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EXECUTIVE SUMMARY

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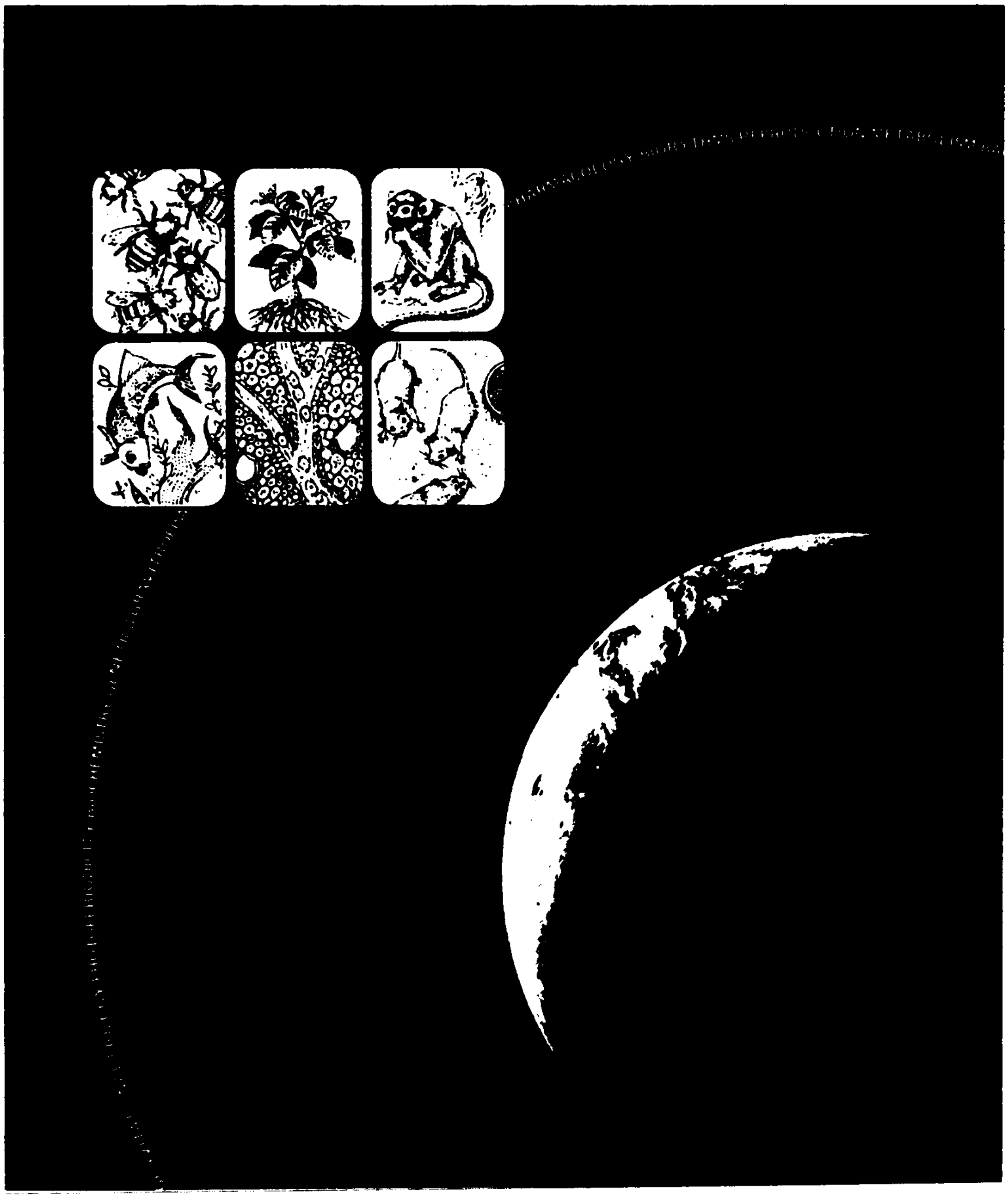
Conceptual Design
and programmatics

Final Report
Volume I
Attachment I

October 1985

System Analysis Study of Space Platform and Station Accommodations for Life Sciences Research Facilities

BOEING
Technology Incorporated
NASA



(NASA-CR-179268) SYSTEM ANALYSIS STUDY OF SPACE PLATFORM AND STATION ACCOMMODATIONS FOR LIFE SCIENCES RESEARCH FACILITIES. VOLUME 1: EXECUTIVE SUMMARY. PHASE A: CONCEPTUAL DESIGN AND PROGRAMMATICS Final

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SYSTEM ANALYSIS STUDY OF SPACE PLATFORM AND STATION ACCOMMODATIONS FOR LIFE SCIENCES RESEARCH FACILITIES

CONTRACT NAS 8-35471

FINAL REPORT
VOLUME I - EXECUTIVE SUMMARY
PHASE A
CONCEPTUAL DESIGN
AND
PROGRAMMATICS

D180-27863-1-I

OCTOBER 1985

For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MARSHALL SPACE FLIGHT CENTER
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FOREWORD

The System Analysis Study of Space Platform and Station Accommodations for Life Sciences Research Facilities (Contract NAS8-35471) was initiated May 19, 1983, and completed February 28, 1986. The study was conducted by Boeing Aerospace Company, Seattle, Washington, and a subcontractor, Technology Incorporated, Houston, Texas. This study was one of two parallel studies conducted for the NASA Marshall Space Flight Center. The Contracting Officer's Representative and Study Manager was Dr. John D. Hilchey.

The study was funded and conducted in three major parts, as shown below:

Part 1: A system analysis study conducted from May 1983 through December 1983.

Part 2: An indepth trade analysis conducted from September 1984 through December 1984.

Part 3: A conceptual design and programmatics study conducted from February 1985 through October 1985.

The final reports from the total contract are contained in several volumes, appendixes, and attachments. The report numbers, titles, and dates for each study part are shown below:

Part 1 documentation - dated December 1983.

D180-27863-1	Volume I	-	Executive Summary
D180-27863-2	Volume II	-	Study Results
	Appendix A	-	Parametric Analysis Data Package
	Appendix B	-	Tradeoff Analysis Data Package
	Appendix C	-	Preliminary Conceptual Design Requirements Data Package
D180-27863-3	Volume III	-	Final Briefing Book

Part 2 documentation - dated December 1984.

D180-27863-2-I	Volume II, Attachment I	-	Indepth Trade Analysis

<u>Part 3 documentation</u> - dated October 1985.

D180-27863-1-I	-	Executive Summary of Volume I, Attachment I, Study Results of Conceptual Design and Programmatics.
D180-27863-2-II	-	Volume II, Attachment II, Study Results of Conceptual Design and Programmatics
Appendix D	-	Requirements
Appendix E	-	Work Breakdown Structure and Dictionary
Appendix F	-	Conceptual Layouts and Drawings

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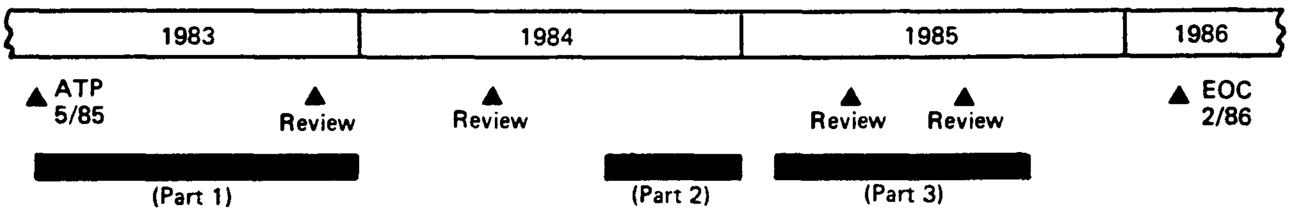
1.0 INTRODUCTION

1.1 OVERVIEW

A phase A study, "System Analysis Study of Space Platform and Station Accommodations for Life Sciences Research Facilities," was conducted for the NASA Marshall Space Flight Center (MSFC). The study was conducted in three parts over a 3-year period. Figure 1-1 shows the study schedule and the documentation associated with each study part. Part 1 defined and analyzed the relevant parameters and significant trades for accommodating nonhuman research on board the space station. Preliminary design requirements were also identified. Part 2 conducted indepth trade analysis concerning reconfiguration, or reoutfitting, of the laboratory facility on orbit versus returning the facility to Earth to do the work. Part 3, conceptual design and programmatics, included (1) updating engineering design and mission requirements, (2) developing conceptual designs and definitions, and (3) developing a work breakdown structure (WBS), schedule, and cost for a life sciences project. This document summarizes selected study results from the conceptual design and programmatics segment (part 3) of the contractual effort.



Documentation

- Part 1 – System Analysis Study
  - Volume I – Executive Summary
  - Volume II – Study Results
    - Appendix A – Parametric analysis data package
    - Appendix B – Tradeoff analysis data package
    - Appendix C – Preliminary conceptual design requirements data package
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    - Appendix D – Requirements
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Figure 1-1. Study Schedule and Documentation

1.2 BACKGROUND

Long-duration life sciences research has long been recognized as an important mission for space. With the advent of a national space station program, studies have been undertaken to establish the scientific needs and define the engineering design required to accommodate those needs.

NASA, from 1980 through 1982, conducted inhouse studies at both MSFC and Ames Research Center. These studies were to assess the feasibility of accommodating and integrating a life sciences research facility (LSRF) on a space platform and space station. The studies identified science requirements, developed and characterized a range of accommodation concepts, and developed preliminary cost estimates and schedules. The results from these studies provided the data base from which to start a phase A study (i.e., system analysis, conceptual design, and programmatics).

In 1983, NASA initiated parallel phase A studies to be conducted by Boeing and Lockheed. Due to resource limitations, the studies were funded incrementally (i.e., part 1 was system analysis, part 2 was an indepth trade analysis, and part 3 was conceptual design and programmatics).

Completion of the phase A studies provides NASA with the data base with which to start the preliminary design (phase B) of an LSRF for space station. The data base now contains a range of conceptual designs, mission scenarios, operation scenarios, and programmatics for LSRF accommodation and integration with space station.

1.3 STUDY OBJECTIVES

The overall goals of part 3 were to complete the phase A contracted studies by developing conceptual designs and programmatics, and to establish a broad data base from which to initiate a life sciences laboratory preliminary design study.

The specific objectives were—

a. To update requirements and tradeoffs and develop a detailed design and mission requirements document.
b. To develop conceptual designs and mission descriptions.
c. To develop programmatics (i.e., WBS and WBS dictionary, estimated cost, and implementing plans and schedules).

1.4 STUDY APPROACH

The approach used for the part 3 study is described under three major tasks. Figure 1-2 shows a schedule for these tasks with a breakout of subtask elements.

a. Task 1—Develop Engineering and Mission Design Requirements.

   Initially, a set of system requirements, ground rules, and assumptions was developed to aid in developing and baselining a system concept. This set was maintained throughout the study and updated at the completion of this task. Attendant to baselining a system concept, the system trades were identified with a rationale stated for selections that were made.

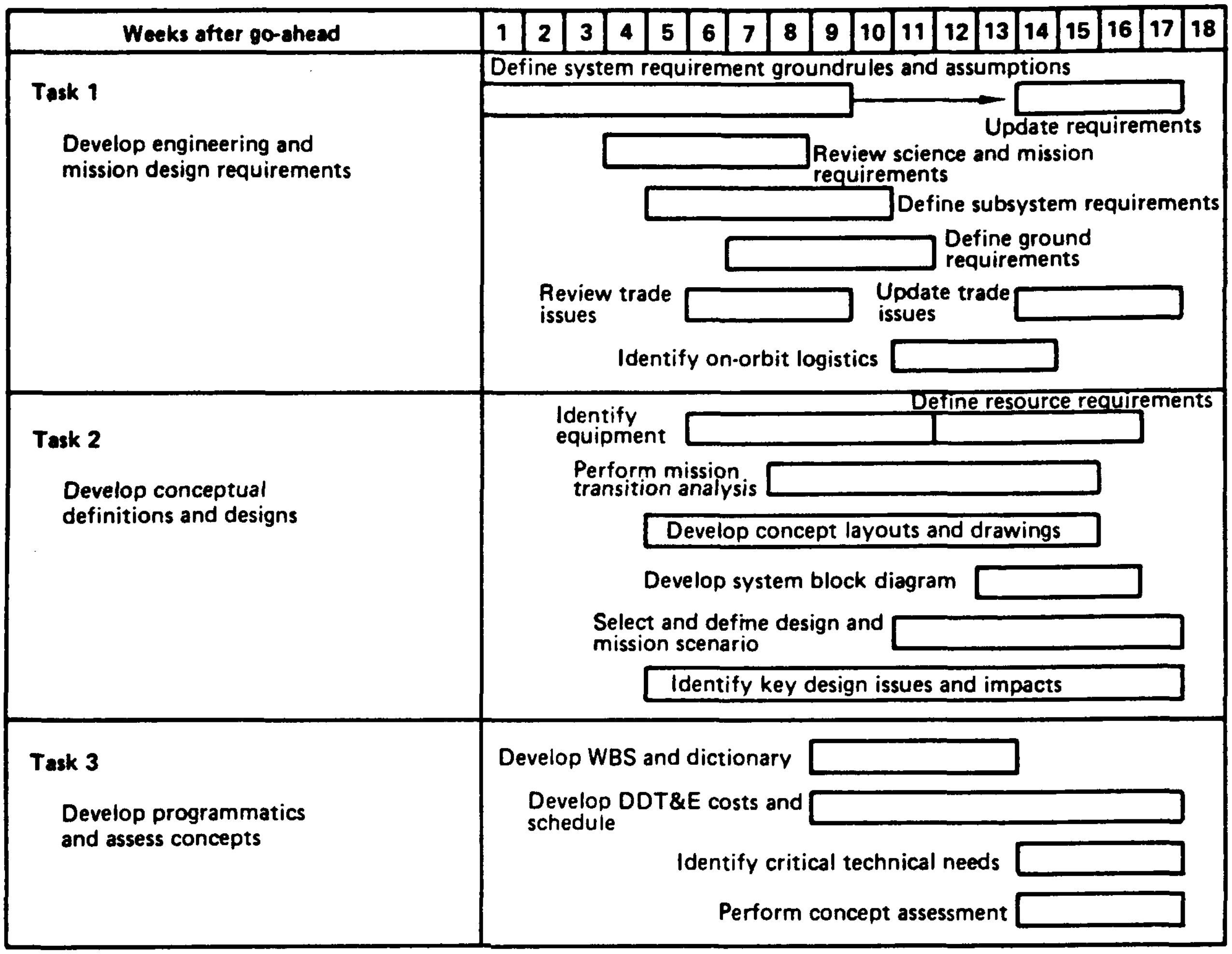


Figure 1-2. Part 3 Study Schedule

Prioritized science requirements were reviewed. Bioisolation approaches, centrifuge options, vivarium cleaning techniques, and specimen transfer concepts were developed and analyzed. Options were developed for Life Sciences Missions SAAX0307 and SAAX0302, and the transition from one-half laboratory to a full laboratory. This formed the basis for subsystem concept development and for concept designs to be developed in task 2.

Subsystem concepts were developed with emphasis placed on the environmental control life support system (ECLSS); its options; and the degree of loop closure for water, CO_2, and O_2. A logistics analysis was performed to determine consumables and waste requirements for operating and supporting the experiments on orbit.

b. Task 2—Develop Conceptual Definitions and Designs.

The Boeing-proposed space station phase B common module configuration was used as a baseline to integrate an LSRF concept design. Based on this concept, layouts, engineering drawings, and a system block diagram were developed. In parallel with the design activity, a mission description and mission scenario were developed with emphasis placed on mission routine and crew involvement.

c. Task 3—Develop Programmatics and Assess Concepts.

This task was directed at developing a WBS and WBS dictionary to level 5; estimated costs; and a design, development, test, and evaluation (DDT&E) schedule. The costs were based on experience from previous space station studies. An assessment was performed to evaluate the effectiveness of the concepts developed for task 2.

1.5 GUIDELINES AND ASSUMPTIONS

A set of ground rules and assumptions was assembled to guide and focus the study results; it is as follows:

a. The Boeing-proposed space station phase B common module configuration was used as the basis for outfitting concept designs, analyses, and requirements. This provided an indepth baseline for definition, including common hardware interfaces and system costs.
b. The LSRF outfitting design shall use common hardware wherever practical. This applies principally to the laboratory animal-life-support environmental control life support (ECLS) hardware.
c. Positive bioisolation shall be provided between the crew-occupied volume and the volume occupied by the animal habitats. This is a major driver in the laboratory design, arrangement, and subsystems. It is established to ensure that microorganisms are not exchanged between specimens and crew.
d. LSRF resupply is every 90 days. This is the expected space station resupply period.
e. The space station logistics module may be used for storage and retrieval of 90-day consumables and storage of down-cargo waste. This mode of operation improves the storage provisions in the LSRF by using the available volume in the space station logistics module all the time it is on orbit.
f. The LSRF program shall supply the capability for transporting live specimens to orbit and return via the space station logistics module.
g. Live-specimen transport in the logistics module shall provide bioisolation protection between the live-specimen environment and the logistics module atmosphere. This is the companion ground rule to the laboratory bioisolation ground rule.
h. A ground care, processing, and holding facility for plants and animals shall be available at the orbiter launch and recovery sites. This facility is essential for the care of live specimens being prepared for transport to orbit and to process and preserve returning specimens for analysis.

2.0 MISSIONS, REQUIREMENTS, AND CONCEPTUAL DESIGN

This section summarizes the science and mission requirements and presents the design options for the IOC and growth laboratory modules.

2.1 MISSIONS

The life sciences missions are defined as laboratory modules that are delivered to orbit and become part of the space station system. The missions, summarized in figure 2-1, were taken from the space station mission data bases formerly known as the Langley mission data base. The figure shows the phasing of two of the major life sciences laboratories to be placed into service over a 10-year period.

For the space station initial operational capability (IOC), mission 307 will be the first life sciences laboratory delivered to orbit. This laboratory (IOC module) will be shared by a human research facility and a nonhuman (plant and animal) research facility. Approximately 2 years later, a second laboratory module (growth module) will be placed in service. At that time, the IOC mission 307 will become a dedicated human research laboratory and will be renumbered mission 303. The new growth module (mission 302) will be outfitted as a nonhuman laboratory.

An analysis was conducted to select the most cost-effective approach for transitioning from the IOC module, with shared facilities, to two unshared, dedicated laboratory modules (when the second module is put in service). The variables involved in this analysis are (1) module assignments, (2) on-orbit crew hours required for transitioning, (3) module scarring, (4) module arrangements, (5) equipment transfers, and (6) equipment transport to orbit.

Two transition options were analyzed.

a. Option 1. Reoutfit (on orbit) existing IOC module as a dedicated human research laboratory, and outfit (on the ground) new growth module as a dedicated nonhuman laboratory.

b. Option 2. Reoutfit (on orbit) existing IOC module as a dedicated nonhuman laboratory, and outfit (on the ground) new growth module as a dedicated human research laboratory.

Option 1, the scenario that transitions the IOC module to a dedicated human research facility, is summarized in figure 2-2. The IOC module (mission 307) is referred to as module A in this analysis. The new growth module (mission 302) is referred to as module B.

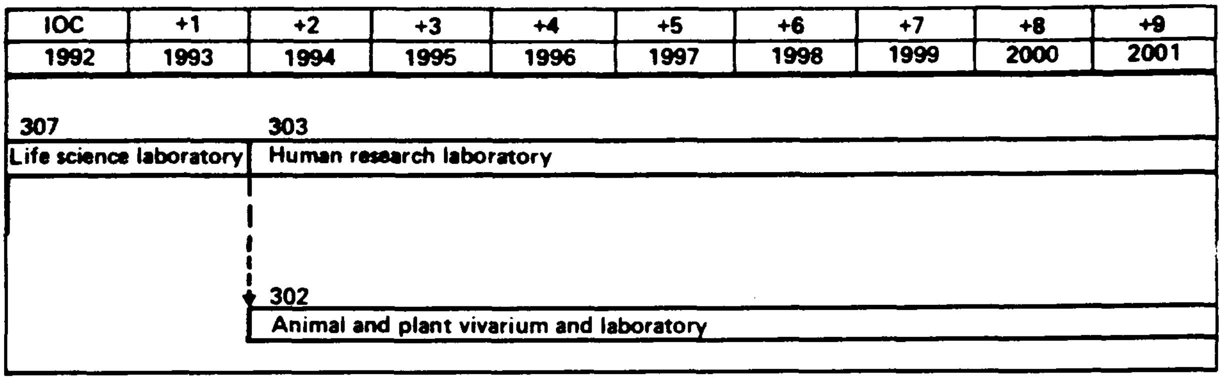


Figure 2-1. Scheduled Life Sciences Missions

1992 – IOC	1994 – Transition on-orbit	1994 – After transition
Lab module A (SAAX 0307) • ½ module for non-human research (with 8-ft centrifuge) • ½ module for human research	Lab module A (SAAX 0307) • Transfer non-human equipment to module B • Disassemble and transfer 8 ft centrifuge to Module B • Add additional human research equipment from module B	Lab module A (SAAX 0303) • Full human research laboratory • Contains scars from 8-ft. centrifuge • Contains scars from supplemental ECS
	1994 – Deliver to orbit and transition Lab module B (SAAX 0302) • Transfer human research equipment to module A • Add and assemble 8-ft. centrifuge from module A • Add non-human equipment from module A	1994 – After transition Lab module B (SAAX 0302) • Full animal and plant vivarium and laboratory (with 3 centrifuges, one 8-ft and two 13-ft)

Figure 2-2. Option 1 Mission Transition Summary

Transition involves transfer of the nonhuman research equipment from module A to module B, especially the disassembly, transfer, and reassembly of an 8-ft centrifuge from module A to module B. Additional human research equipment transported to orbit in module B is transferred and installed in module A.

Nonhuman environmental control system (ECS) subsystem in module A is abandoned when the transition is completed. Abandoned ECS equipment is transported back to Earth on a low-priority basis in the logistics module. The structural scars left by the centrifuge in module A are permanent. The favored centrifuge for the IOC module is an 8-ft centrifuge.

New, additional nonhuman research equipment is installed and integrated into module B before the module is transported to orbit. For example, a 13-ft centrifuge could be installed and checked out on the ground. Module B could also be outfitted with the required ECLS equipment to fully accommodate an expanded laboratory capability.

The analysis showed option 1 to be far superior to option 2. A complete analysis and substantiating data for this conclusion are present in reference 1. A summary of the reasons for selecting option 1 follows:

a. The 8-ft IOC centrifuge is much less complicated and less time consuming than the 13-ft centrifuge for disassembly, moving to the growth module (module B), reassembling, and retesting.
b. The specimen ECLS system increased growth requirements for (1) increased atmosphere capacity, (2) cage-washing water processing, and (3) O^2 generation are more effectively accommodated in a new growth module on the ground (module B) than by rewiring, replumbing, adapting, and adding to the IOC (module A) ECLSS on orbit.
c. The IOC equipment racks are easily moved and accommodated in their optimum locations.
d. The growth module (module B) would be outfitted with the 13-ft centrifuge, including the access centrifuge on the ground where it can be integrated and checked out prior to launch.
e. The IOC (module A) would be left with the 8-ft centrifuge scars and abandoned ECLSS, which would be removed and transported back to the ground.

2.2 SCIENCE AND MISSION REQUIREMENTS

The major source for identifying science and mission requirements was the McDonnell Douglas study completed in 1983 (refs. 2 and 3). In this study, 54 representative plant and animal experiments were identified and analyzed specifically for equipment requirements, operations and measurement requirements, unique operational limits, and experimental protocol. In addition to experiment identification, an equipment information catalog was published. This work formed the basis for science requirement identification. A life sciences planning meeting (ref. 4), held in 1985, substantiated the list of generic experiments and the basic scientific requirements that have been established over the last several years.

The key life sciences laboratory requirements were identified as—

a. Provide micro-g, 1-g, and variable-g environments for live research specimens.
b. Provide for the transport of live specimens to and from orbit.
c. Accommodate a variety of specimens (e.g., rodents, small and large primates, plants, cell tissue, eggs, etc.).

d. Provide bioisolation between the plant and animal vivarium and the crew-occupied areas of the space station.
e. Accommodate a variety of laboratory apparatus and equipment.
f. Accommodate experiment equipment and specimen holding facilities in standard equipment racks within the space station common module.

2.3 EQUIPMENT REQUIREMENTS

Prioritized equipment lists were developed by NASA Ames Research Center. These lists were designed to support the missions previously cited. The three lists are presented in figures 2-3, 2-4, and 2-5. The lists represent groups of equipment to be added to the respective modules in blocks to support progressive mission requirements. The equipment on this list was used as the basis for the developed design concepts.

Equipment description	Power (watts)	Weight (kg)	Volume (m^3)	Experiments supported (Reference McDonnell-Douglas numbers)
Rodent holding facility (24 rats)	500	440.0	1.50	All rat and mouse experiments
General purpose workbench	500	325.0	2.00	All experiments
Specimen mass measurement device	15	17.0	0.04	All experiments
Plant growth chamber	315	200.0	2.00	PC 1-4 and 6-10
Refrigerator	200	70.0	0.33	All experiments
Freezer (-70 degrees or lower)	500	100.0	0.36	All experiments
Incubator	100	70.0	0.21	RD 2a and 4; PC 5-7 and 11
Animal physiological monitoring system	40	24.0	0.06	All animal experiments
Dynamic environmental measuring system	8	13.6	0.03	All experiments
Accelerometer measurement system	10	13.0	0.03	All experiments
Dissecting microscope	110	18.0	0.05	All experiments
Binocular microscope	200	13.0	0.04	All experiments
Biomedical recorder	130	34.0	0.08	All animal experimemts
Kits (animal/plant dissect, fluids..)		34.0	0.05	Selected experiments
Rodent food		45.0	0.03	All rodent experiments
Rodent water		200.0	0.30	All rodent experiments
Hand washer	375	27.0	0.98	All experiments
Storage (30%)			2.43	

PC = Plant and CELSS
RD = Reproduction and Development

Figure 2-3. Prioritized Equipment List - Set 1

2.4 DESIGN CONCEPTS

A number of conceptual designs were developed during the study. Only the final selected design for IOC and for the growth space station configuration are presented here.

2.4.1 IOC Module Concept

The IOC nonhuman research facility shares a space station common module structure and subsystems with the human research laboratory. It was assumed that the

Equipment description	Power (watts)	Weight (kg)	Volume (M^3)	Experiments supported (Reference McDonnell- Douglas numbers)
Small primate holding facility	200	300.0	2.00	All primate experiments
Primate handling kit		10.0	0.03	All primate experiments
Primate food		50.0	0.03	All primate experiments
Primate water		100.0	0.15	All primate experiments
Rodent breeding facility	150	280.0	2.00	RD 1, 2c, 3, 5-8
Refrigerator	200	70.0	0.33	All experiments
Freezer (-70 degrees of lower)	500	100.0	0.36	All experiments
CELSS experiment	50	30.0	0.10	PC 1-11
Spectrophotometer	300	32.0	0.08	All experiments
Video camera and recorder	49	19.0	0.02	All experiments
Specimen centrifuge up to 1 g	1500	830.0	3.00	All experiments
Rodent food		45.0	0.03	RD 1, 2c, 3, 5-8
Rodent water		200.0	0.30	RD 1, 2c, 3, 5-8
Storage (30%)			2.53	

PC = Plant and CELSS
RD = Reproduction and Development

Figure 2-4. Prioritized Equipment List - Set 2

Equipment description	Power (watts)	Weight (kg)	Volume (m^3)	Experiments supported (Reference McDonald Douglas numbers)
Rodent holding facility (24 rats)	500	440.0	1.50	All rat and mouse experiments
Plant growth chamber	315	200.0	2.00	PC 1-4 and 6-10
Refrigerator	200	70.0	0.33	All experiments
Freezer (-70 degrees or lower)	500	100.0	0.36	All experiments
Kits (animal/plant dissect, fluids..)		34.0	0.05	Selected experiments
Rodent food		45.0	0.03	All rodent experiments
Rodent water		200.0	0.30	All rodent experiments
Metabolic measurement facility	225	100.0	1.00	MB 1-7
Laboratory centrifuge	480	30.0	0.07	All experiments
Mass spectrometer	190	41.0	0.08	BL 4; MB 1-7; PC 4 and 9
Gas chromatograph	100	25.0	0.15	MB 1-7; PC 4 and 9
Oscilloscope	100	11.8	0.03	Selected experiments
pH/ion analyzer	3	2.3	0.01	All experiments
Microprocessor	8	10.0	0.03	All experiments
Biotelemetry system	28	36.0	0.03	All animal experiments
Radiation dosimeter	14	3.9	0.01	RB 1 and 2; selected experiments
Cage cleaning system	500	100.0	1.00	All animal experiments
Storage (30%)			2.09	

PC = Plant and CELSS
MB = Metabolism
BL = Bone loss
RB = Radiation Biology

Figure 2-5. Prioritized Equipment List - Set 3

module would be divided vertically with 7.5 linear feet taken up by the radial berthing ports and the remaining length of 20 ft. divided 50/50 between human research and nonhuman research. These dimensions assumed the 27.5-ft module length baselined by NASA for the study. In developing the IOC concepts, eight basic configurations were evaluated. These concepts varied primarily with respect to the size, number, and placement of centrifuges. The centrifuge issue is a major module design driver; 8- and 13-ft centrifuges were considered.

The 8-ft centrifuge is a relatively simple design with sample holding facilities mounted around the parameter. The 13-ft centrifuge is more complex but provides a great deal of experimental flexibility. Figure 2-6 illustrates the 13-ft centrifuge concept. This latter centrifuge is actually two centrifuges in one. The first part of the centrifuge rotates continually while the second part is used to remove samples from the first and then decelerates to a stop so the samples may be removed for examination. After sample examination, the second centrifuge accelerates to the speed of the first and the sample is returned.

An 8-ft-diameter centrifuge was selected for the IOC life sciences research facility in support of mission experiment requirements. The location in the berthing-port area has the least impact on the common module and the laboratory arrangement. The IOC selected concept arrangement is illustrated in figure 2-7, which shows the 8-ft-diameter centrifuge located in the berthing-port area. This allows full use of the half module laboratory volume for laboratory equipment with 12 rack spaces available. Equipment selection is based on the experiments list and equipment catalog previously described in section 2.2.

The configuration accommodates 12 single-rack spaces (20-in width by 30-in depth by 80-in height). Of this complement, four single racks are assigned for specimen holding facilities. These facilities include two racks for rodents, one for small primates, and one for plants. The remaining racks are assigned experiment support equipment and storage. The IOC concept uses collapsible cages that are changed every 7 days, stored, and returned to the ground every 90 days. The specimen ECS is separate and isolated from the crew compartment and a separate isolated specimen water system is provided. These subsystems are housed in the floor and ceiling tilt-down panels. All equipment, including the 8-ft-diameter centrifuge, are transferable on orbit.

On-orbit resource requirements were derived from the laboratory equipment set accommodated in the IOC concept. These requirements represent approximately 4.7 kW of power and 10.3 m^3 of volume for equipment, with an additional 3 m^3 for storage.

Figure 2-8 summarizes the number of rodents, small primates, and plants that could be accommodated in the IOC concept. A laboratory rack contains four standard holding units, each containing 6 rodents, or 24 rodents per rack. A standard holding unit accommodates one small primate per unit and four small primates per standard equipment rack. A standard holding unit accommodates one plant unit with 43 wheat

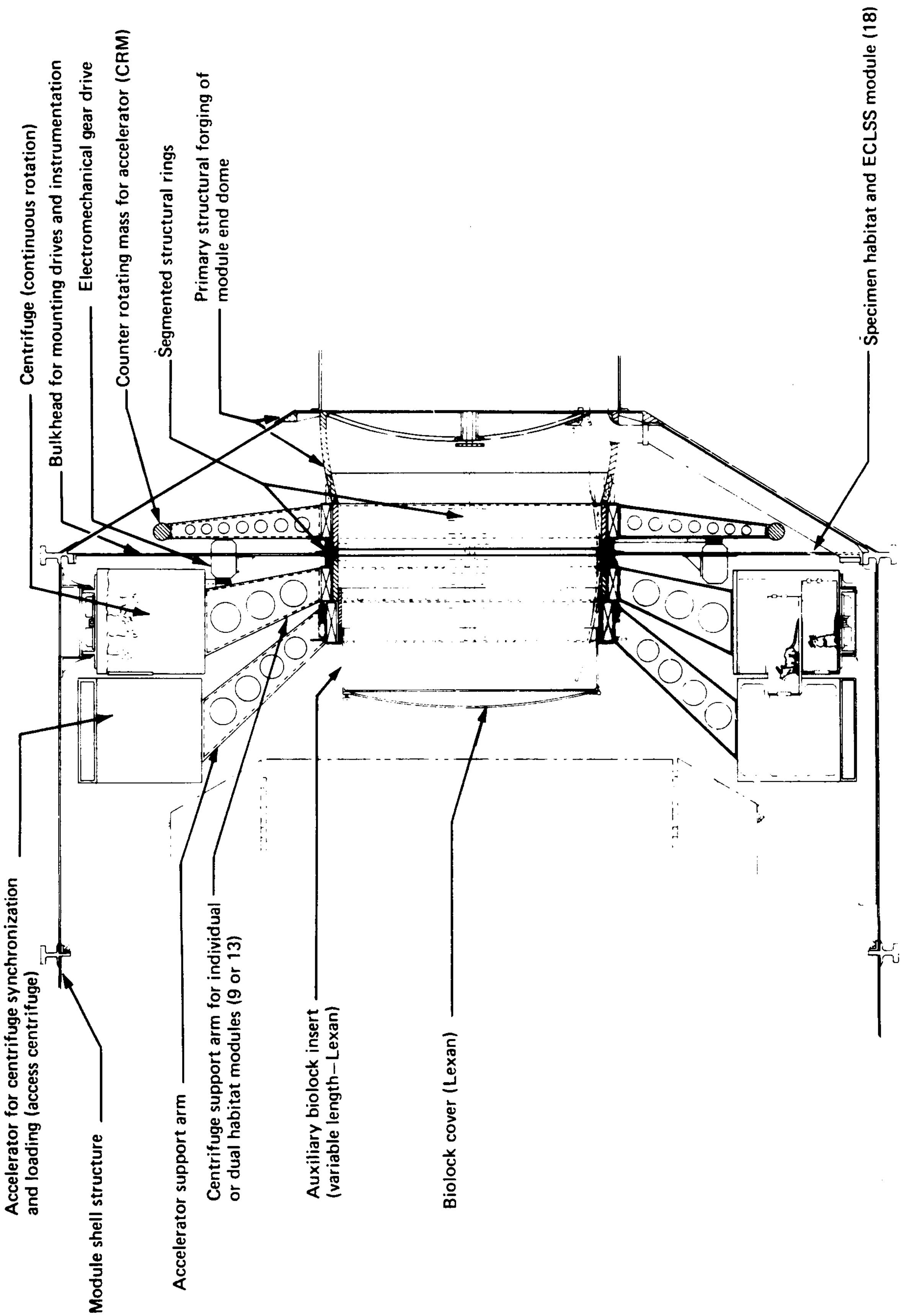


Figure 2-6. Details of 13 ft Centrifuge With Access Centifuge and Counterbalance

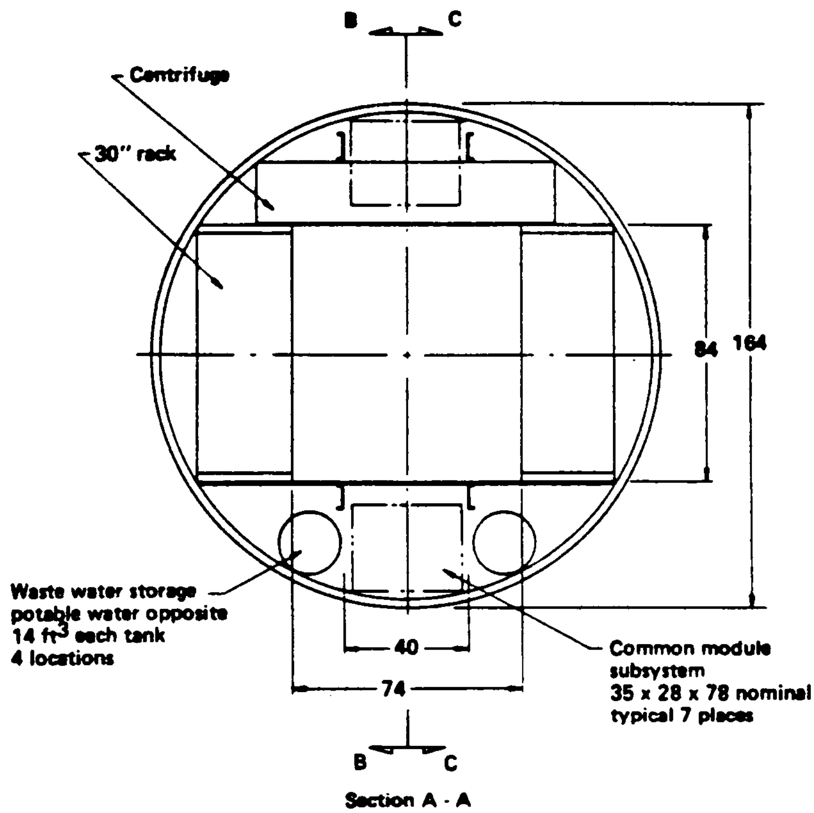


Figure 2-7. Selected IOC Module Concept

Specimen facility	Rodents		Small primates		Plants (wheat)	
	Holding units	Number of specimens	Holding units	Number of specimens	Holding units	Number of specimens
Micro-g lab racks	8	48	4	4	4	172
8-ft, 1-g control centrifuge	5	15	2	2	2	86
Total	-	63	-	6	-	258

Figure 2-8. Specimen Totals for IOC Module

plants and four plant units with 172 wheat plants per standard equipment rack. The IOC module concept is shown in figures 2-9 and 2-10.

2.4.2 Growth Module Concept

According to the space station mission data bases, the life sciences growth mission is a second laboratory module delivered and attached to the space station. Based on conclusions from the mission transition analysis (sec. 4.0), the new growth module will be

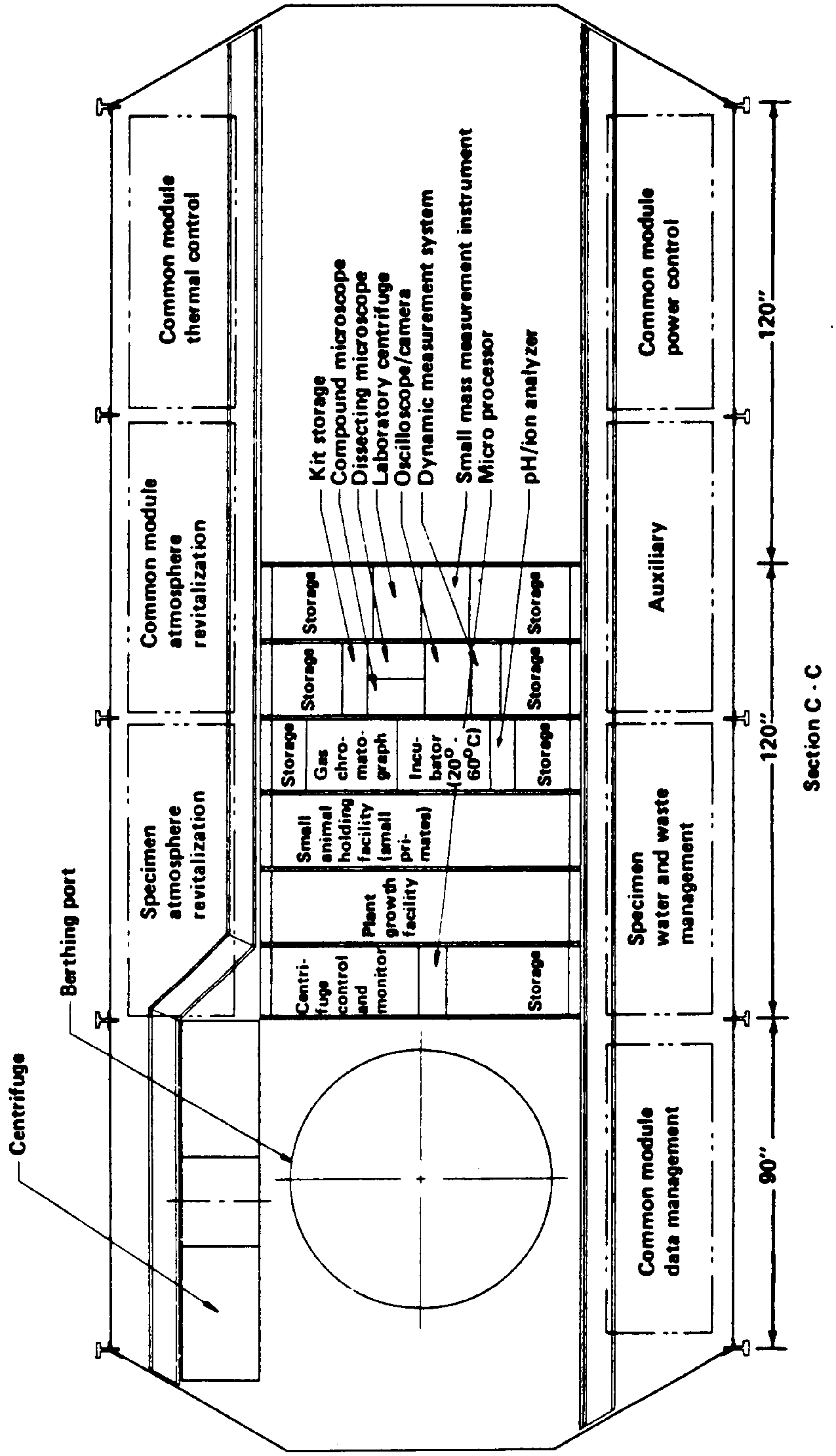
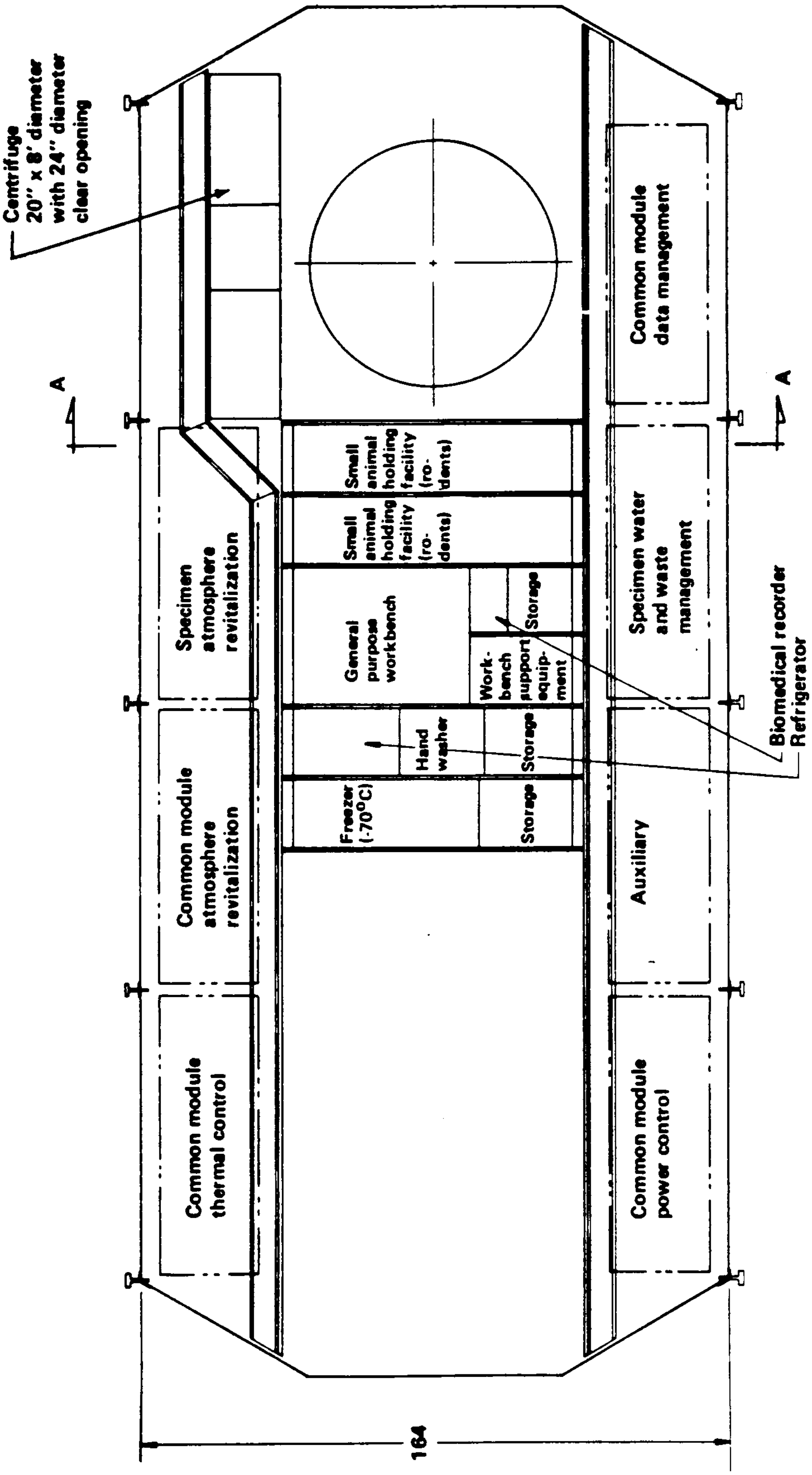


Figure 2-9. Selected IOC Module Concept - View A



Section B - B

Figure 2-10. Selected IOC Module Concept - View B

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dedicated entirely to nonhuman research. This concept features outfitting the new module on the ground and transferring the existing IOC equipment racks after the new module is delivered to orbit. The new growth module will provide 20 ft of module length for nonhuman research equipment. The module will still use 7.5 ft of length for the radial berthing ports.

The eight basic centrifuge configurations studied for IOC were used for the growth options. The major difference in configurations is the additional space available in the growth module.

The selected growth concept shown in figures 2-11 and, 2-12 was influenced by (1) the requirement for transition on-orbit from the IOC module, (2) the objective to maximize the arrangement efficiency and number of experiment racks, (3) the centrifuges and their locations, and (4) the common module configuration.

The principal features of the selected growth configuration follow:

a. The 8-ft-diameter IOC centrifuge located in the berthing port area.
b. Two 13-ft-centrifuges (one continuous running and one access).
c. Eight additional rack spaces (20 total)
d. Six single racks available for specimen holding facilities.
e. One double-wide rack for large primate facility.
f. Cage cleaning/sterilization on-orbit.
g. Specimen ECLS isolated from the crew cabin.
h. Regenerative ECLS concepts.

The 8-ft-diameter IOC centrifuge located in the berthing port area is a variable speed device that can produce an artificial g environment of 0.1g to 2.0g with a variation in RPM from approximately 8 to 39 RPM.

The 13-ft centrifuges are efficient both volumetrically and in performance. They provide the means for 1-g control specimens where the control centrifuge is running constantly. Its companion 13-ft-diameter access centrifuge is dual purpose; it allows access to the constantly running control centrifuge by having the capability for synchronizing with the control centrifuge for the transfer of plant/animal specimen habitat units. In its dual mode, the access centrifuge is used as a variable-g centrifuge with the capability for 16 specimen holding facilities (16 small primates, 48 rodents, or 16 plant units).

The three centrifuges each have their unique capabilities giving the laboratory flexibility for conducting, concurrently, several groups of test objectives with a variety of test specimens. This flexibility would probably not be used in an IOC laboratory. In the growth laboratory where considerable supporting equipment is available, the ability

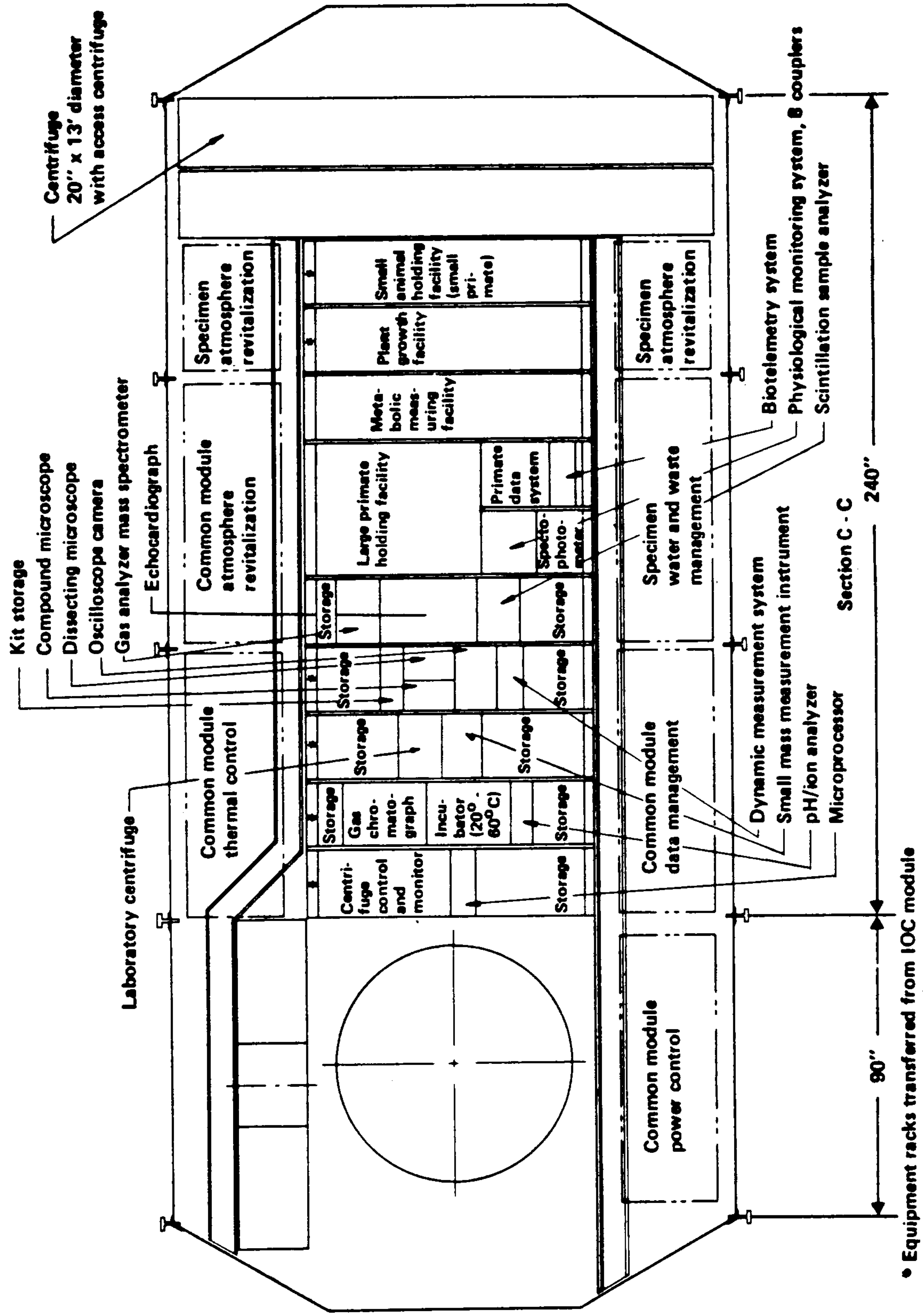

Figure 2-11. Selected Growth Module Concept - View A

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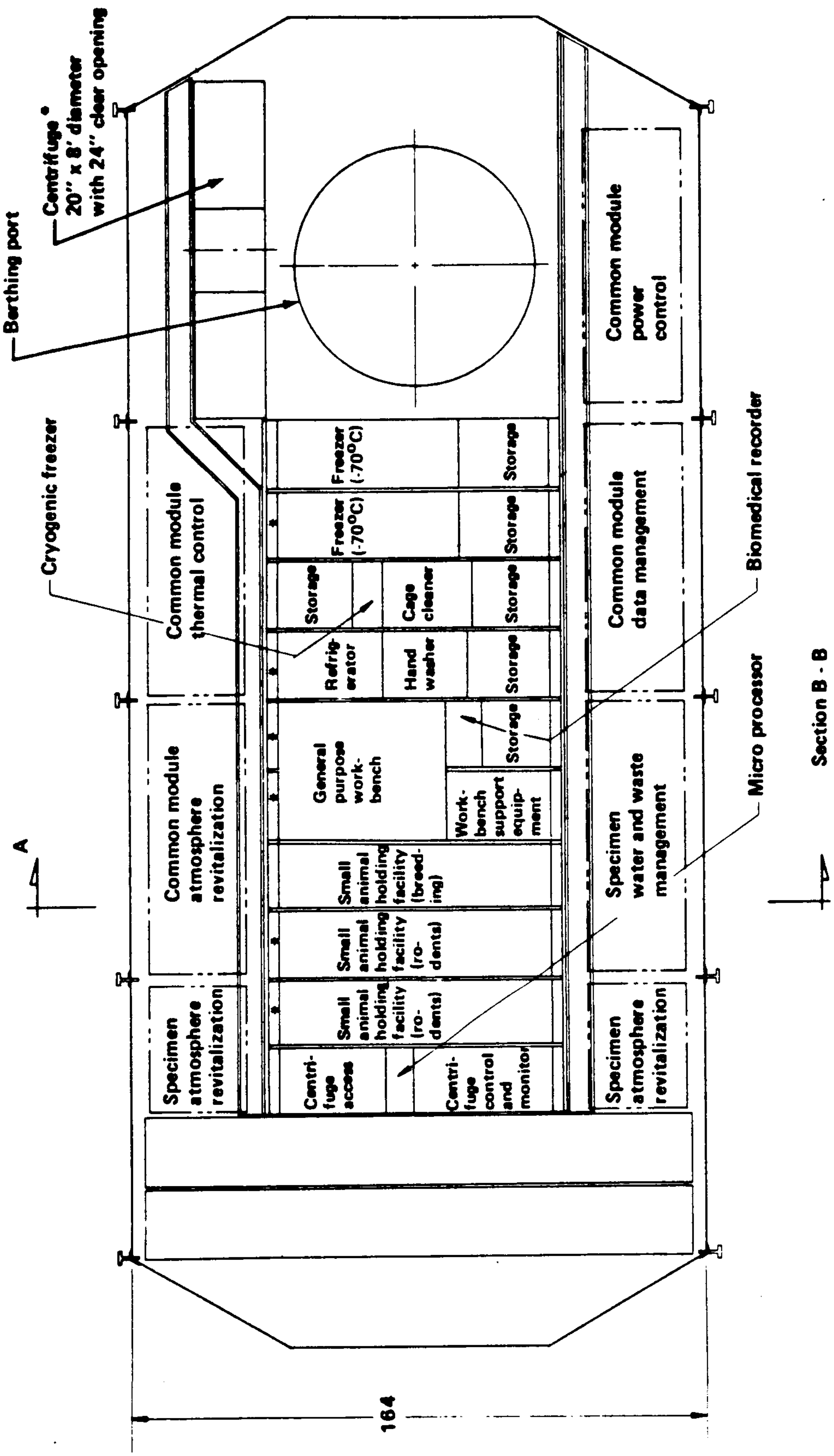

• Equipment racks transferred from IOC module

Figure 2-12. Selected Growth Module Concept - View B

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to carry-on several test programs concurrently will improve the efficiency and performance of the life sciences laboratory.

The growth module specimen capability is contained within the three centrifuges, six single racks available for specimen holding facilities, and one double-wide rack for a large primate facility. This capability is summarized in figure 2-13.

Specimen facility	Rodents		Small primates		Large primates		Plants (wheat)	
	Holding units	Number of specimens	Holding units	Number of specimens	Holding units	Number of specimens	Holding units	Number of specimens
Micro-g lab racks	12	72	4	4	1*	1	4	172
13-ft, 1-g control centrifuge	12	36	2	2	0	0	4	172
13-ft, 1-g variable-g access centrifuge	12	36	2	2	0	0	2	86
8-ft, 1-g variable-g centrifuge	7	21	0	0	0	0	2	86
Total	-	165	-	8	-	1	-	516

*One double-wide rack.

Figure 2-13. Specimen Totals for Growth Module

3.0 CRITICAL ISSUES

Five critical issues were identified during an indepth review of the previously mentioned science requirements and the space station requirements (ref. 5). The term "critical issues" as used in this document refers to those issues where the engineering or design solutions have, or could have, considerable impact on the overall laboratory facility concept and operation.

The issues identified required special study efforts to determine the full impact on design. These issues are—

a. Bioisolation technique.
b. Specimen habitat standardization.
c. Specimen cage cleaning.
d. Transport of live specimens.
e. Centrifuge sizing/placement.

3.1 BIOISOLATION TECHNIQUE

Bioisolation is the separation of the crew environment from the research specimen (plants and animals) environment to prevent microbial cross-contamination. This isolation is also extended to include the separation of the environment between species on board the life sciences laboratory.

There are several ways to accomplish bioisolation in the closed environment of a space station laboratory module. For example, isolation can be done at cage, rack, vivarium, or laboratory-module levels. Atmospheric isolation can be achieved by using air filtration techniques, by using separate ECLSS, or by constructing physical partitions (biolocks) to isolate various volumes using cleanroom technology. The physical partitioning is illustrated in figures 3-1 and 3-2 for longitudinal partitioning and figure 3-3 for transverse partitioning using a collapsible biolock device.

Atmospheric isolation by air filtration and separate ECLSS is discussed in section 4.0, Technology Issues.

3.2 SPECIMEN HABITAT STANDARDIZATION

There is a need to standardize the habitat units size and configurations. This standardization must occur between the microgravity facility, the centrifuge facilities, and the specimen transport facility for rodents, small primates, and plants. If these units are not standardized, excessive costs and crew hours will be required to operate the system. The problem of cage maintenance and cleaning will also be unnecessarily complicated.

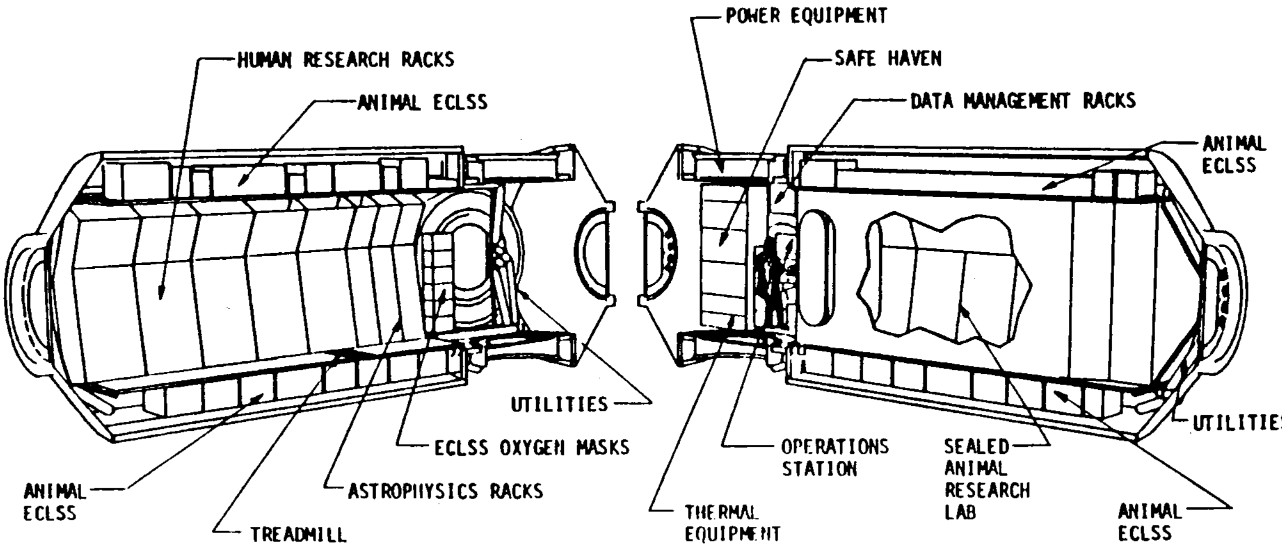

Figure 3-1. Longitudinal Bulkhead

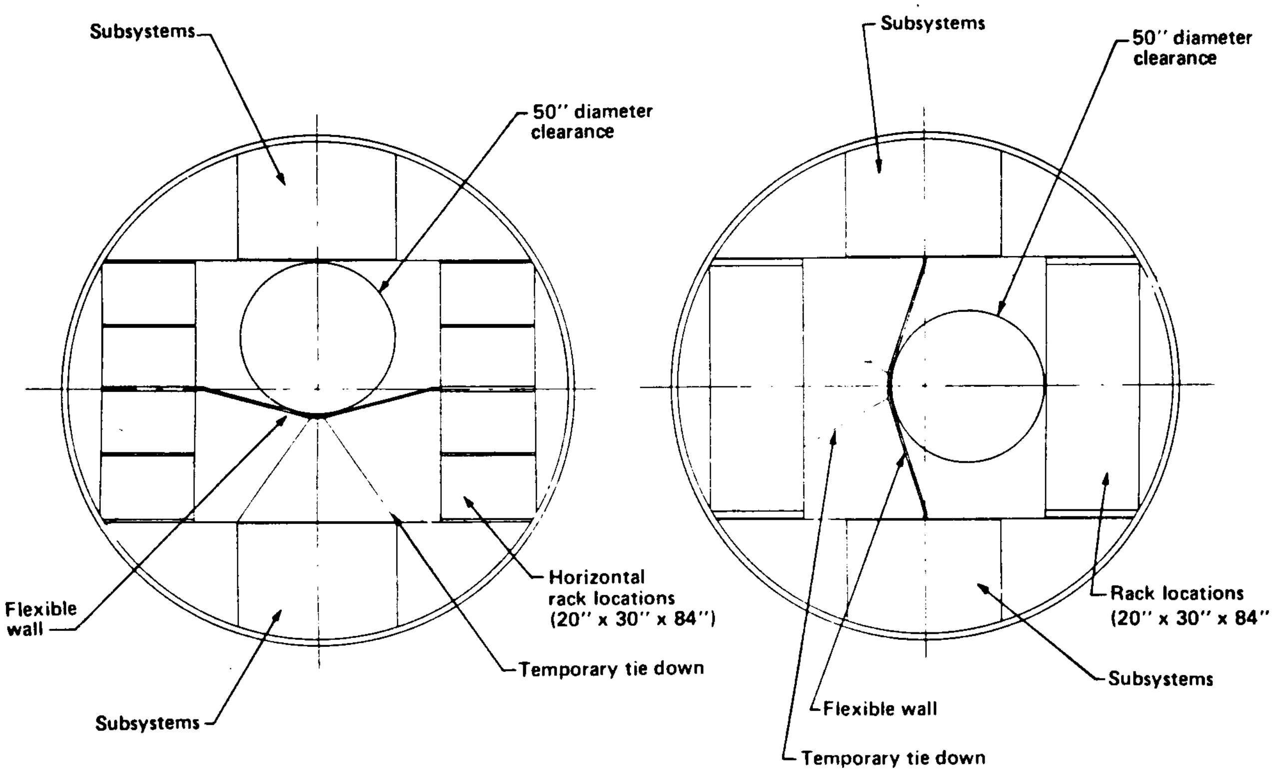

Figure 3-2. Cross Section of Longitudinal Bulkhead

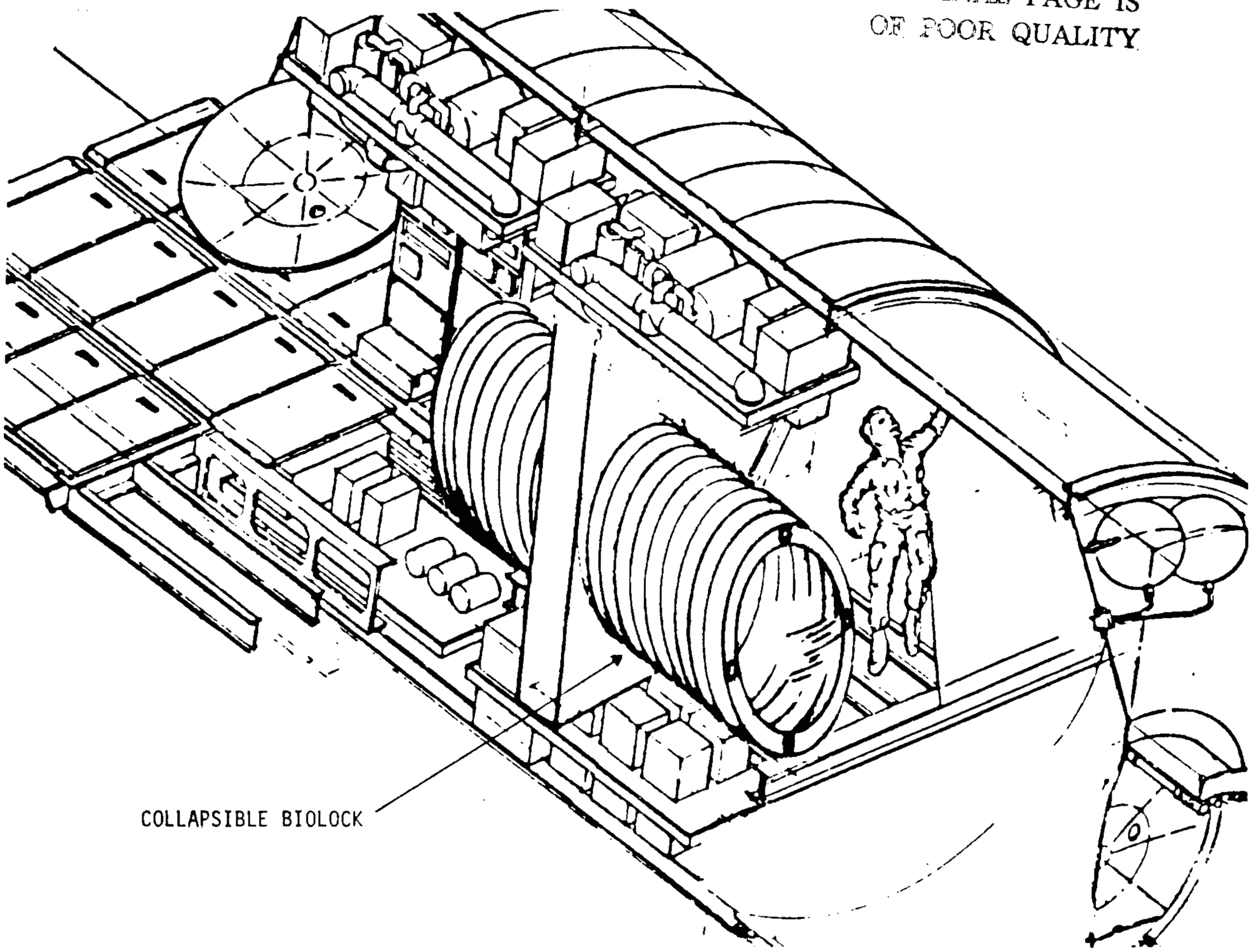

Figure 3-3. Collapsible Biolock Concept

The specimen habitat, wherever it is used, has the same fundamental functions: (1) specimen confinement (cage), (2) air supply, (3) water and food supply, (4) containment scrubber, and (5) waste management. These functional interfaces, particularly the ECLS functions, must be considered as the units are standardized in size and configuration. Individual specimen cage sizes should comply with the guidelines published by the Institute of Laboratory Animal Resources (ref. 6). Figure 3-4 shows a proposed standard habitat unit size of 17.5-in width by 14-in depth by 22-in height configured for small primates, rodents, and plants. The figure also shows how nine of these standard habitat units can be installed on an 8-ft centrifuge. Figure 3-5 shows how the proposed unit might be configured for adaptation to a rack-type facility.

3.3 SPECIMEN CAGE CLEANING

Cage cleaning seems, on the surface, to be a detail that would not require a great deal of attention. Unfortunately, that is not the case. Cage cleaning is a driving critical issue for both design of the laboratory and its operation.

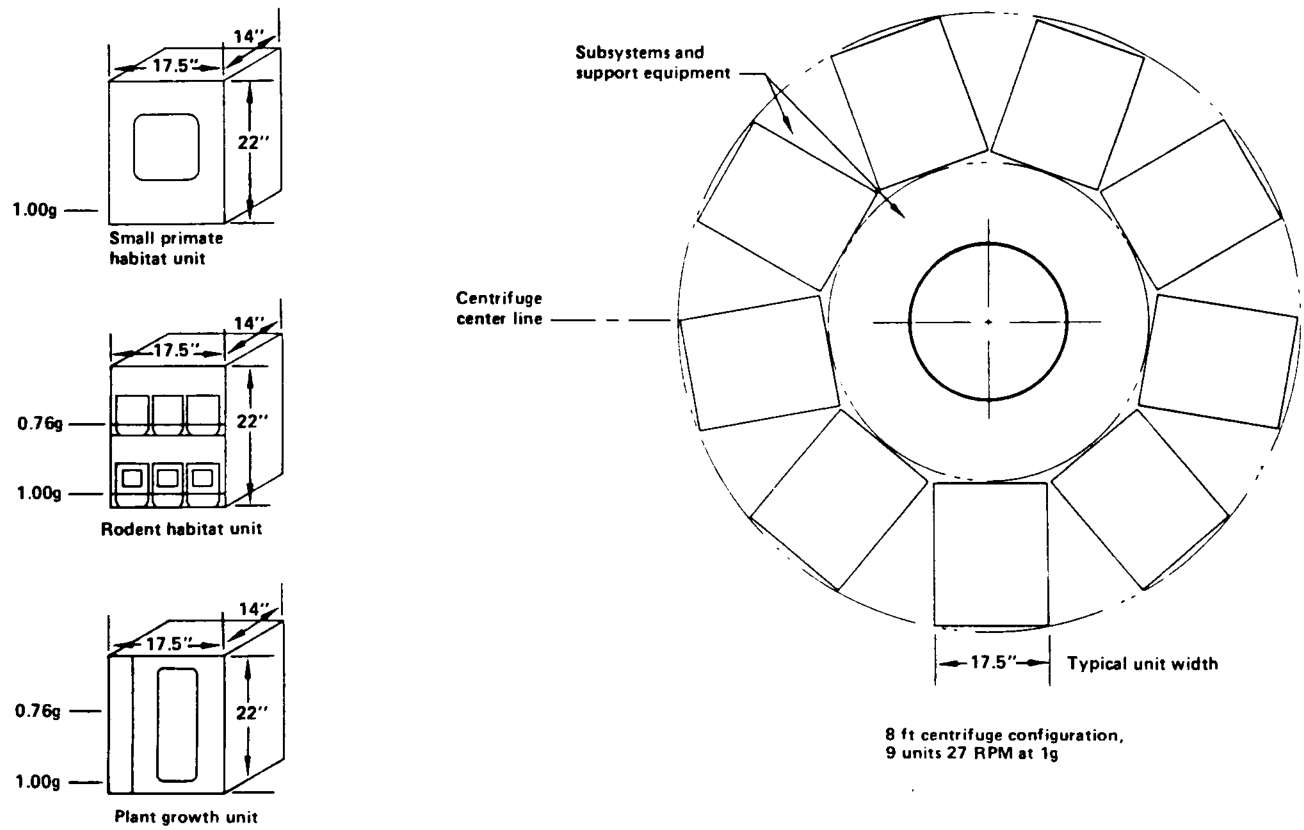

Figure 3-4. Common Habitat Unit Concept

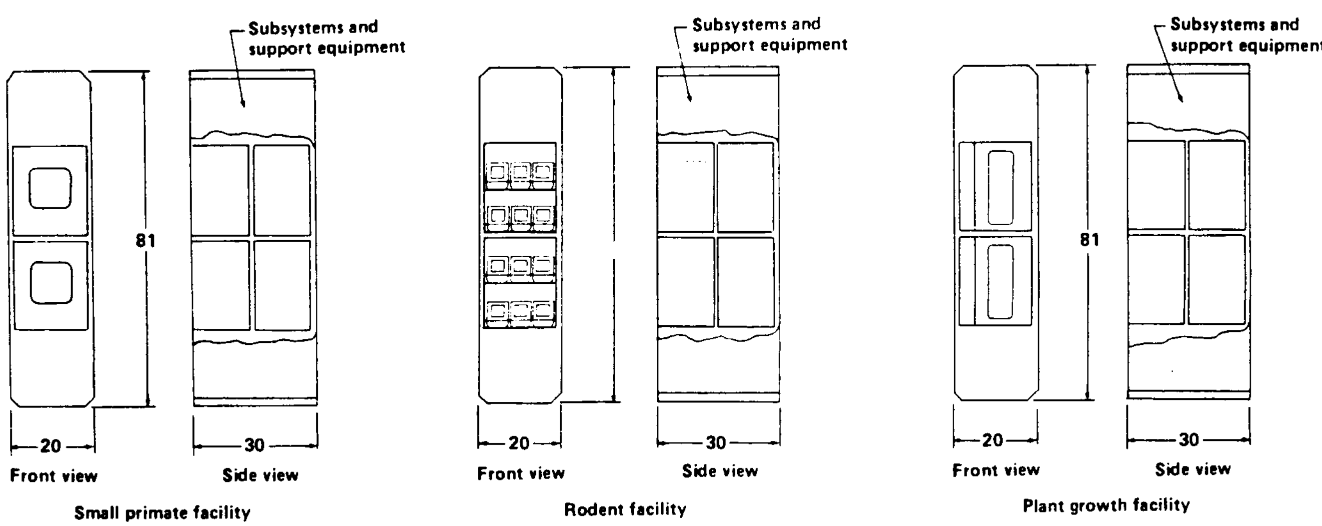

Figure 3-5. Common Habitat Facility Concept

Experience with laboratory animals has shown that rodent feces, when dried on surfaces, requires considerable scrubbing to remove. Experience to date with the Spacelab specimens indicates cage-washing every 7 days is reasonable. Cages must also be washed and sanitized before reuse. This does not appear to be a demanding task until the numbers are examined. The growth laboratory is used as an example. If the cages are cleaned every 7 days, the growth laboratory with 165 rodents will require 2121 washing operations every 90 days. In simple numbers this number of operations equates to approximately one caged washed per hour, night and day, for the life of the laboratory—a sizable on-orbit task.

There are two basic options—

a. Wash and sterilize cages on orbit.

b. Return dirty cages to Earth.

Option (a) was selected as the method for the growth laboratory and is discussed in section 4.0, Technology Issues. Option (b) was adopted for the IOC laboratory and is an outgrowth of the specimen habitat standardization issue. To facilitate this option, a replaceable cage liner with high-density packing capability is required. As cages require cleaning, the liners are replaced with clean units stored in the logistics module. The replaced units are disassembled to fold flat for prepackaging and storage for return transport. Rodents chew uncontrollably, particularly on plastics and wood; therefore, the cage material used in this concept was stainless steel. Figure 3-6 shows a collapsible cage concept for rodents. Each cage weighs 3.65 lb.

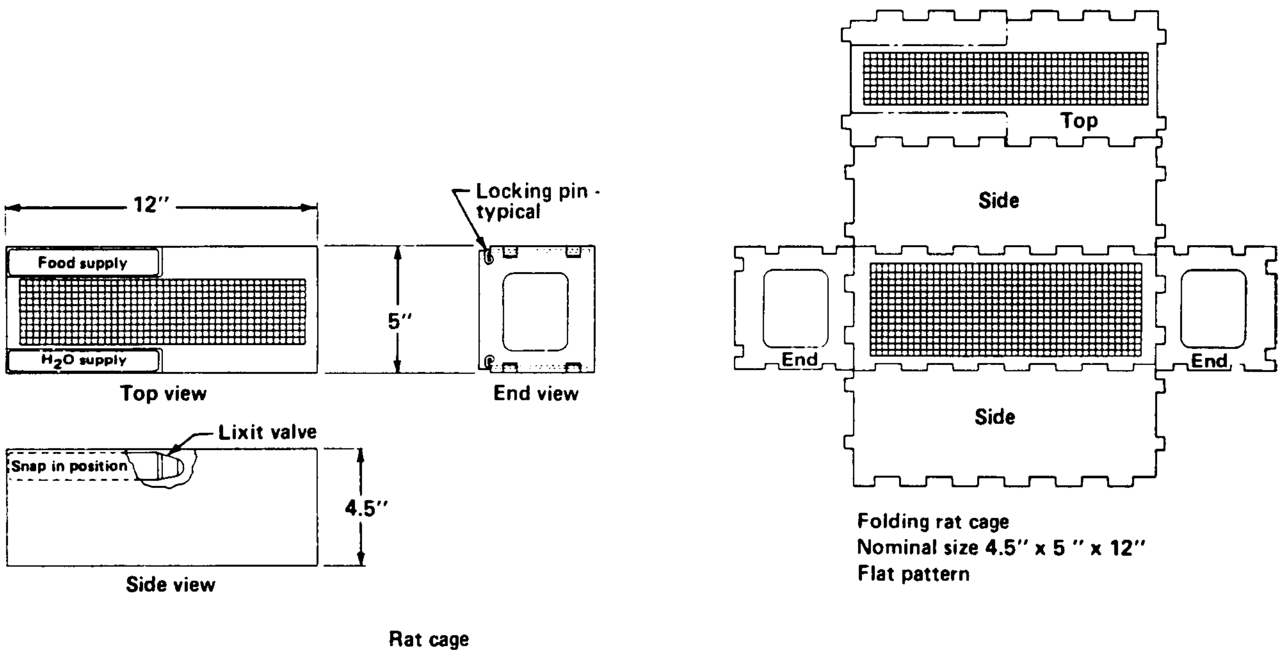

Figure 3-6. Collapsible Cage Concept

The number of liners and their mass and storage volume for the IOC and Growth Laboratory Concepts are presented in figure 3-7. These data indicate that when the specimen population approaches the numbers represented by the growth concept, the ground cage-cleaning concept is no longer practical. The growth cage cleaner/ sterilizer/water processing is discussed in section 4.0 Technology Issues.

Returnable liners (90 days)	IOC Number	Mass (lb)	Storage volume (ft^3)
• Rodents (63)	810	2,957	23.4
• Primates (small) (6)	78	1,690	10.4
IOC total	888	4,647	33.8

	Growth Number	Mass (lb)	Storage volume (ft^3)
• Rodents (165)	2,121	7,743	61.2
• Primates (small) (8)	103	2,231	13.8
• Primate (large) (1)	13	1,037	4.6
Growth total	2,237	11,011	79.6

Assumes:
Stainless steel (GA 3/64 in)
Except large primate (GA 1/16 in)
Weekly cage changeout

Figure 3-7. Returnable Cage Logistics

3.4 TRANSPORT OF LIVE SPECIMENS

The life sciences experiment program will require replacement specimens (animals) every 90 days. The transport of these rodents and primates requires containment and life support. This logistics problem is complicated by the absence of ECLS in the space station logistics module, as defined by the Boeing proposal. Any ECLS support to specimen transport must be added to the logistics module or included in the transport facility equipment for installation in the logistics module. The transport facility specimen holding units must also have the capability to be oriented appropriately to launch and reentry accelerations as experienced in the logistics module transported in the orbiter cargo bay.

The specimen transport facilities are envisioned to contain several experiment racks. These facilities will include the ECLSS and the specimen holding units, and have provisions for animal transfer to the on-orbit laboratory specimen holding facilities. The specimen transport facility will have a sizable impact on the logistics module. An indepth analysis is required in the future to resolve the detailed requirements and interface with the logistics module. Potentially, these requirements could have severe impacts on the space station logistics system.

3.5 CENTRIFUGE SIZING/PLACEMENT

The space station can accommodate a centrifuge diameter range to approximately 13 ft. The smallest diameter is dictated by the specimen foot-to-head gravity gradients that would be experienced. In the past, 15% or less has been recommended. Figure 3-8 shows the 15% gradient relationship of an 8-ft-diameter centrifuge. A 15% gravity gradient limits the size of specimen that could be accommodated, in this case approximately 7.2 in in height. Under this guideline, rodents and small plants can be accommodated; however, squirrel monkeys are borderline, as their average sitting height is about 10 in. An 8-ft-diameter centrifuge is the smallest centrifuge that should be considered.

The largest diameter, 13 ft, is limited by the common module diameter. The gravity gradient relationship for a 13-ft centrifuge is approximately 12 in specimen height. This

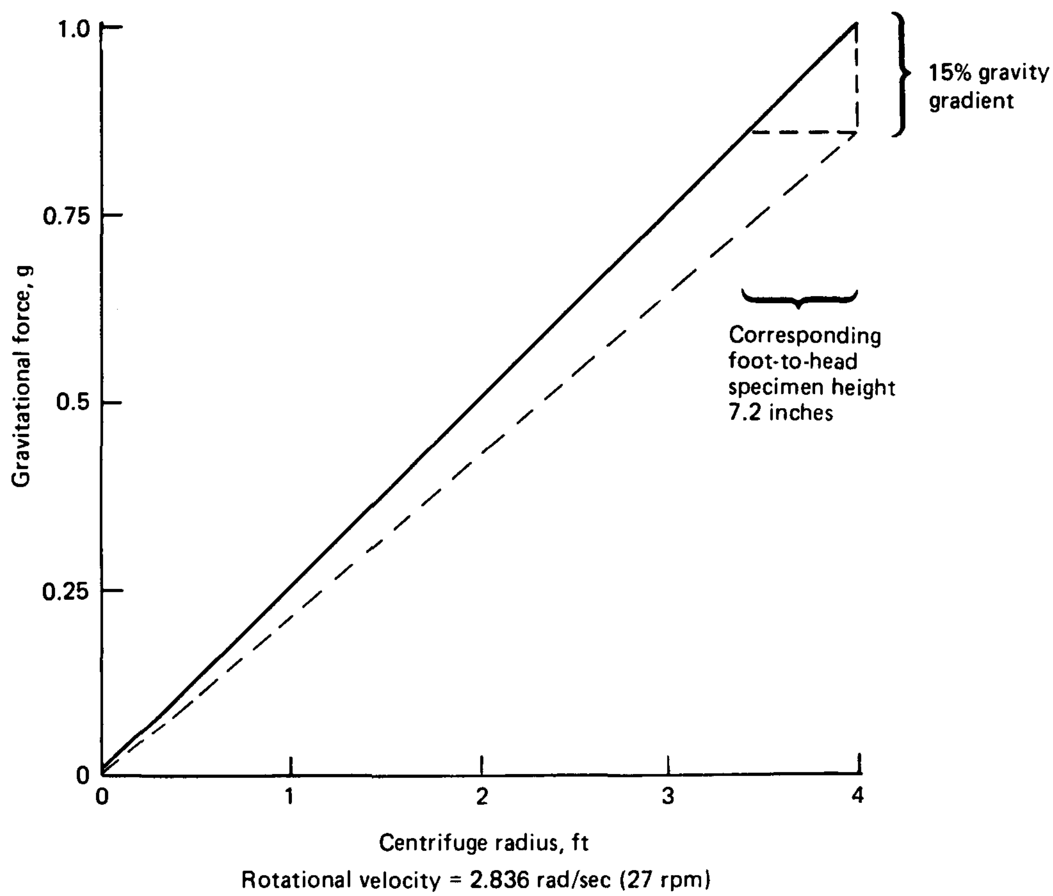

Figure 3-8. Gravity Gradient Relationship for 8-ft Diameter Centrifuge

size centrifuge could accommodate plants, rodents, and squirrel monkeys; a Rhesus monkey (approximately 24 inches sitting height) would experience about a 31% gravity gradient across its body.

More specimens can be accommodated as the centrifuge diameter increases; however, the volume occupied also increases; an 8-ft centrifuge will accommodate approximately 9 habitat units; a 13-ft centrifuge approximately 18 habitat units. The size of each species habitat is a variable that has been discussed earlier under habitat standardization.

Science requirements require removing specimens from the centrifuge at predetermined times, which means stopping and starting the centrifuge every few days. This exposes the remaining specimens to a variety of disturbing conditions (probably undesirable). It is not clear at this time if there is a firm requirement for a continuously running centrifuge or if periodic stopping and starting is acceptable. As can be seen, the laboratory arrangement is greatly influenced by the number and placement of the centrifuges. This issue must be settled very early in the laboratory development.

4.0 TECHNOLOGY ISSUES

Four areas have been identified as candidates for advanced technology development activity.

a. Bioisolation/ECLSS closure.
b. IOC and growth centrifuges.
c. Cage cleaner/sterilizer/water processing.
d. Specimen transport facility.

In a priority sense, each of these technology developments occupies equal importance. There may be a reluctance to initiate early action on cage cleaner/sterilizer/water processing since it is associated with the growth laboratory; that could be a mistake. An early solution is crucial to the successful design and operation of the growth laboratory.

4.1 BIOISOLATION/ECLSS CLOSURE

Advanced technology development activities are required to obtain the degree of ECS closure needed while maintaining bioisolation of the specimen facilities and the crew cabin. Three basic options were evaluated during this study.

Option 1 - Specimen Facilities Use LSRF Cabin Air. In this option, the specimen ECS is a system shared with the crew cabin ECS. The common module equipment supplies makeup oxygen and removes excess carbon dioxide from the air. The shared ECS system schematic (figure 4-1) depicts the common-module ECS supplying air to the specimen facilities through a 0.3-μm microbial filter and a humidity-control heat exchanger. The condensate is returned to the space station ECS for processing. The air is supplied to the specimen cages with a recirculation loop for temperature regulation. Cage exhaust air is directed through a condensing heat exchanger with the recovered water. Directed to animal waste water processing and storage. Before return circulation, the air is processed through an activated charcoal bed and a microbial filter, followed by CO_2 removal.

Option 2 - Specimen Facility Isolated From Cabin Air. Option 2 is a more conservative approach involving physically separating the two environmental control systems (i.e., man and research specimens). Microbial and odor filters are still included in the ECS, but if the filters should fail, cross-contamination will not occur with the

crew ECS. This option would be more costly than option 1; however, it provides a more positive approach to bioisolation (Figure 4-2.).

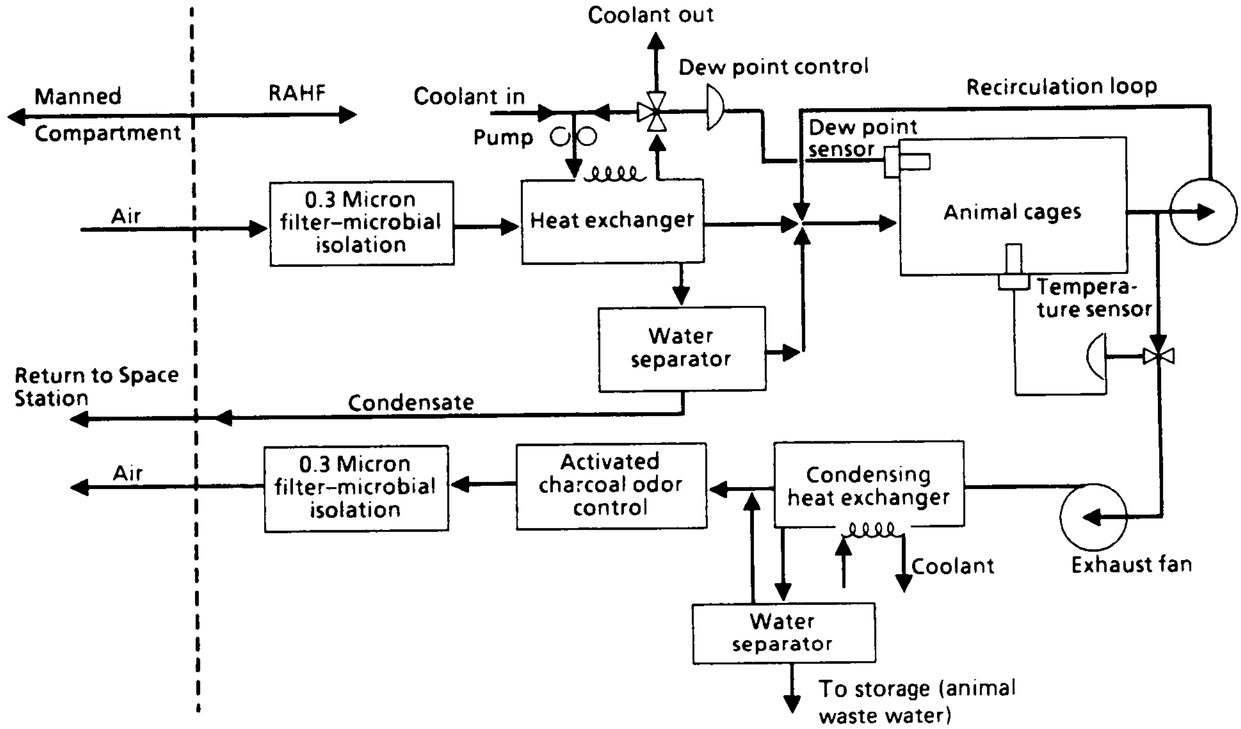

Figure 4-1. Specimen Facility ECS - System Shared With Crew Cabin ECS

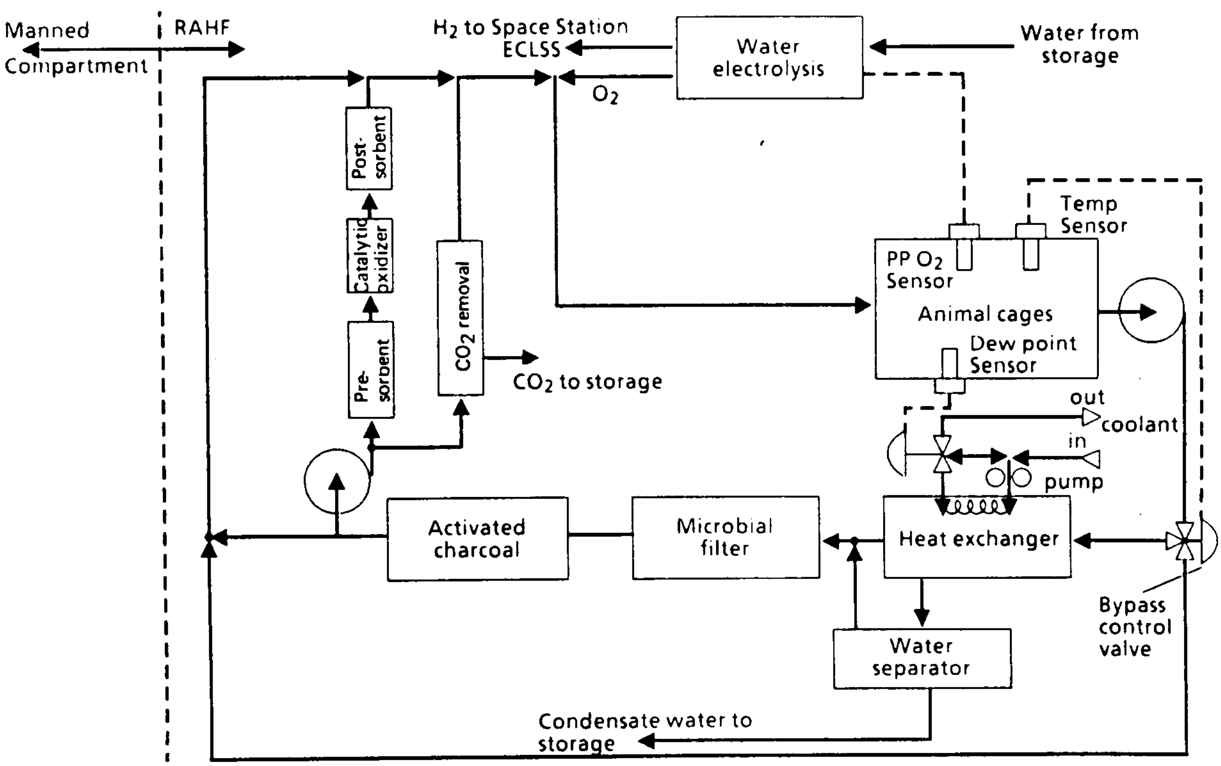

Figure 4-2. Specimen Facility ECS - System Isolated From Crew Cabin ECS

Option 3 - Biolocks Added to Option 1 or 2. The third option considers the addition of partitions (biolocks) as a means of physically isolating portions of a module containing nonhuman holding facilities from the remaining laboratory volume. Biolocks were considered to be "secondary line of defense" for option 1 or 2. They provide an airlock-type mechanical barrier for which small pressure differentials can be maintained between two compartments allowing air to flow in only one direction.

This is just a sample of the potential approaches that require evaluation in order to settle upon a long-term solution toward definition of the advanced technology development required. It should be emphasized that the system approach settled upon must integrate well with the ECS processes adopted for the space station system.

4.2 IOC AND GROWTH CENTRIFUGES

This study has defined the IOC and growth centrifuge arrangements that fit the existing requirements. These centrifuges have been defined as critical issues because they drive the design, arrangements, and transition approach for the IOC and growth laboratories. Because they are a very costly and highly complex equipment, they have been identified as an advanced technology item. They are potentially long-term developments that must include considerations of laboratory standardization of habitats, bioisolation, integration with the ECS system, satisfying the specimen experiment requirements for various artificial "g" conditions, and integrating compatibility with the space station common module structural, mechanical, and electrical interfaces.

4.3 CAGE CLEANER/STERILIZER/WATER PROCESSING

This study defined the importance and the dependence of the growth laboratory on the availability of a cage cleaner/sterilizer equipment unit as a standard laboratory equipment item. The study emphasized the requirement for a cage cleaner. It was also determined that the technology required is not directly available and must be developed. This advanced technology development divides into three principal developments: (1) cage cleaner, (2) cage sterilizer method, and (3) water processing. Of the three, the water processing method is the most critical because of its potential effect on laboratory logistics. There is a strong question as to the degree that cage cleaning water can be processed for reuse. Contamination from feces and cleaning chemicals may require frequent changeout of cleaning water or solvent. The issues of reprocessing cleaning water must be resolved since it can have far-reaching effects on laboratory logistic requirements and their associated costs.

4.4 SPECIMEN TRANSPORT FACILITY

This facility in an abbreviated form must be available for the IOC life sciences laboratory facilities. If there are to be live animal specimens involved in space there must be a specimen transport facility available to transport specimens to and from orbit in the logistics module. The space station logistics supply system is very heavily loaded for supplying the space station. A specimen transport facility is a fixed facility within the logistics module and therefore has potentially heavy impact on the logistics capacity. This potential impact is complicated by the requirement for bioisolation of the specimen transport facility from the logistics module environment. The added ECS equipment can further aggravate the weight/volume/power impacts.

The advanced technology development is potentially a major cost item and could involve complex interface issues with the space station logistics system.

5.0 PROGRAMMATICS

LSRF programmatic factors were developed during this study. The study products are a work breakdown structure (WBS) and WBS dictionary, a life sciences program schedule, and cost estimates for the IOC module and the growth module. These programmatics are based on the selected IOC and growth configurations.

5.1 WORK BREAKDOWN STRUCTURE

The WBS and WBS dictionary were developed to provide the framework for task planning and control. The WBS is the basis for budgeting, task assignment, cost collection, and reporting, and is the contract document that permits contractual performance measurement and tracking of the full-scale development phase tasks. The WBS was developed around the concept of a module outfitting contractor. A common module is supplied at level 3 as a built-up unit containing the outfitting accommodations. A life sciences (nonhuman) module outfitting task is defined at the same level with an integration and assembly task to produce a life sciences module system, task 5.0 at level 2. The laboratory equipment is supplied to the outfitting task from level 4 in conjunction with subsystems and utility networks. This provides a logical planning and cost accumulation framework. The life sciences program scope and general organization of the WBS are shown in figure 5-1. The complete WBS and dictionary are documented in reference 1.

5.2 SCHEDULE

A program schedule was developed in accordance with the WBS. The schedule (fig. 5-2) represents the system definition and development, and design and test of the IOC and growth life sciences (nonhuman) laboratory. Included is the supporting research and technology (SR&T) in advance of system development. It is apparent that equipment SR&T activity should be under way by early 1986 to support the IOC module development.

Delay in SR&T for critical and unique items will increase the program risk factors. The most critical items for IOC are (1) new specimen holding facilities for both the micro-g and artificial gravity environments to support long-duration research, (2) specimen centrifuge for artificial gravity requirements, and (3) sample preservation system for freezing specimen tissues (-70° to $-195^{\circ}C$). Another critical item is a specimen cagewasher and sterilizer. The washer may not be required for IOC but will certainly be needed for growth.

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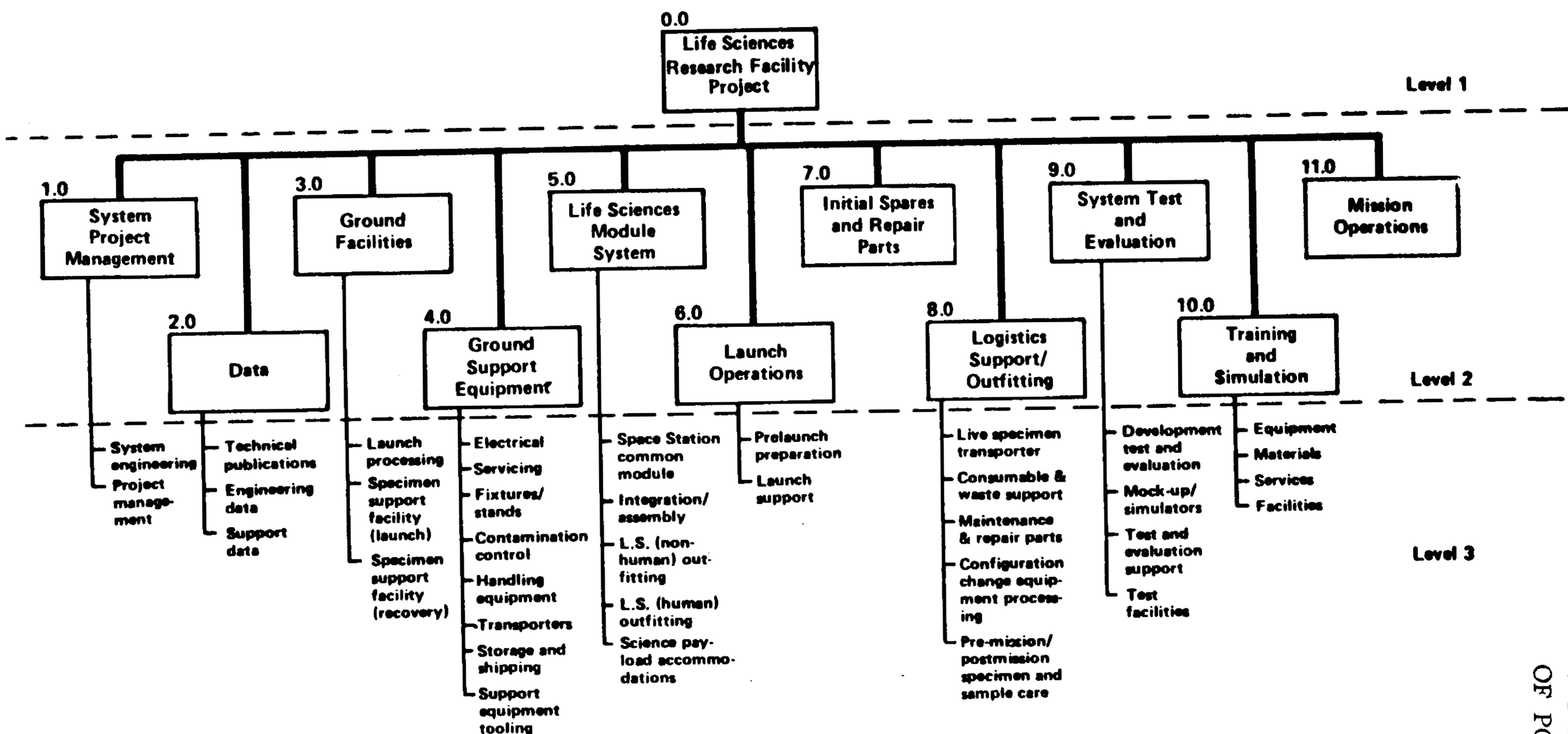

Figure 5-1. Work Breakdown Structure for the LSRF Projet

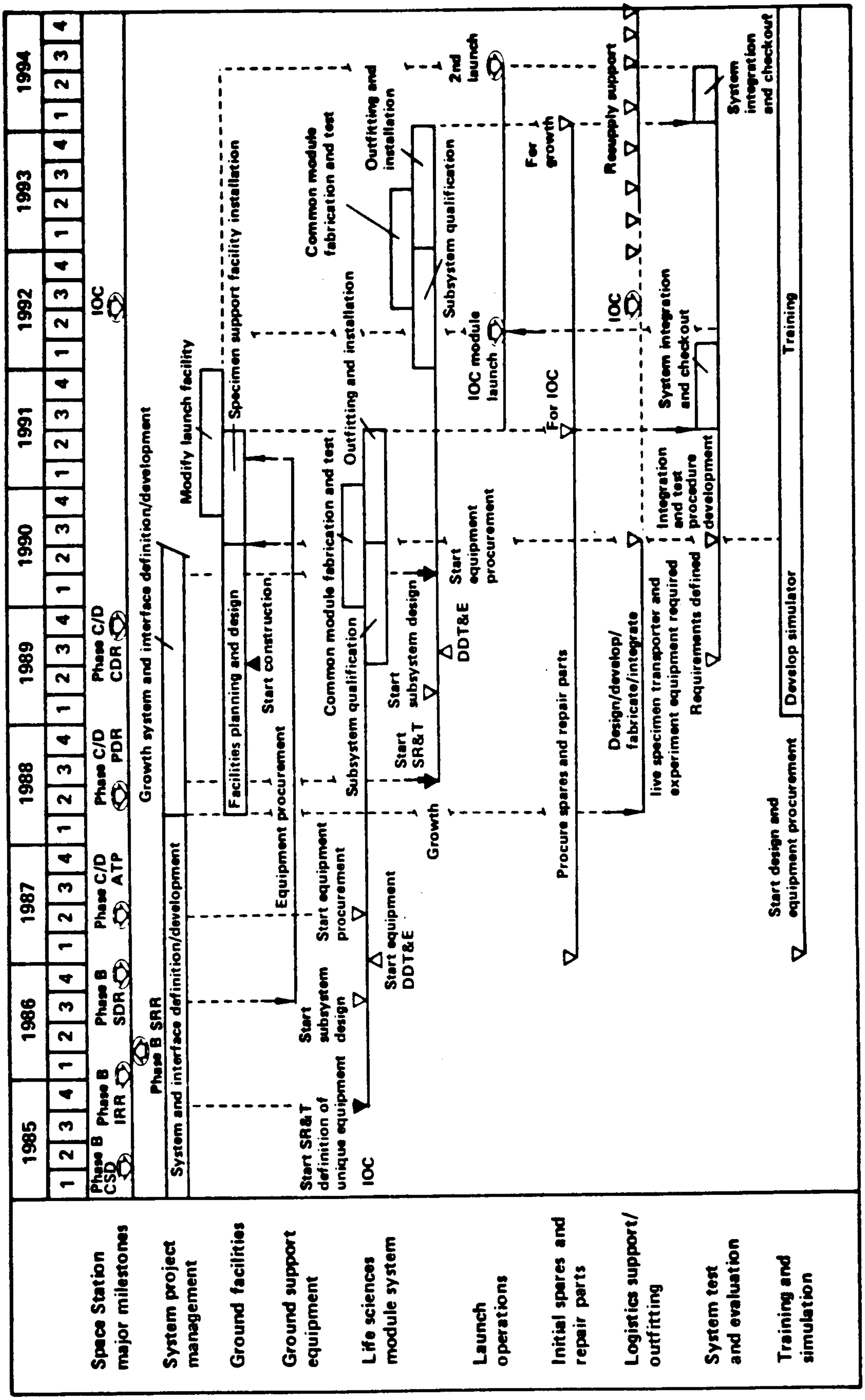

Figure 5-2. Life Sciences Research Facility Development and Operations Schedule

5.3 COST

Program costs were developed for the outfitted IOC and growth module concepts. Costs were also developed for a unique growth module concept that assumed there was no shared laboratory capability at IOC. The cost estimates were made using computer-based cost modules. The Boeing-developed, parametric cost module (PCM) was used to estimate the cost of all mechanical hardware, integration, and assembly of equipment, and the cost of such support functions as system engineering and integration, system test, software, peculiar support equipment, tooling, liaison, data, and program management. The RCA PRICE H module was used to estimate the cost of electronics.

5.3.1 IOC Costs

The estimated cost for the IOC module and LSRF outfitting is $273.3 million, as shown in figure 5-3. This cost includes the estimated price of a space station common module (excluding all nonrecurring design costs) plus the outfitting costs for the nonhuman research portion of the shared module. The cost of laboratory equipment includes an 8-ft centrifuge and 12 racks of equipment items.

Items	Cost $ million	
Laboratory common module *		$162.8
Life Sciences module outfitting (non-human)**		110.5
Structures and mechanisms	6.0	
Electrical power	Common module	
Thermal control	Common module	
Data management	Common module	
ECLSS	14.7	
Communications and tracking	Common module	
Distribution utility networks	Common module	
Laboratory equipment	62.7	
Project management	6.3	
Data	1.8	
Final assembly and checkout	4.9	
Initial spares	2.0	
Peculiar support equipment	2.1	
Tooling and special test equipment	0.7	
System test	3.7	
Software	1.1	
System engineering and integration	3.4	
Liaison engineering	1.1	
Total cost		$273.3

* Included is a rough order of magnitude cost to build one laboratory common module including management, tooling and support equipment costs. Excluded are all non-recurring design costs.

** The Life Sciences module outfitting includes both non-recurring and recurring costs.

Figure 5-3. IOC Configuration Cost Summary

5.3.2 Growth Cost

Figure 5-4 summarizes the growth module cost. This cost, $311.6 million, is in addition to the IOC module cost and includes a second common module and the additional laboratory equipment required for nonhuman portion of the growth capability. This additional equipment includes two 13-ft centrifuges and eight additional racks of equipment.

Items	Cost $ million	
Laboratory common module*		$162.8
Life Sciences module outfitting (non-human)**		148.8
Structures and mechanisms	11.6	
Electrical power	Common module	
Thermal control	Common module	
Data management	Common module	
ECLSS	27.0	
Communications and tracking	Common module	
Distribution utility networks	Common module	
Laboratory equipment	60.9	
Project management	11.6	
Data	3.3	
Final assembly and checkout	8.8	
Initial spares	2.6	
Peculiar support equipment	4.3	
Tooling and special test equipment	1.2	
System test	7.8	
Software	2.0	
System engineering and integration	5.7	
Liaison engineering	2.0	
Total cost		$311.6

* Included is a rough order of magnitude cost to build one laboratory common module including management, tooling and support equipment costs. Excluded are all non-recurring design costs.

** The Life Sciences module outfitting includes both non-recurring and recurring costs. This case also assumes the transfer of the IOC lab equipment to the growth module.

It was also assumed the additional ECLSS and structure needed for the IOC module would not be transferred to the growth module.

Figure 5-4. Growth Configuration Cost Summary

6.6 REFERENCES

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