, techniques, and measurement instrumentation can be applied to SPA Program.
- Design space processing payloads which make optimum use of automation to a preliminary design level.
- Provide payload interface data for planning typical early Shuttle SPA missions.
- Provide estimates of development cost and schedules for automated SPA payloads.

SECTION 2

STUDY APPROACH AND SCOPE

Seven tasks were undertaken to meet the objectives of the study. Figure 2-1 shows the interrelationship of these seven tasks. Task 1, Review and Compile Experiment Requirements and Hardware Data, and Task 2, Survey of Industrial Automation Equipment, were conducted in parallel, and provided the data base for the remainder of the study. Tasks 3, 4, and 5 resulted in the selection of representative experiments and preliminary design and definition of selected automated space processing concepts. Task 6 investigated the equipment combinations and resource requirements for possible experiments to be flown on Shuttle flights in the 1979 to 1982 time-period. Task 7 defined the cost, schedule, and SR&T requirements for the major equipment items identified in the study.

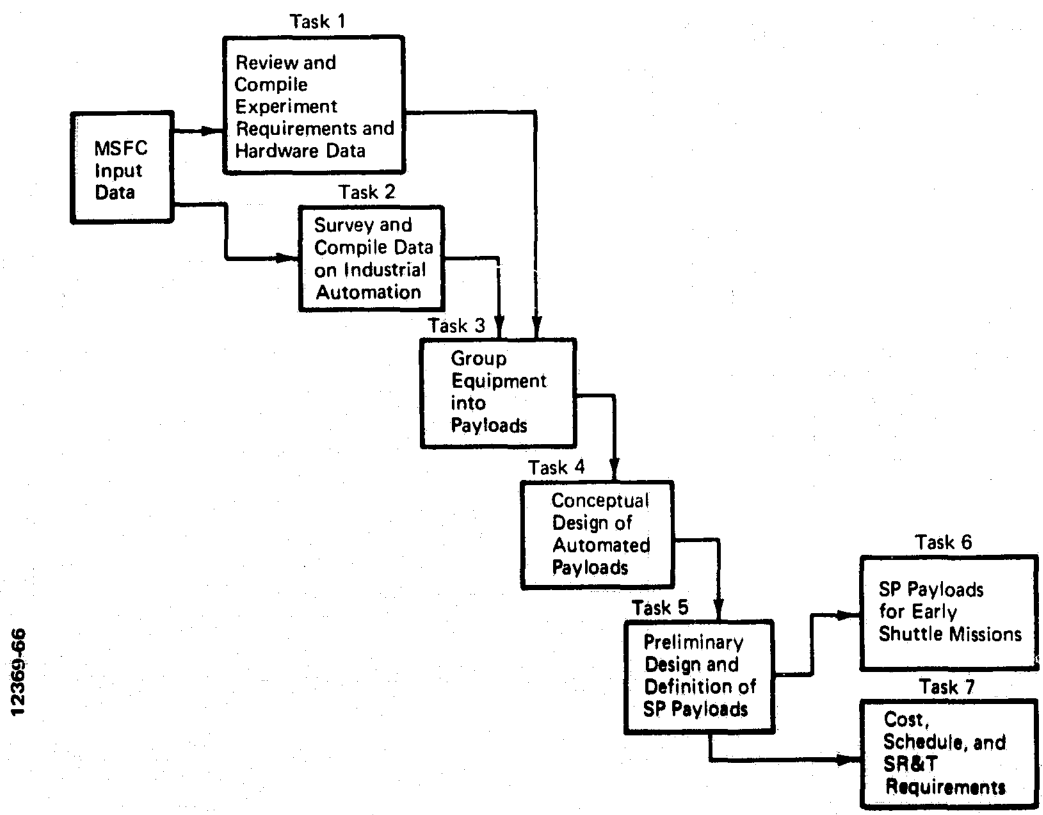


Figure 2-1 Study Logic

The study was conducted between March 1974 and February 1975, as shown on Figure 2-2.

The study activities were integrated with inputs from related NASA in-house studies and data from other contractual sources provided by the COR. Input data on electromagnetic levitation experiments and equipment was supplied by the General Electric Company Space Division Space Sciences Laboratory under separate contract to NASA. Also under separate contract to NASA, the Westinghouse Company Research and Development Center provided data on furnace experiments and equipment.

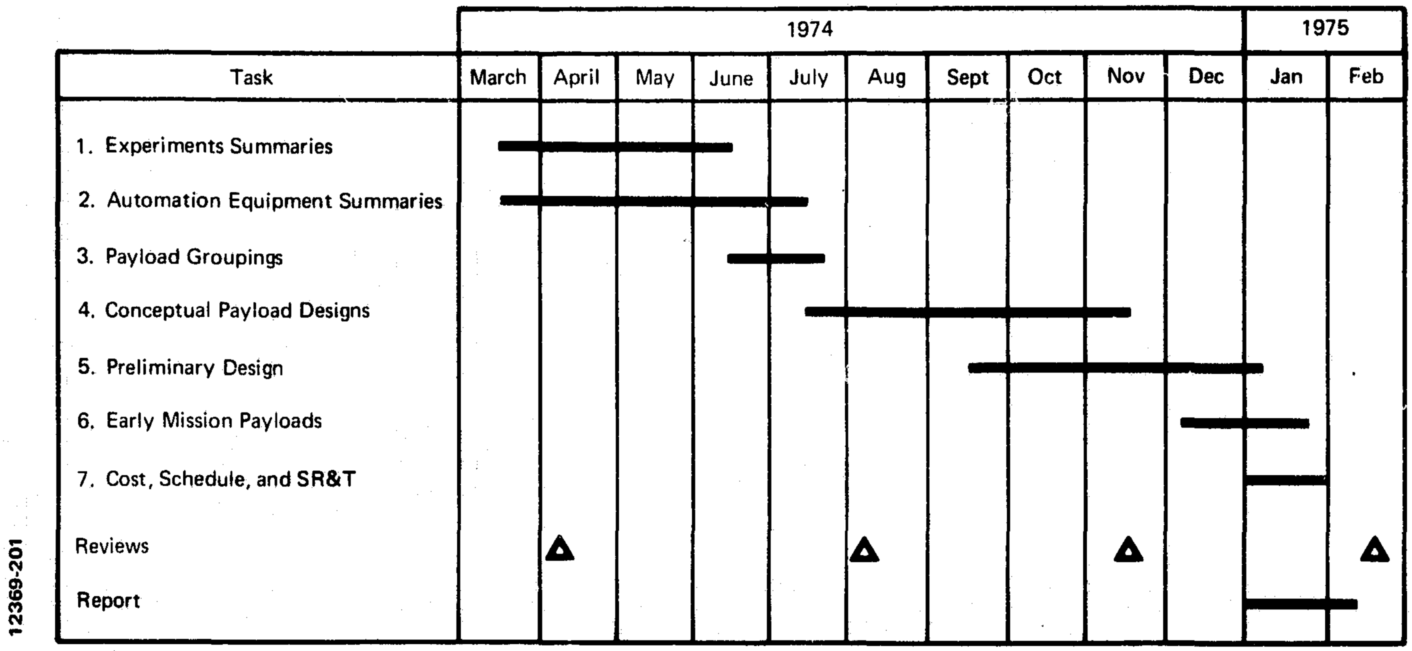


Figure 2-2 Study Schedule

SECTION 3

SIGNIFICANT RESULTS AND CONCLUSIONS

3.1 EXPERIMENT REQUIREMENTS AND HARDWARE DATA

The objectives of this task were to identify "typical" process experiments and to detail the procedures and hardware required to implement them in an independent automatic facility.

A review of existing documentation provided a list of potential experiments. Of these, several in each class (biological, crystal growth, glass, metallurgical, and physical and chemical processes in fluids) were selected for further investigation. The requirements for each of these were then organized to identify areas of commonality and uniqueness. Procedures for each were examined to identify requirements for automation of the process. Table 3-1 is an example of the experiment data documented.

Characteristics of 70 experiments were investigated. Of these, 42 were deemed to have sufficient merit to warrant further documentation. Eighteen of these experiments were then selected for further study, as listed in Table 3-2.

The preliminary hardware requirements for the selected experiments were itemized. The status of each class of hardware was evaluated and categorized, as shown in Table 3-3. Most of the space processing hardware flown on Space Shuttle missions will be different from anything flown on previous programs. However, if the concept and most of the components are space-qualified, an X appears in that column. Similarly, if presently available commercial hardware is readily adaptable to our requirements, the X appears in that column. Those items requiring a major developmental effort to achieve the desired function in a space-qualified design are listed in the remaining category.

Table 3-1

Experiment Designation G-8

TITLE: Alumina Glass

OBJECTIVE: To produce Al_2O_3 glasses by levitation and melting in zero g.

TOTAL PROCESS TIME: 2 hr

PROCESS:

	Steps	Parameters
1.	Pressurize chamber.	1 atmosphere.
2.	Insert sample.	1 in. diameter sphere.
3.	Levitate sample.	
4.	Melt sample.	2,045°C.
5.	Hold at temperature.	5 min.
6.	Cool sample.	100 min.
7.	Retrieve and stow sample.	

SPECIAL HARDWARE:

1.	Manipulator.	
2.	Chamber.	
3.	Levitation and mixer, acoustic.	
4.	Heater, resistance.	2 kW.
5.	Gas control system.	

RECORDING AND ANALYSIS REQUIREMENTS:

1. Event times.
2. Temperature/pressure/time profile.
3. Visual record of critical process phases.
4. Post-mission analysis.
    a. Measurement of optical properties.
    b. Correlation of measured properties with process parameters.

Table 3-2

Selected Experiments

1.	Containerless Preparation of Ultra-Pure Metal.
2.	Dispersion Strengthening (Composite Materials).
3.	Containerless Preparation of Ultra-Pure Alloys.
4.	High Melting-Point Oxide Glasses (Zirconia).
5.	High Melting-Point Oxide Glasses (Alumina).
6.	Chalcogenide Glass.
7.	Dispersion of Particles in Glass.
8.	Supercooling and Homogeneous Nucleation.
9.	Crystal Pulling from Containerless Melt.
10.	Purification by Zone Refining.
11.	Solidification of Composite Materials.
12.	Solidification of Immiscible Materials.
13.	Solidification of Eutectic Materials.
14.	Crystal Growth by Vapor Transport.
15.	Crystal Growth by Pulling from Molten Zone.
16.	Crystal Growth from Solution.
17.	Preparation of Conventional Glass by Furnace Method.
18.	Electrophoretic Separation of Cells, Serums, and Proteins.

Table 3-3

Experiment Hardware Status Summary

Equipment Group	Units	Status: Space Qualified	Status: Commercial Item	Status: Developmental
1. Atmospheric Composition	a. Gas/Vacuum System (Components)	X		
	b. Gas Analyzer	X		
2. Position Control	a. Acoustic			X
	b. Electromagnetic			X
	c. Mechanical		X	
3. Cooling	a. Furnace Heat-Sink			X
	b. Gas Quench	X		
	c. Liquid (H_2O) Quench	X		
	d. Refrigeration	X		
4. Enclosures/Furnaces	a. General-Purpose Enclosure	X		
	b. Tube Furnaces		X	
5. Heating	a. Resistance	X		
	b. Induction		X	
	c. Radiation			X
6. Manipulation	a. Sample Insertion			X
	b. Sample Retrieval			X
	c. Sample Stowage			X
	d. Crystal Pulling		X	
7. Mixers	a. Acoustic			X
	b. Electromagnetic			X
	c. Mechanical			X
8. Temperature Measurement	a. Resistance Thermometers	X		
	b. Thermocouples	X		
	c. Pyrometers		X	
9. Biological Separation	a. Static Electrophoresis	X		
	b. Continuous-Flow Electrophoresis			X
	c. Isotacoelectro-phoresis			X

3.2 CAPABILITIES AND CHARACTERISTICS OF INDUSTRIAL AUTOMATION EQUIPMENT, CONTROLS, AND TECHNIQUES

The purpose of this task was to establish a data bank or catalog of industrial automation equipment, controls, and techniques. The task resulted in the identification of the functions and hardware required to automate space processing experiments and functions, a description of the environment and operating restrictions imposed by flight systems, and an initial screening and evaluation of industrial hardware relative to the environment. The data on applicable industrial equipment were organized, compiled, and presented in the format shown in Table 3-4.

Table 3-4

Commercial Item Survey Data

- Candidate Commercial Item Description
  a. Crystal puller, with translational and rotational drives for providing motions required for withdrawal of seed crystal in single-crystal growing production.
- Item Name
  a. ADL crystal withdrawal mechanism.
- Supplier
  a. Arthur D. Little, Inc.
  Acorn Park
  Cambridge, Mass 02140
  Phone: 617/864-5770.
- Model Number
  a. Catalog number 3637-035
- Performance Specifications
  a. General description.
  b. Cast aluminum frame.
  c. 0.3125-in.-diameter stainless steel withdrawal shaft.
  d. Optional water-cooled withdrawal shaft.
  e. Rotational drive motor (variable-speed, dc, shunt-wound motor, Bodine NSH-12R).
  f. Vertical drive motor (variable-speed, dc, shunt-wound motor, Bodine NSH-12R).
  g. Manual positioner for rapid shaft-height adjustment.
  h. Upper and lower limit switches (interconnected with vertical drive motor).
  i. Two Minarik model SH-14 motor controls (each interwired with rotational drive motor, vertical drive motor, and upper and lower limit switches).
  j. Removeable shaft-sealing gland complete with O-ring and wiper rings. Seal effective at pressures ranging from 10^{-5} Torr to 100 atmospheres.
  k. Operating characteristics.
  Total withdrawal distance: approximately 8.5 in.
  Rotational rate range (variable speed): 0 to 32 rpm.
  Withdrawal rate range (variable speed): 9.1 to 1.8 in./hr.
- Data Output
  a. None
- Power
  a. 40 watts, 115 volts dc
- Weight
  a. 15 Kg.
- Volume
  a. Approximately 2 cu ft.
- Packaging/Mounting
  a. Fabricated from an aluminum casting. All internal units (lead screw, bearings, etc.) are sealed by an access plate and dust cover so that corrosion or accumulation of abrasive dust particles cannot occur.
- Cost
- Modification for Space Applications
  a. Replace drive motors with brushless dc motors and replace manual speed control with computer or controller automatic speed control interface.
- Shipping, Storing, and Handling Considerations
  a. No special requirements.

Table 3-5 summarizes the availability of industrial automation equipment. Most of the material handling functions require special custom-design hardware. Basic sensors can probably be used without modification, since they are frequently designed for hostile environments. The supporting electronics, however, generally must be re-packaged to withstand the environment and to meet interface specifications. Industrial hardware for control, sequencing, and data acquisition is abundantly available, but most of this hardware requires re-packaging. Exceptions to this include ruggedized/militarized minicomputers, magnetic tape recorders, and film cameras. Process control actuators which have been designed for hostile environment operation are generally available.

Table 3-5

Automation Hardware Availability Summary

Automation Hardware	Applicable Commercial Unit Available	Modifications Required
1. MATERIAL HANDLING		
. Raw material storage	Custom	New design.
. Product storage	Custom	New design.
. Material transfer	Custom	New design.
. Sample levitation	Custom	New design.
. Crystal puller	Yes	Brushless motors and computer control.
. Boat puller	Yes	Brushless motor, computer control, and repackage electronics.
2. PROCESS AND ENVIRONMENT MEASUREMENTS		
. Temperature		
Pyrometer	Yes	Repackage electronics.
Thermocouple	Yes	None.
Resistance sensor	Yes	None.
Thermistor sensor	Yes	None.
. Pressure		
Solid-state sensor	Yes	None.
Strain gage sensor	Yes	None.
Variable reluctance sensor	Yes	None.
. Vacuum		
Ion gage	Yes	
Thermocouple gage	Yes	Repackage electronics.
. Gas constituents		
Mass spectrometer	Yes	None.
Gas chromatograph	Yes	
Gas analyzers	Yes	Repackage electronics.
3. PROCESS AND ENVIRONMENT CONTROLLERS		
. Sensor dedicated	Yes	Repackage electronics.
. Programmable controllers	Yes	Repackage electronics.
. Relay controllers	Yes	
. Minicomputers	Yes	None.
4. COMMAND SEQUENCING		
. Programmable controllers	Yes	Repackage electronics.
. Relay controllers	Yes	
. Minicomputers	Yes	None.
5. DATA ACQUISITION		
. Data acquisition systems	Yes	Repackage electronics.
. Magnetic tape recorders	Yes	None.
. Television cameras	Yes	Repackage electronics.
. Film cameras	Yes	None.
6. PROCESS CONTROL ACTUATORS		
. Relays	Yes	None.
. Valves	Yes	None.
. Motors	Yes	None.

3.3 PAYLOAD GROUPING

The objective of this task was to form experiment sets or groupings that will provide the basis of the conceptual design effort.

Four prime criteria were utilized to group the 18 selected experiments of Table 3-2 into payload equipment groups. They were:

1. Material compatibility.

2. Material handling commonality.

3. Supporting function requirements (number of functions, process sequencing and variation, gases, vacuum, or fluid requirements).

4. Resource requirements (weight, volume and form factors, power and energy, heat rejection, and time requirements).

Three primary groups that are readily identified are (1) levitation or containerless melt group, (2) furnace or closed container group, and (3) electrophoretic separation of biologicals. Within these major groupings, experiments have been further classified according to their hardware implementation.

Table 3-6 shows the levitation experiment groupings. Materials shown are "typical" of each process. The L-1 group consists of experiments in processing materials which require or can tolerate a vacuum environment and have low-to-medium resistivity, allowing electron-beam heating and low-frequency levitation. L-2 is a group consisting of materials of moderate resistivity that permit efficient heating by electromagnetic radiation at a relatively low frequency (100 kHz). L-3 is a group consisting of high resistivity materials requiring pre-heating to lower the resistivity to a value compatible with electromagnetic levitation and heating at a high frequency (15 MHz). Group L-4 consists of experiments requiring containerless processing, but the materials of the group are not electrically compatible with the electromagnetic levitation technique. Consequently, acoustic levitation is used.

Table 3-6

Levitation Experiment Groups

L-1	L-2	L-3	L-4
Chalcogenide Glass (GeTe) Ultrapure Alloys (WC) Purification and Under-Cooled Solidification (W) Amorphous Solidification (PdSi)	Dispersion Composites (Beryllia in Be)	High Melting Point Oxide Glass (Zirconia)	Crystal Pulling from Melt (Si) High Melting Point Oxide Glass (Alumina) Striking Glass (AgCl in High Silicate)

Table 3-7 shows the furnace experiment grouping. The F-1 group is characterized by the high melting-point of materials (higher than 1,200°C). The F-2 group consists of those materials having low or moderate melting-point temperatures (lower than 1,200°C). The F-3 group requires precisely controlled temperature gradients and a means for transporting the sample through the gradient.

Table 3-7

Furnace Experiment Groups

F-1	F-2	F-3
Crystal Growth in Flux (YIG) Crystal Pulling from Molten Zone (TiO_2) Conventional Glass (SiO_2)	Crystal Growth from Vapor (CdSe) Composite Materials (Al_2O_3 fibers in Al) Immiscible Materials (Cu-Pb)	Zone Refining (Si) Eutectic Materials (CuAL)

E-1 has been identified as experiments involving electrophoretic separation of biological materials (cells, serums, proteins, etc.).

3.4 AUTOMATED PAYLOAD CONCEPTUAL DESIGN

The four levitation facilities, three furnace facilities, and one electrophoresis facility defined in the payload grouping analysis were reviewed for design and equipment requirements. The specific equipment required to implement the facilities were identified, and layouts were prepared to determine facility interfaces and the general configuration. In some instances, variations of the basic requirements were examined, resulting in several alternate concepts. Twelve different facility concepts were developed. These are summarized in Table 3-8.

Table 3-8

Concept Summary

Concept	Description	Facility/Experiment Capability
L-1	Electromagnetic Levitation (35 kHz). Vacuum (10^{-5} to 10^{-7} Torr). Electron-Beam Heating. Multiple Samples (6).	Spherical samples, 1 to 4 cm diameter. Low resistivity, high secondary emission. Melting, purification, and homogeneous solidification of metals, their alloys and compounds, and chalcogenide glasses.
L-2	Electromagnetic Levitation (100 kHz). Vacuum or Atmosphere (10^{-7} Torr to several atmospheres). Induction Heating. Multiple Samples (6).	Spherical samples, about 2 cm diameter. Low resistivity, low secondary emission, e.g., beryllia dispersion in beryllium.
L-3	Electromagnetic Levitation (15 MHz). Vacuum or Atmosphere (10^{-7} Torr to several atmospheres). Induction Heating. Pre-Heating (imaging or resistance). Multiple Samples (6).	Spherical samples, 1 cm diameter. High resistivity materials requiring pre-heating to improve electromagnetic efficiency, e.g., high melting point oxide glasses. Controlled cooling.
L-4	Acoustic Levitation. Inert or Active Gas (5 Torr to several Atmospheres).	Spherical samples, 1 to 4 cm diameter. Ultra-high resistivity, glasses and crystals, controlled cooling.
L-4A	(a) Resistance Heater.	(a) Low absorptivity materials.
L-4B	(b) Arc Imaging Heater. Multiple Samples (6).	(b) High absorptivity materials.
F-1	High-Temperature Resistance Heater Tube Furnace.	Self-contained cartridge samples. Equivalent diameter 4 to 10 cm. Glasses and crystals to 2,200°C. Controlled cooling.
F-1A	(a) Multiple Furnace Units (6).	
F-1B	(b) Sample Handling (6).	
F-2	Low-Temperature Resistance Heater Tube Furnace.	Self-contained cartridge samples. Equivalent diameter 1 to 2 cm. Immiscibles, composites, and low-temperature (less than 1,200°C) crystals.
F-2A	(a) Multiple Furnace Units (6).	
F-2B	(b) Sample Handling (6).	
F-3A	(a) Moving-Zone Image Heater.	Zone refining and directional solidification. Rod-shaped samples. (a) 1 cm diameter by 58 cm long, to 1,100°C.
F-3B	(b) Fixed-Zone, moving sample; multiple samples or large rod.	(b) 2 cm diameter by 58 cm long, to 1,900°C.
E-1	Continuous Flow Electrophoresis Unit.	Three biological specimens. Collect up to 50 separated fractions.

3.5 SPACE PROCESSING PAYLOAD PRELIMINARY DESIGN

Five of the most representative facility concepts were selected for more detailed design and analysis. The configurations selected were:

1. Electromagnetic Levitation Facility (L-1).

2. Acoustic Levitation Facility (L-4).

3. Furnace Facilities (F-1 and F-2).

4. Zone Refining Facility (F-3).

5. Electrophoresis Facility (E-1).

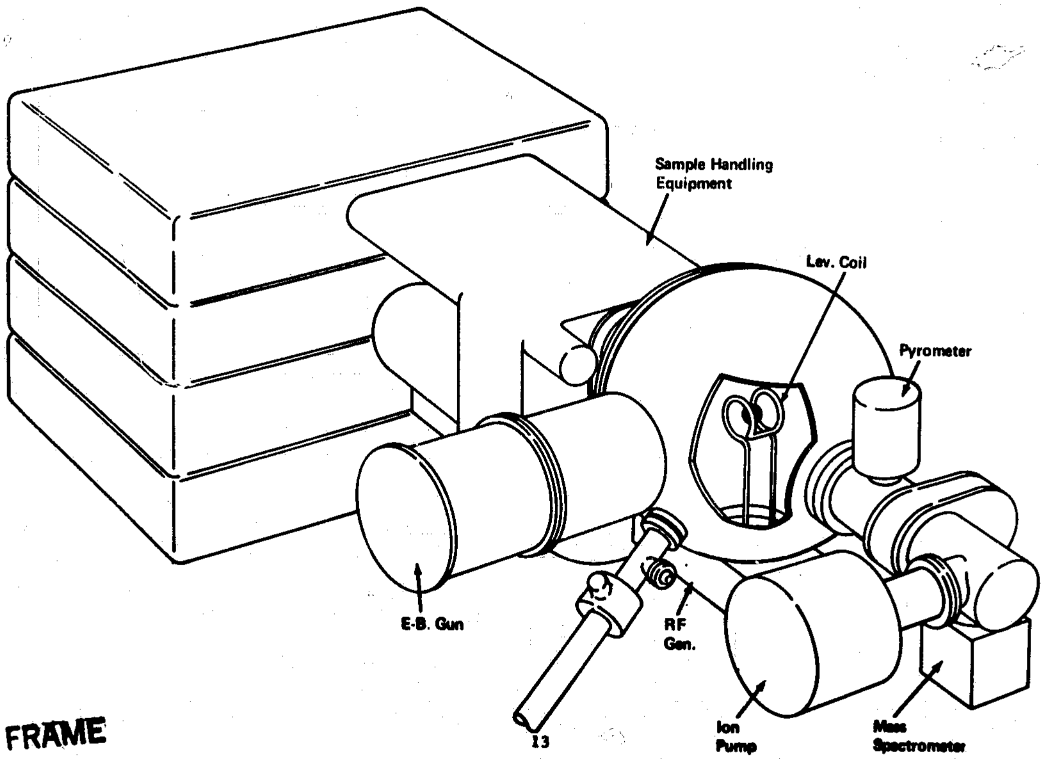
In the design and analysis, special consideration was devoted to mechanical, thermal, and electrical interfaces with the spacecraft. The functions of core equipment, which provides the central processor unit and data collection and control functions, were also investigated with a view toward standardization. Developmental requirements were identified, and qualification and acceptance testing needs were outlined. Characteristics of the selected facilities are summarized in Table 3-9; artist's concepts of five of the facilities are shown in Figure 3-1.

Table 3-9

Processing Facilities Design Summary

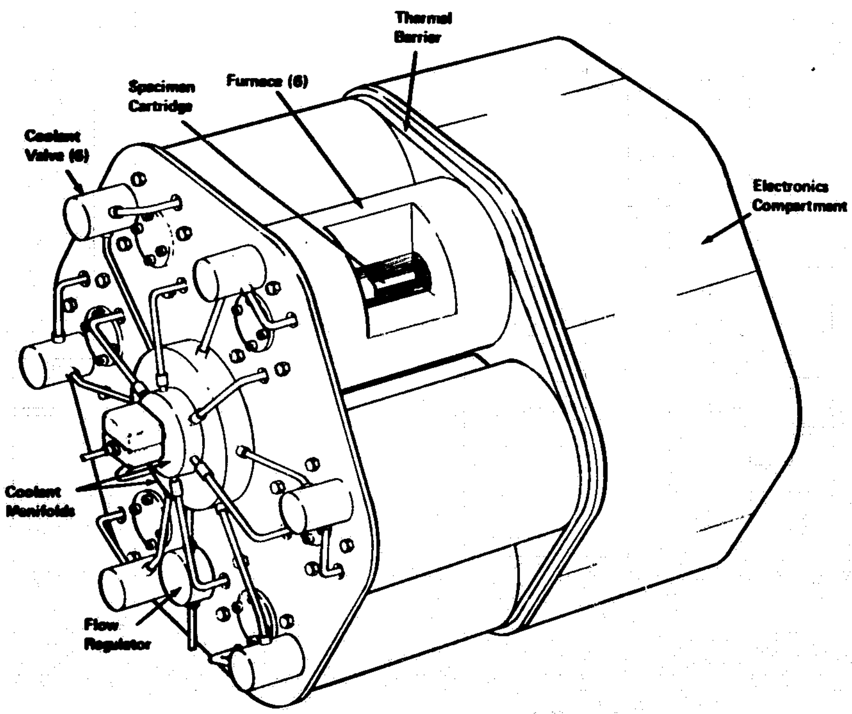
Processing Facility	Weight (lb)	Volume (cu ft)	Sample		Peak Power (kW)	Average Power (kW)
			Material	Diameter (cm)		
L-1 Electromagnetic Levitation	1162	108	Tungsten Tungsten GeTe	1 2 2	4.5 7.6 4.5	2.0 4.8 1.0
L-4a Acoustic Levitation	811	108	Silicon Silicon Alumina	4 11.5 1	3.3 5.8 6.0	2.7 4.5 3.6
F-1a High Temperature Furnaces (6)	641	48	TiO_2 YIG	4 (equiv.) 10 (equiv.)	5.1 3.0	3.4 1.9
F-2a Low Temperature Furnaces (6)	666	48	CdSe Al_2O_3 in Al	1 (equiv.) 2 (equiv.)	2.1 2.0	1.8 1.9
F-3a Zone Refining (Image Heater)	466	22	CuAl	1 (equiv.)	3.7	3.3
F-3b Zone Refining (Resistance Heater)	894	45	Silicon	2 (equiv.)	4.1	3.0
E-1 Electrophoresis	250	7	NA	NA	1.4	0.9

Electromagnetic Levitation Facility (L-1)

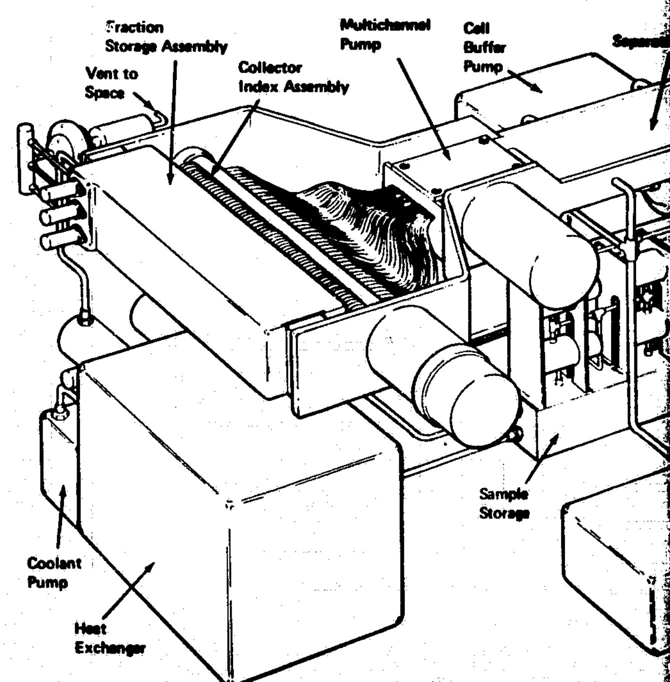


FOLDOUT FRAME

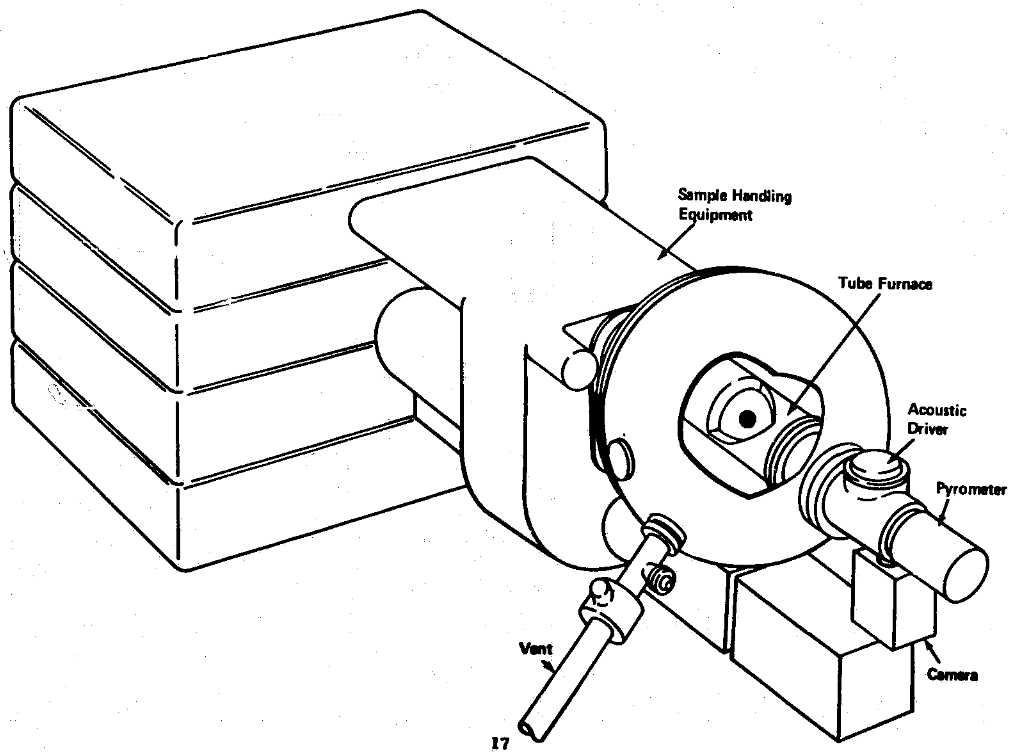
Multiple Furnace Facility (F-1A, F-2A)



Electrophoresis Facility (E-1)

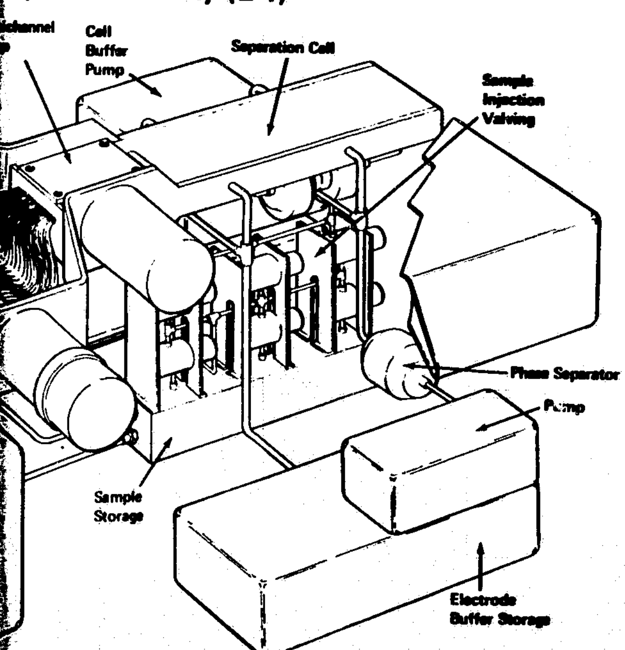


Acoustic Levitation Facility (L-4)



FOLDOUT FRAME 2

rophoresis Facility (E-1)



Zone Refining Facility (F-3A)

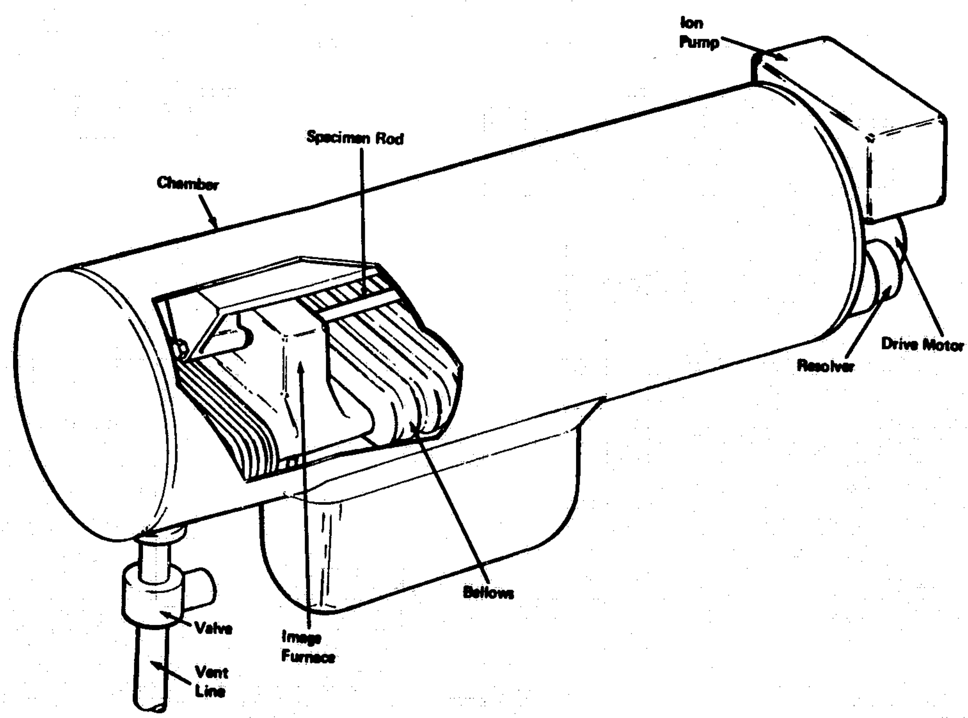


Figure 3-1 Automated Space Processing Facility Concepts

As can be seen from Table 3-9, the average and peak power dissipations of each facility are strongly dependent on the sample size and sample material. To produce the 3-cm-diameter ductile tungsten X-ray targets recommended recently by General Electric in their "Beneficial Uses of Space Study" would require peak powers of 20 kW or more. Because of the significant system level impacts of these power levels on APPS and Shuttle interface design, one of the very important aspects to be considered by the SPA working group to be formed in the near future is the sample materials and sizes to be accommodated on early Shuttle SPA missions.

3.6 AUTOMATED SPACE PROCESSING PAYLOADS FOR EARLY SHUTTLE MISSIONS

Using the preliminary facility designs, automated payloads made up of one or more facilities were defined for conducting equipment and technique verification tests and space processing experiments on Shuttle flights in the 1979 to 1982 time-period.

An Early Mission Space Processing Payloads Strawman Program, summarized in Table 3-10, was used as a basis for this effort. Payloads (1, 2, and 3) designed for mounting and operation in the Shuttle cargo bay with complete dependence on the Shuttle Orbiter for power and thermal control were configured. In addition, payloads (4, 5, and 6) were configured which are designed for mounting in an Auxiliary Payload Power System (APPS) unit which provides power and thermal control independent of the shuttle orbiter. The characteristics of these payloads were determined and are summarized in Table 3-11. The three payloads most nearly meeting the Strawman Program requirements are Payloads 4, 5, and 6. These payloads are an unpowered version of the APPS unit dependent on the Shuttle Orbiter, a 7.5-kW-powered APPS unit, and a 15-kW-powered APPS unit. Figure 3-2 shows the configuration of Payloads 5 and 6. Payload 4 has a configuration very similar to that of Payload 5. This study has determined that it is entirely feasible to provide automated payloads meeting the constraints and resources available on the early Shuttle mission opportunities in the 1979 to 1982 time period.

Table 3-10

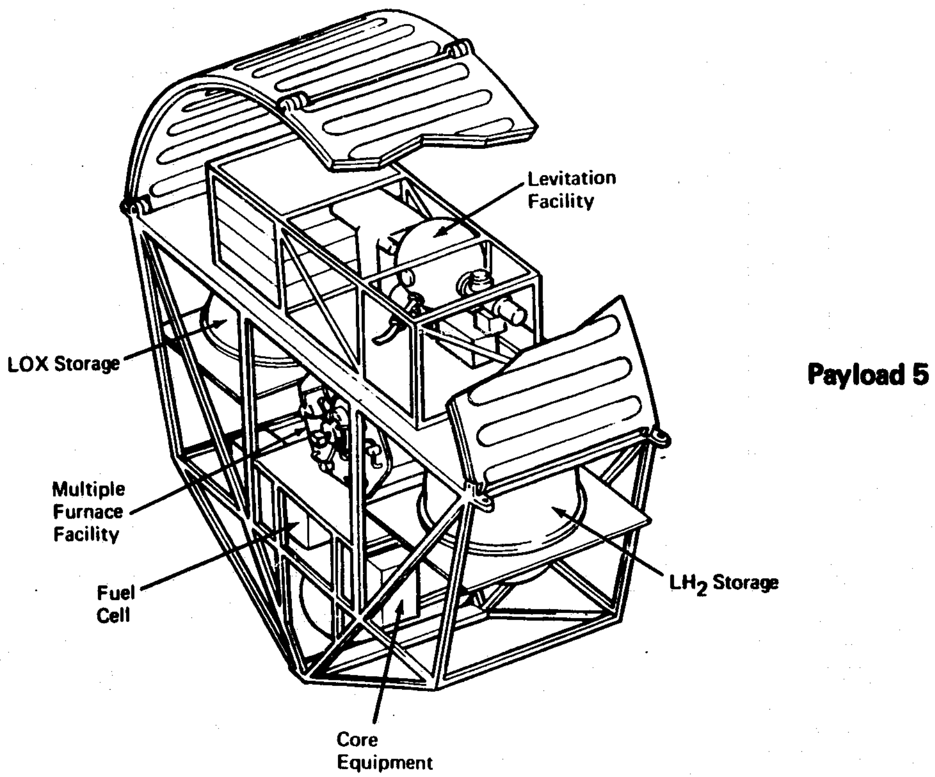
Space Processing Payloads; Strawman Program for Early Missions

Shuttle Orbiter Flight and Duration	Objective	Payload
Flight 2 (1 to 3 days)	1. Longer duration to extend rocket experiment results.	1. Rocket Spinoff Payload.
Flight 3 (1 to 3 days)	1. Verify and extend results from Skylab and ASTP. 2. Performance test critical equipment technology for Spacelab flight. 3. Investigate metallurgical phenomena. 4. Investigate crystal growth phenomena. 5. Test major APPS systems. 6. Verify payload/Shuttle interface. 7. Verify Shuttle payload support systems.	1. Multiple Furnace Facility. 2. Utility Contactless Processing. 3. Electrophoresis Technology (Test). 4. Core Unit.
Flight 6 (7 days)	1. Crystal growth and metallurgical processing that exceeds Skylab/ASTP capability. 2. Test of new apparatus, e.g., contactless processing facility with electron-beam heating. 3. Purification of high melting point materials in contactless processing facility. 4. Comparison of contact versus contactless high-temperature processing. 5. Checkout of APPS power and the thermal subsystems. 6. APPS/STS thermal control interface test. 7. Payload/STS interface verification test.	1. Contactless Processing Facility with electron-beam gun. 2. Multiple Furnace Facility. 3. Core.
Flight 8 (Joint NASA/ESRO Spacelab Mission) (7 days)	1. Electrophoresis of live samples. 2. Extend crystal growth results from previous missions. 3. Extend metallurgical results. 4. Investigate fluid phenomena.	1. Low-Temperature Furnaces. 2. Electrophoresis (Continuous Flow and Static Separation). 3. General Purpose Sub-element.
Flight 10 (7 days)	1. Contactless processing of unique glasses. 2. Purification of high-temperature materials by zone refining. 3. Metallurgical processing by zone refining. 4. Crystal growth by contactless processing. 5. Extension of previous crystal growth and metallurgical processes. 6. Checkout of all up APPS power and thermal subsystems. 7. APPS/STS thermal control interference test.	1. Contactless Processing Facility (Acoustic). 2. High-Temperature Multiple Furnaces. 3. Float Zone Refiner (2). 4. Core.

Table 3-11

Automated Space Processing Payloads for Early Missions

Payload	Equipment	Automated Facilities Weight		Total Payload Weight		Peak Power (kW)	Average Power (kW)	Total Energy (kWhr)
		(lb)	(kg)	(lb)	(kg)			
1	Low-Temperature Multiple Furnaces. Electrophoresis. Core.	1,109	504	1,329	604	3.3	1.9	138
2	Low-Temperature Multiple Furnaces. Electromagnetic Levitation. Core.	1,999	909	2,219	1,008	4.1	2.3	116
3	Low-Temperature Multiple Furnaces. Electromagnetic Levitation. Electrophoresis. Core.	2,258	1,026	2,508	1,140	4.3	2.0	143
4	Low-Temperature Multiple Furnaces. Electromagnetic Levitation. Electrophoresis. Core.	2,048	931	3,000	1,364	4.3	2.0	143
5	High-Temperature Multiple Furnaces. Electromagnetic Levitation. Core.	1,799	818	5,299	2,409	5.9	3.3	410
6	Acoustic Levitation. Low-Temperature Multiple Furnaces. Zone Refiner. Molten Zone Crystal Growth. Core.	2,392	1,086	7,892	3,586	15.2	12.5	1,500



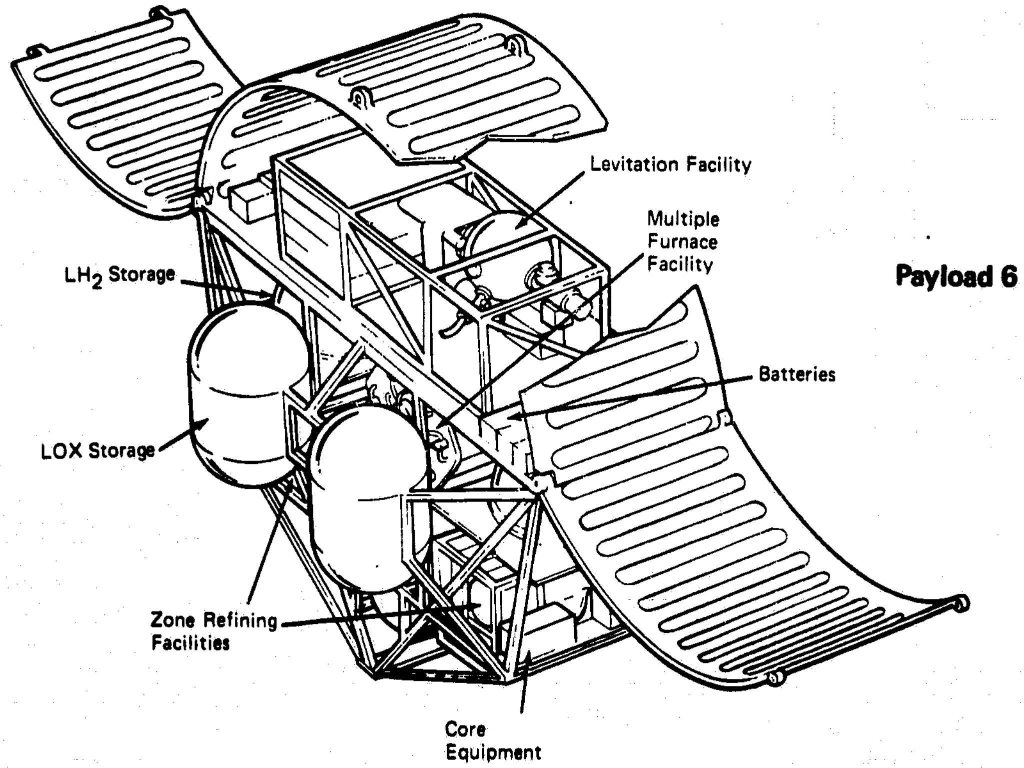


Figure 3-2 Payload Configurations

3.7 COST, SCHEDULE, AND SR&T

An analysis was performed to determine the cost to develop the five automated facilities through the first flight article in accordance with a program that includes an electronics breadboard, a mechanical test unit, a prototype, one flight article, and refurbishment of the prototype as a flight spare. A typical development schedule is shown in Figure 3-3. This schedule shows a hardware development and flight unit delivery time requirement of approximately 20 months. This is typical. The separate facilities will require more or less time depending on the relative complexity of the facility and its test program. A schedule showing the development, fabrication, assembly, test, and payload integration for shuttle flights 3, 6, 8 and 10 of the Early Mission Strawman Program is given in Figure 3-4. The schedule indicates that automated facilities could also be made available for integration with the Spacelab on Flight 8 in the event a decision is made to include automated equipment in addition to the semi-automatic facilities developed for operation by the scientist-astronauts in the Spacelab.

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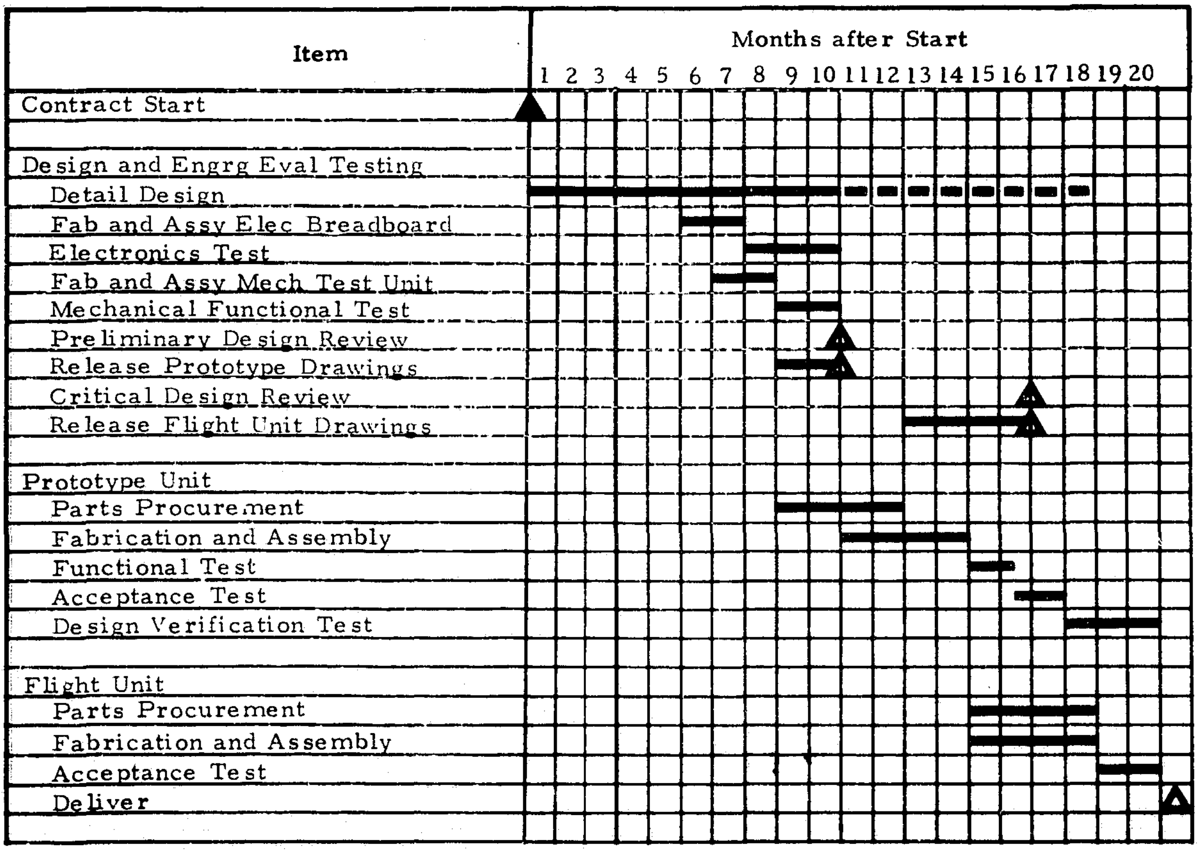

Figure 3-3 Single Facility Typical Development Schedule

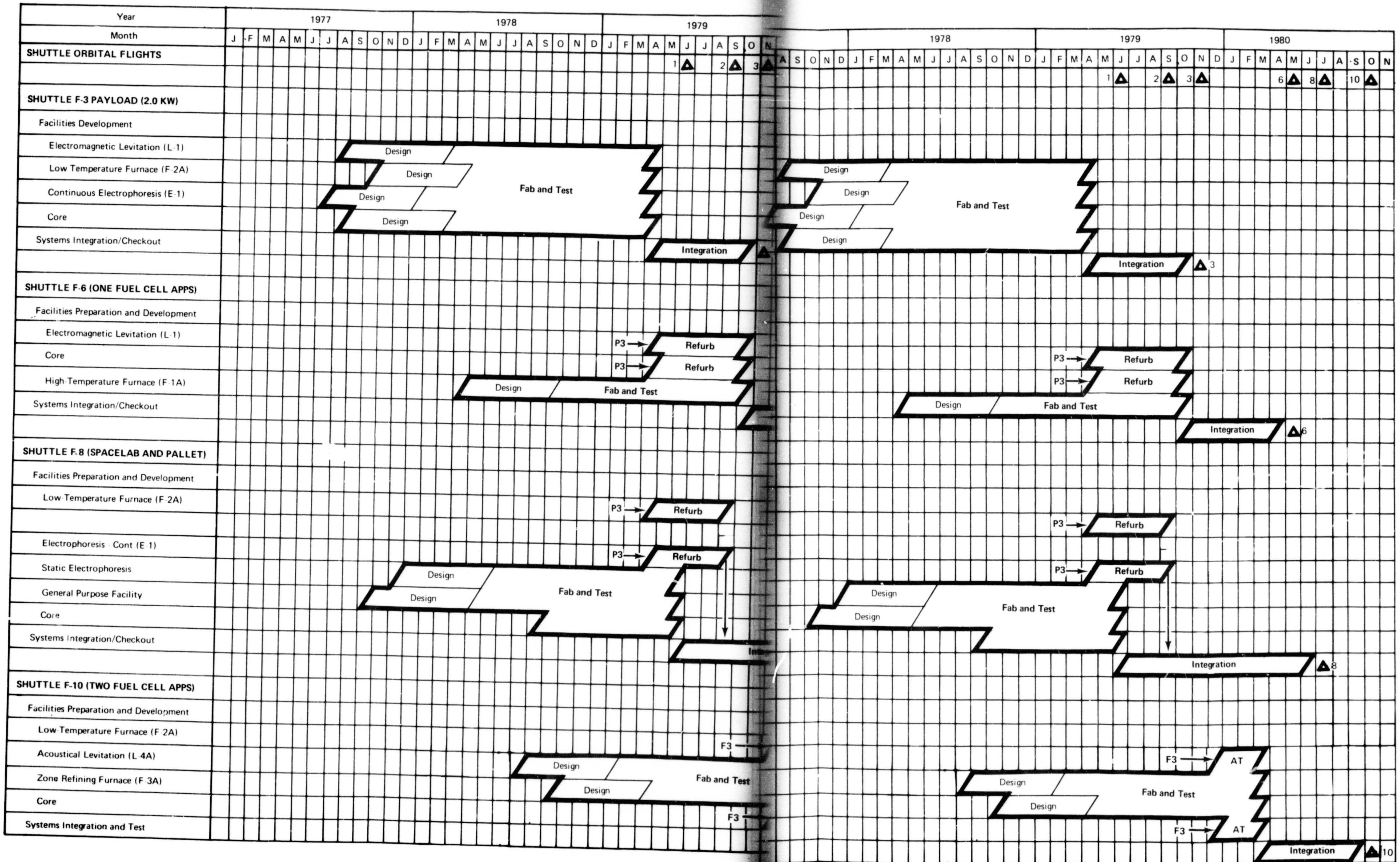

Figure 3-4 Automated Space Processing Facilities Development Schedule

FOLDOUT FRAME 1

FOLDOUT FRAME 2

A work breakdown structure for this effort to level 5 is shown in Figure 3-5. The program costs developed in accordance with the work breakdown structure and the schedules are summarized in Table 3-12. The cost assumptions used in developing these numbers are:

1. Separate development for each facility.

2. Costs are for first flight unit only. Do not include spacecraft integration, payload integration, or launch and mission support services.

3. A typical development program allowing 20 months to flight hardware delivery was utilized.

4. Hardware development program includes:

   - Complete electronics breadboard.
   - Functional mechanical test unit, including mechanisms, fluids as required, and structure.
   - One prototype unit, refurbished and flown.
   - One flight unit.

5. Facilities are not in a stand-alone condition; i.e., each facility requires operation in conjunction with a core facility.

6. Costs are in 1975 dollars.

7. Where commercial equipment items are used, it has been assumed that the cost will be four times the standard catalog costs to harden the equipment sufficiently for the Shuttle environment (according to Analysis of Commercial Equipment and Instrumentation for Spacelab Payloads; Contract NAS 8-30541; 16 Sept. 1974; Space Division Rockwell International).

8. Materials costs include 50% for factory spares for the prototype and the flight hardware.

A number of Supporting Research and Technology efforts have been recommended as a result of the detailed evaluation of the facility preliminary design concepts and their development requirements. These studies are listed by title in Table 3-13. The studies are required to ensure high confidence in the ability to achieve successful development of the equipment and the technology necessary for the program.

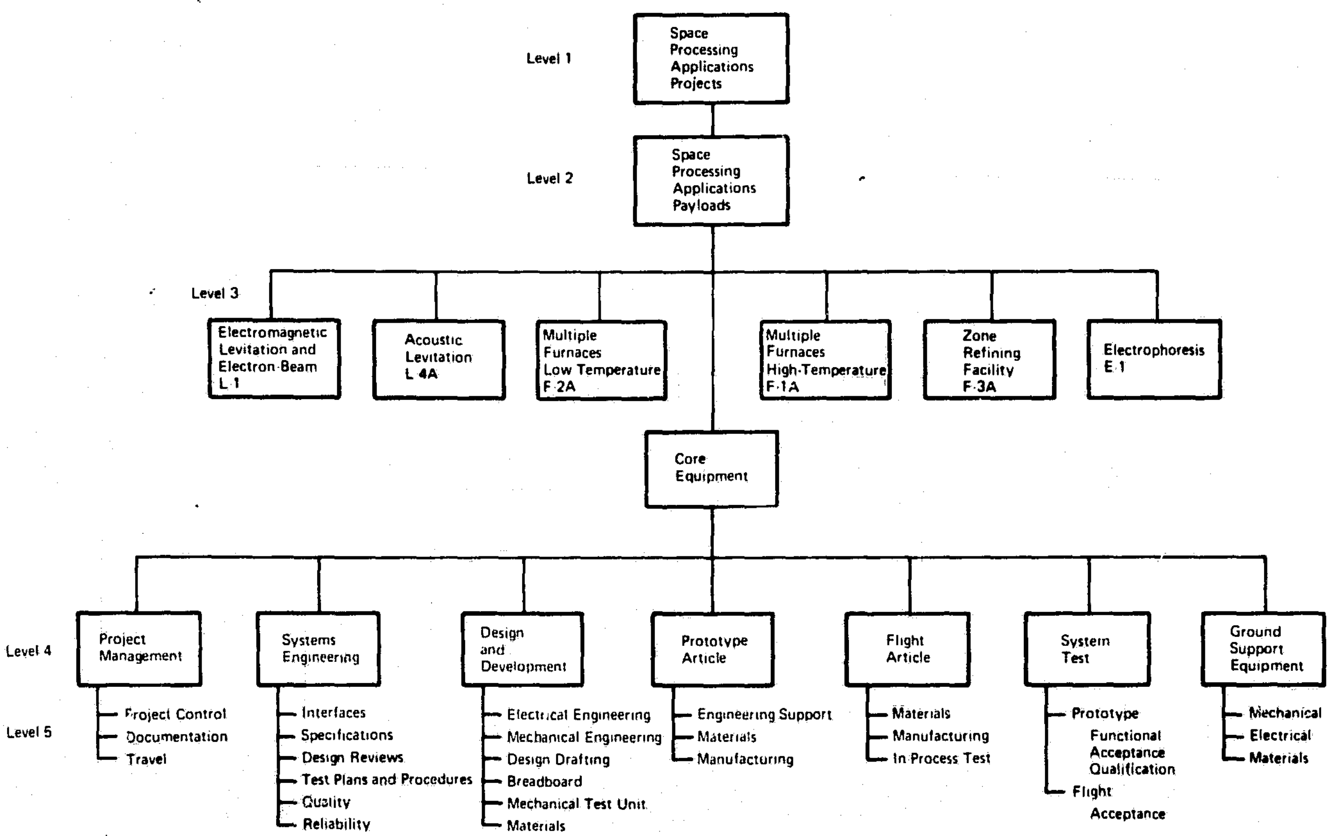

Figure 3-5 Work Breakdown Structure

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Table 3-12

Program Costs for Separate Development

Facility	Designation	Estimated Cost ($ millions)
Electromagnetic Levitation; Electron-Beam Heating	L-1	3.21
Acoustical Levitation; Tube Furnace Heating	L-4A	2.79
High-Temperature Multiple Furnace Unit	F-1A	2.30
Low-Temperature Multiple Furnace Unit	F-2A	2.25
Zone Refiner; Moving Zone Image Heater	F-3A	2.44
Continuous-Flow Electrophoresis	E-1	3.28
Core*	-	4.17
	Total	20.44

*Two flight units required.

Table 3-13

SR&T for Automated Space Processing Equipment Development

Environmental chamber for material processing and supporting instrumentation (10^{-6} Torr to 10 atmospheres).
Sample storage and manipulation mechanisms (for containerless and furnace processing).
Electron-beam gun (continuous adjustment power range to 4.5 kW).
Pyrometer development (to 3,500°C).
Partial pressure and residual gas instrumentation for materials processing.
Image recording techniques.
Solid state RF generator development.
High frequency RF generator development.
Acoustic levitation component development.
Furnaces for zone refining applications.
Electromagnetic levitation sample presence detector.
Electrophoresis sample detection and fraction collection assembly development.
Furnace sample processing chamber development.
Zone refining transport mechanism.
Heater materials for high-temperature furnaces (to 3,000°C).
Process controller interface development.

SECTION 4

SUGGESTED ADDITIONAL EFFORT

This study has resulted in a number of concepts and designs for automated facilities for performing space processing experiments. It has demonstrated the uses of these concepts and has shown that feasible payloads can be developed to take advantage of the mission opportunities existing on the first few Space Shuttle flights.

Further studies of the facility concept design, in the light of the fully integrated payload concepts, are required. This includes studies of the payload within the Spacelab (both manual and automated), mounted on the pallet, in the cargo bay, on the Auxiliary Payload Power System Unit, and on free flying payloads. These studies should include participation of scientists and engineers proposing material science investigations in space so that the designs will reflect the total needs and desires of the Space Processing Applications Program. Critical evaluation of the facility concepts resulting from the present study needs to be performed in order to determine their usefulness in the light of the overall program. Further design and analysis of the most promising concepts must be performed in the areas of structural and thermal analyses, power management and control, and electromagnetic interference. Further definition of the specific components needed to build up the facilities is required, including preparation of detailed design specifications and review of the specifications with potential suppliers/developers, in order to determine the least-cost approach to obtaining the required components.

It is suggested that the SR&T efforts outlined in Section 3, Table 3-14, be undertaken in order to further develop the hardware and operational techniques so that the facility development can proceed in a timely manner.