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Conceptual Design
and Programmatics

BOEING

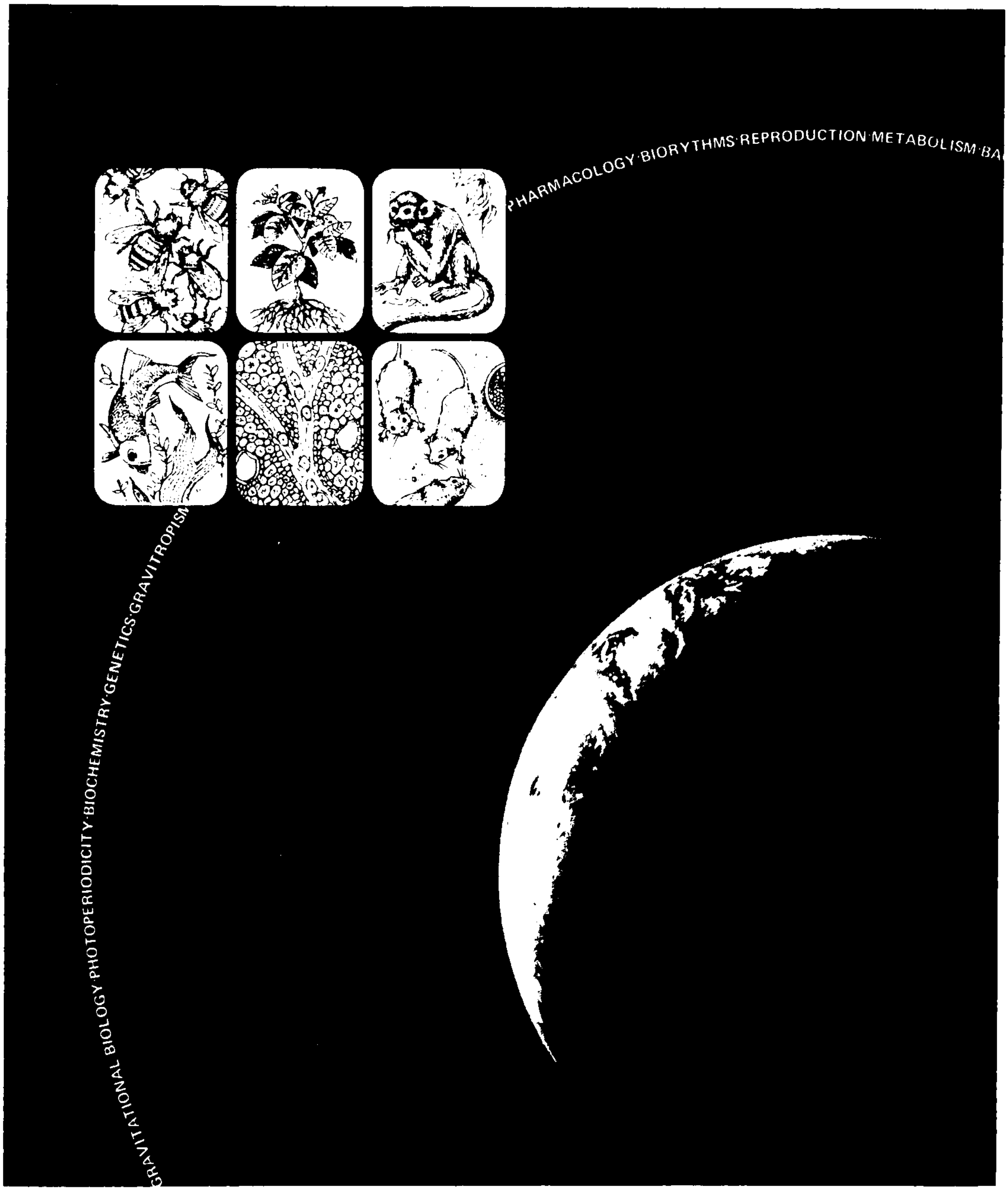
Technology Incorporated

NASA

Final Report
Volume II
Attachment II

October 1985

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



(NASA-CR-179272) SYSTEM ANALYSIS STUDY OF SPACE PLATFORM AND STATION ACCOMMODATIONS FOR LIFE SCIENCES RESEARCH FACILITIES. VOLUME 2: STUDY RESULTS, ATTACHMENT 2. PHASE A: CONCEPTUAL DESIGN AND PROGRAMMATICS Final G3/18

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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 II - STUDY RESULTS
ATTACHMENT II

PHASE A
CONCEPTUAL DESIGN
AND
PROGRAMMATICS

D180-27863-2 II

OCTOBER 1985

For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MARSHALL SPACE FLIGHT CENTER

HUNTSVILLE, AL 35812

Prepared by: Lowell F. Wiley
Lowell F. Wiley

Approved by: Edith A. Gustan
Edith A. Gustan
Study Manager

Richard L. Olson
Richard L. Olson, PhD.
Manager Crew
Systems/Life Support

Boeing Aerospace Company
P.O. Box 3999
Seattle, Washington 98124

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LIST OF ACRONYMS AND ABBREVIATIONS

100K	Class-100,000 cleanroom
10K	Class-10,000 cleanroom
AEM	animal enclosure module
ASE	airborne support equipment
ATMO	Atmosphere Control System (a design function)
BAC	Boeing Aerospace Company
CDG	Concept Development Group
CDR	critical design review
CELSS	controlled ecological life support system
CER	cost estimating relationships
CG	center of gravity
CHEM	Chemical Analysis Instrumentation (a design function)
CONF	Confinement System (a design function)
CONS	Consumables (a design function)
CSD	contract start date
DATA	Data Management System (a design function)
DDT&E	design, development, test, and evaluation
ECLS	environmental control life support
ECLSS	environmental control life support system
ECS	environmental control system
ELEC	Electrical Power Management System (a design function)
EM	engineering model
EMER	Emergency Power System (a design function)
EMU	extravehicular mobility unit
EOC	end of contract
ESE	Experiment Support Equipment (a design function)
EVA	extravehicular activity
g	gravity

GSE	ground support equipment
HVAC	heating, ventilation and air conditioning
HYG	Hygiene (a design function)
IOC	initial operational capability
IRR	interface requirements review
IVA	intravehicular activity
KSC	Kennedy Space Center
LIGH	Illumination (a design function)
LM	logistics module
LSRF	life sciences research facility
MICR	Microscopy (a design function)
MIT	Massachusetts Institute of Technology
MMU	manned maneuvering unit
MMSE	multimission support equipment
MPS	materials processing in space
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
O&C	operations and checkout
OMV	orbital maneuvering vehicle
OPF	orbiter processing facility
ORU	orbital replacement unit
OTV	orbital transfer vehicle
PCM	parametric cost model
PDR	preliminary design review
PI	principal investigator
P/L	payload
PRICE H	RCA hardware estimating model

RAHF	research animal holding facility
REFR	Refrigeration (a design function)
RFP	request for proposal
RQ	respiratory quotient
RSS	rotating service structure
SDR	system design review
SIMG	Gravity Simulation (a design function)
SL	Spacelab
SLF	shuttle landing facility
SR&T	supporting research and technology
SS	Space Station
STOW	Storage (a design function)
STRU	Structures (a design function)
STS	Space Transportation System
SWST	Solid Waste Management System (a design function)
TBD	to be determined
TDRSS	Tracking and Data Relay Satellite System
THER	Thermal Control System (a design function)
TRAN	Transportability (a design function)
VAB	Vehicle Assembly Building
VPF	vertical processing facility
WBS	work breakdown structure
WWTR	Water Management System (a design function)

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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 the 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

Part 3 documentation - dated October 1985.

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

1.0 INTRODUCTION

1.1 OVERVIEW

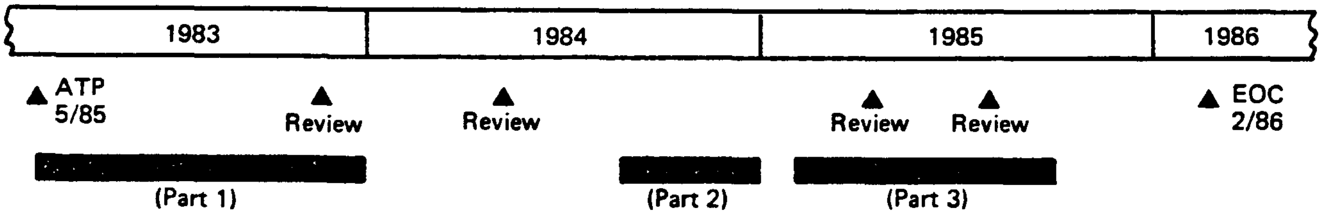
A Phase A study, "System Analysis Study of Space Platform and Station Accommodations for Life Sciences Research Facilities," was conducted for the NASA Marshall Space Flight Center (MSFC). The study was conducted in three parts over a 3-year period. Figure 1.1-1 shows the study schedule and the documentation 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 presents the study results from the conceptual design and programmatics segment (part 3) of the contractual effort. The document is submitted as attachment II to volume II of the final report for the System Analysis Study of Space Platform and Station Accommodations for Life Sciences Research Facilities. In addition to this document (attachment II Study Results), three appendixes have been added to transmit the detailed data that were developed from this effort. These appendixes cover (1) requirements, appendix D; (2) WBS and WBS dictionary, appendix E; and (3) conceptual layouts and drawings, appendix F.

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).



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
  Volume III – Final briefing book

- Part 2 – Indepth Trade Analysis
  Volume II, Attachment I – Study Results

- Part 3 – Conceptual Design and Programmatics
  Volume II, Attachment II – Study Results
    Appendix D – Requirements
    Appendix E – Work Breakdown Structure and Dictionary
    Appendix F – Conceptual Layouts and Drawings

Figure 1.1-1. Study Schedule and Documentation

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 1.4-1 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 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.

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

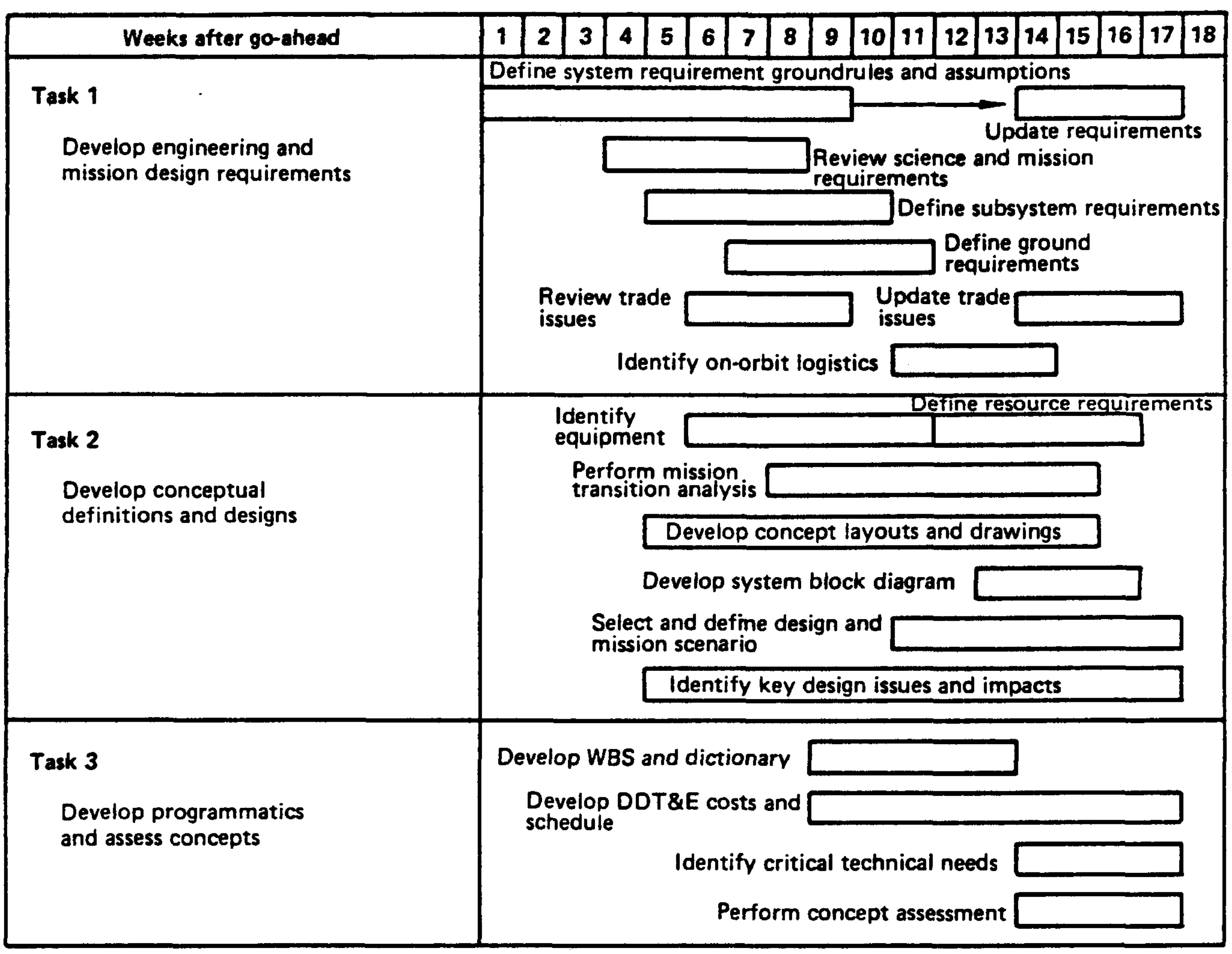


Figure 1.4-1. Part 3 Study Schedule

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 was developed. In parallel with the design activity, a mission description and mission scenario was 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 constrain 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 utilize 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 SUMMARY

This section summarizes the results and significant findings of the conceptual design and programmatics portion of the Phase A study. The major task activities were—

a. Review and update engineering and science requirements.
b. Analyze life sciences mission transition scenario.
c. Review and update key trade issues.
d. Develop conceptual definition and designs.
e. Develop WBS and WBS dictionary, program schedule, and estimated costs.

Requirements. Requirements for this study were collected from several sources. They were reviewed and collated into a requirements document, and published as appendix D to this report. The document format was modeled after attachment C4 (Space Station System Requirements) to the NASA Space Station Phase B RFP (ref. 10). The requirements document forms the foundation for the LSRF system specification and can readily be updated as program definition matures.

The key life sciences requirements that were identified are listed below:

a. Provide micro-g, one-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 into standard equipment racks within the common module.

Mission Transition. The life sciences missions stated in the Space Station Mission Data Base describe a laboratory module to be put into service at space station initial operational capability (IOC). This module is to be shared between a human research facility and a nonhuman research (plant and animal) facility. A second (growth) module is planned for delivery to orbit approximately 2 years after IOC. At that time, the IOC module will no longer be a shared laboratory. With two laboratory modules on orbit, one module will be dedicated to human research, the other module will be dedicated to nonhuman research.

There are two options available for the transition from one shared module at IOC to two nonshared modules for the growth phase. One option is to declare the growth module the nonhuman laboratory; thus, making the old IOC module the human research laboratory. This option allows outfitting and qualifying the more sophisticated plant and animal laboratory equipment (e.g., a 13-ft-diameter centrifuge and expanded ECLS system to handle the increased growth requirements) while the module is on the ground. The existing IOC nonhuman research equipment would be transferred to the growth module after the module is delivered to orbit. New human research equipment would be taken to orbit and transferred to the IOC module.

The second option is to make the IOC module the dedicated nonhuman research module. With this option, the additional plant and animal laboratory equipment is transferred to orbit, installed, and qualified in the IOC module. The equipment includes the same major items stated for the first option (i.e., the 13-ft-diameter centrifuge and an expanded ECLS system). It is anticipated that a smaller (8-ft-diameter) centrifuge would be used in the IOC shared module. The smaller centrifuge could be transferred to the growth module, option 1, or left in the IOC module for option 2.

An analysis was conducted to determine the optimum transitioning of the modules. The results indicated that it would be better to make the new growth module the dedicated nonhuman research laboratory. The reasons for this conclusion are—

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

Trades. Six major trade issues were identified as having a significant impact on the system design of a plant and animal research facility. These issues are—

a. Specimen facility bioisolation.
b. ECLSS closure.

c. Centrifuge configuration.
d. Standardization.
e. Specimen transport facility.
f. Specimen cage cleaning.

These trade issues were analyzed to the depth necessary to define the options and understand their basic influence on the LSRF system. At the conclusion of the trade analysis, the options that appeared to be cost effective and attainable were selected for our IOC and growth conceptual designs. The following is a summary of the selected options.

a. Specimen facility bioisolation.
   1. IOC mission—isolated specimen environmental control system (ECS) and no biolocks.
   2. Growth mission—isolated specimen ECS and no biolocks.
b. ECLSS Closure.
   1. IOC mission.
      a. Oxygen resupplied by logistics module.
      b. Carbon dioxide collected, stored, and returned.
      c. Respiration and perspiration water collected as humidity condensate, purified, and reused as potable water by the animals.
      d. Urine collected and returned.
      e. Fecal water returned with feces.
      f. Cage-washing water—no selection because of lack of equipment definition.
   2. Growth mission.
      a. Oxygen supplied by water electrolysis.
      b. Carbon dioxide collected and reduced by Sabatier methanation to produce water (hydrogen for this process comes from water electrolysis).
      c. Respiration and perspiration water collected in humidity condensate, purified, and reused as potable water by the animals.
      d. Urine collected and processed in wick evaporator; water collected from condenser, purified, and reused as potable water.
      e. Fecal water, feces, and urine solids collected and returned.
      f. Cage-washing water—no selection because of lack of equipment definition.
c. Centrifuge configuration.
   1. IOC mission—one 8-ft centrifuge for 1-g controls.
   2. Growth mission—transfer the IOC 8-ft centrifuge and add two 13-ft centrifuges to accommodate 1-g, fractional-g, and levels greater than 1-g.

d. Standardization.
   1. IOC mission—standardized habitat units for the microgravity facility, the centrifuge facility, and the specimen transport facility.
   2. Growth mission—standardized habitat units for the microgravity facility, the centrifuge facility, and the specimen transport facility.
e. Specimen transport facility.
   1. No selections were made because of insufficient definition of the space station logistics module at this time.
f. Specimen cage cleaning.
   1. IOC mission—replaceable cage liners and high-density cage packaging for storage and transport to Earth.
   2. Growth mission—on-orbit cage washing.

Conceptual Design. Life sciences laboratory configuration concepts were developed and analyzed for the IOC and growth missions. The analysis was an interactive process involving the requirements, trades, and mission definition assessments conducted during the study. IOC and growth concepts were both selected as an optimized set of options that meet the program and mission requirements, and minimize the IOC cost impact. Major features selected for the module concepts are—

a. IOC module.
   1. One 8-ft centrifuge located in berthing-port area.
   2. Specimen ECLSS isolated and separate from crew ECLSS.
   3. Specimen respiration and perspiration water recycled, all other consumables and wastes delivered and returned by the logistics module.
   4. Total of 12 readily interchangeable equipment rack spaces available. (Nominal rack dimension is 20-in width by 30-in depth by 80-in height).
   5. Four of the 12 racks available for specimen holding facilities.
   6. Approximately 30% of the rack space designated for storage of small research equipment and immediate-use consumables.
   7. Cage cleaning accomplished by replaceable cage liners that are returned to Earth.
   8. All equipment transferrable to the growth module, except ECLSS equipment.
b. Growth module.
   1. Designed to accommodate all IOC equipment, including 8-ft centrifuge.
   2. Delivered to orbit with full complement of ECLSS equipment.
   3. Specimen ECLSS isolated and separate from crew ECLSS.

4. Regenerable ECLSS, except fecal water, feces, and urine solids collected and returned to Earth.
5. Total of 20 equipment rack spaces available.
6. One doublewide rack for large-primate facility is available within the 20 racks.
7. Approximately 30% of the rack space designated for storage of small research equipment and immediate-use consumables.
8. Cage cleaning accomplished by washing and sterilizing cages.

Programmatics. A WBS with dictionary, a life sciences project schedule, and cost estimates were developed during the study. These programmatics are based on the selected IOC and growth concepts.

A WBS was defined for a life sciences program with a module system divided into the procurement of a space station common module, nonhuman research equipment outfitting, and human research equipment outfitting. This breakdown, combined with the other top-level system divisions, forms the base for the WBS. The WBS, as developed for this study, is published separately as appendix E.

A life sciences project schedule was developed based on the WBS and life sciences mission model described at the present time. The schedule is tight at best; it is apparent that the critical technology items need to be addressed within the next few months to minimize the technical risks involved. The critical items were identified as (1) new specimen holding facilities for long-duration residence, (2) specimen centrifuge for artificial gravity requirements, (3) sample preservation systems with temperatures from -70°C to -195°C, and (4) cage washing and sterilizing equipment.

Costs were estimated for the selected IOC and growth concepts. Computer programs (the Boeing parametric cost model (PCM) and RCA PRICE H model) were used to make the estimates, which include module, subsystems, and engineering and integration costs. They do not include costs for such items as ground facilities, launch operations, training and simulation, and common module nonrecurring costs. The estimated cost, in 1985 dollars, for each module concept is—

a. IOC module—nonhuman outfitting only, $273.3 million.
b. Growth module—$311.6 million, assuming transfer of IOC laboratory equipment to growth module.

3.0 ENGINEERING AND MISSION DESIGN REQUIREMENTS

A major objective of task 1 was to define engineering and mission design requirements for a life sciences research facility (LSRF). Material was collected, analyzed, and consolidated from several sources, including—

a. Space Station Mission Data Base for missions 307 and 302.
b. Previous LSRF system requirements from the part 1 study. Appendix C, Preliminary Conceptual Design Requirements Data Package.
c. The 54 strawman experiment analysis worksheets published by McDonnell Douglas (ref. 7).
d. The equipment information catalog published by McDonnell Douglas (ref. 13).
e. Space Station Definition and Preliminary Design Request for Proposal (RFP) (ref. 10).
f. Information from Life Sciences Space Station Planning meeting "Red Book" (ref. 14).

An LSRF requirements document was developed and published as appendix D to this report. This requirements document forms the foundation for the LSRF system specification and is prepared from the perspective of the space station module outfitter. It stresses common module interface, space station interface requirements and experiment equipment interface. The following sections are a synopsis of the major headings in the requirements document.

3.1 SCIENCE AND MISSION REQUIREMENTS

The major source for identifying science and mission requirements was the McDonnell Douglas study completed in 1983 (refs. 7 and 13). 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. 14), 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.

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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.

3.2 SYSTEM REQUIREMENTS

The system requirements format is patterned after the C-4 system requirements included in the Space Station Definition and Preliminary Design RFP (ref. 10). The Space Station C-4 requirements were analyzed and applied to the LSRF where applicable. The subsystem breakdown used for the laboratory requirements is (1) structures, (2) mechanisms, (3) electrical power, (4) thermal, (5) data management system, and (6) environmental control and life support system (ECLSS). This breakdown is consistent with the Space Station C-4 requirements and habitability/man systems.

The system requirement activity was initiated with the establishment of a top-level functional flow, as shown in figure 3.2-1. This flow defines the top-level functional elements required to produce, outfit, and process an LSRF from initiation of hardware to an operating laboratory on orbit. This flow also assists in the definition of the involvement of various program interfaces, each of which generates program and technical requirements and elements of cost.

The next step in establishing the system requirements was to define the subsystems and the functions that must be provided to complement the functions supplied by the common module. The common module definition used for this study was based on the Boeing Space Station proposal. The common module subsystem functions, as they apply to the LSRF, are listed in figure 3.2-2. The common module incorporates the structural tiedown for each standard experiment rack and supplies the connect interface at the base and top of each rack to connect to ac and dc electrical power, and thermal, video, and data buses. Other interface functions must be implemented by the laboratory.

The subsystem functions that must be added to the common module to provide an outfitted, operating laboratory are also listed in figure 3.2-2. This analysis defines the functional requirements of each of the LSRF subsystems and the interface between the common module and the outfitting subsystems and experiment equipment. An equipment interface analysis was made to determine the types of interfaces required for each experiment equipment rack and the demand and compatibility with the common-module supplied utilities. The result of this interface analysis is summarized in section 6.0.

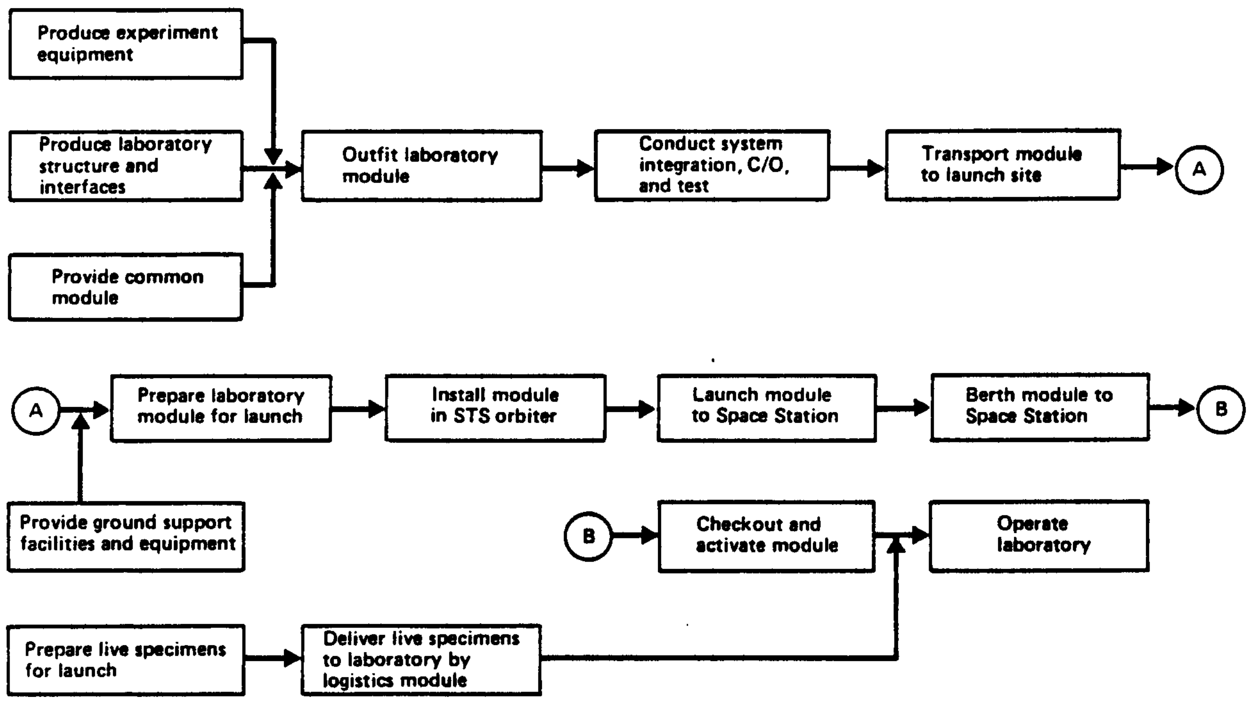

Figure 3.2-1. Top-Level Functional Flow

3.3 GROUND REQUIREMENTS

The LSRF ground operations involve functions associated with (1) LSRF launch processing; (2) live specimen care, handling, and processing for transport to the space station; (3) return specimen processing and storage; (4) logistics resupply of equipment and expendables; and (5) processing and disposal of return wastes.

This study has not emphasized ground requirements; however, it is important to carefully examine the ground requirements to a depth necessary to identify those requirements that could have strong influence on the LSRF system concept. These sections will review and emphasize the ground functions that should be considered in future study and system definition activities.

3.3.1 Ground Processing

Previous work under this contract examined the trade between upgrading and refurbishing an LSRF on orbit versus returning it to Earth, refurbishing it, and delivering it back on orbit with the shuttle-orbiter. The analysis emphasized the importance of ground accessibility particularly associated with the large-diameter centrifuges. Access continues to be an unresolved issue, as related to a module removable enddome. The 13-ft-diameter centrifuges, because of their size and complexity, pose a problem of installation in the 14-ft inside-diameter common module. If the design is constrained to

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Subsystem	LSRF	Common module
Structures	• Provide laboratory equipment mechanical installation design and structural support • Provide laboratory storage accommodation • Provide bioisolation design features and installation • Provide experiment equipment installation interchangeability through modularity and commonality	• Provide primary pressurized structure • Provide basic secondary structure • Provide berthing mechanism • Provide structural interfaces for LSRF outfitter
Data management* system	• Provide experiment monitoring and control • Provide data storage and retrieval	• Provide data distribution • Provide subsystem monitor and control
Communications*	• Provide for crew communications (laboratory unique intercommunications hardware)	• Provide audio distribution • Provide video distribution
Thermal Control	• Provide laboratory equipment heat transport	• Provide internal heat transport • Provide body mounted radiator • Provide thermal utility bus interface
Experiment	• Provide centrifuge artificial gravity • Provide plant/animal enclosures • Provide specialized and general purpose laboratory test capability • Provide plant/animal analysis capability • Provide specimen refrigeration	None
Crew	• Provide hand holds, pushoffs, and restraints • Provide orientation cues • Provide zero-g neutral body posture accommodation	• Provide handwasher • Provide stowage
ECLSS	• Provide specimen pressure and air composition control • Provide specimen temperature and humidity control • Provide specimen atmosphere revitalization • Provide laboratory water collection, processing, and dispensing • Provide laboratory waste treatment and disposal	• Provide crew atmospheric pressure and composition control • Provide crew temperature and humidity control • Provide crew CO_2 removal and reduction • Provide crew atmosphere revitalization • Provide crew air quality monitor • Provide crew O_2 generation
Electrical Power	• Provide experiment electrical power distribution and control • Provide experiment electrical power conditioning and protection • Provide laboratory lighting and control	• Provide primary power • Provide power distribution and control • Provide basic lighting and control

* All ground communications including data transfer are provided by Space Station operations

Figure 3.2-2. Subsystem Functional Allocations be installed through a 50-in hatch, it could be a significant impact on cost and complexity. The other alternative is to equip the laboratory with a removable enddome. This approach would allow the centrifuge to be assembled external to the laboratory on a fixture, balanced, tested, and installed in the laboratory as a tested unit. The approach simplifies design, reduces complexity, and greatly affects the installation costs. Whether the centrifuge is installed at the launch site or at an outfitting contractor facility, the open- versus fixed-enddome issue remains the same.

3.3.2 Specimen Ground Processing Facility

A ground facility located at the launch site is required to perform the following support functions:

a. Provide care, shelter, and isolation for live specimens awaiting transport to the space station.
b. Provide care, shelter, and isolation for live specimens returning from the space station.
c. Prepare and service live-specimen transport equipment.

4.0 MISSION TRANSITION ANALYSIS

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 4.0-1, were taken from the Space Station Mission Data Bases formerly known as the Langley Mission Data Base. The figure shows the overall phasing of several major life sciences laboratories to be placed into service over a 10-year period. Missions 307, 303, and 302 were the only ones considered during this study.

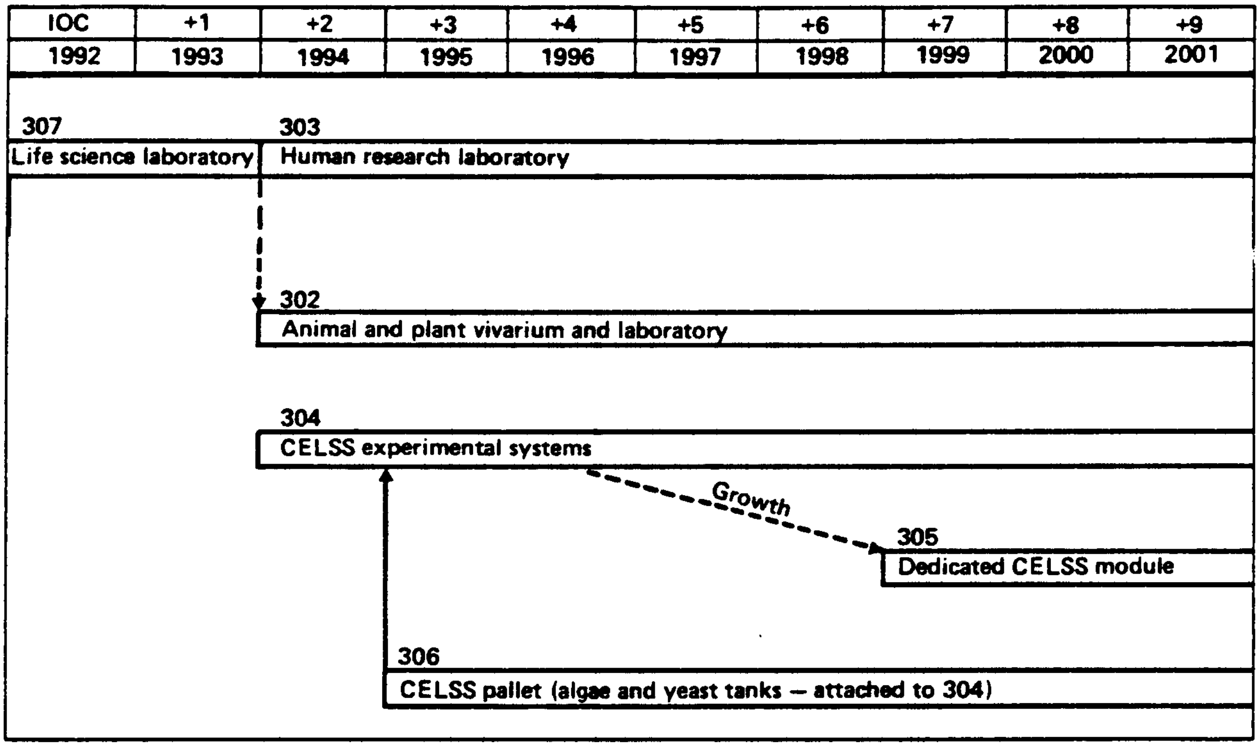

Figure 4.0-1. Scheduled Life Sciences Missions

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.

The objective of the mission transition analysis task was 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 for this task.

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.

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.

4.1 OPTION 1 TRANSITION ANALYSIS

Option 1, the scenario that transitions the IOC module to a dedicated human research facility, is summarized in figure 4.1-1. 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.

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

1992 – IOC Lab module A (SAAX 0307) • $\frac{1}{2}$ module for non-human research (with 8-ft centrifuge) • $\frac{1}{2}$ module for human research	1994 – Transition on-orbit 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	1994 – After transition 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 4.1-1. Option 1 Mission Transition Summary

from module A to module B. Additional human research equipment transported to orbit in module B is transferred and installed in module A.

Nonhuman 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 located in the berthing-port area of the module. Structural scars in this area would not impose a large penalty.

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.

4.2 OPTION 2 TRANSITION ANALYSIS

Option 2 is summarized in figure 4.2-1. In the option 2 scenario, the IOC laboratory, module A, becomes a dedicated, nonhuman research facility when the new growth laboratory, module B, is delivered to orbit. With this approach, the IOC laboratory would be launched with provisions for later installation of a second centrifuge. In 1994, module B would be delivered to orbit and designated the human research laboratory. It would transport the second centrifuge and other LSRF equipment to orbit for installation in the old module A. Module A human equipment would be transferred to the new growth module B and the additional nonhuman equipment would be transferred from module B to module A. When completed, this transitioning converts the IOC module into an animal and plant vivarium and laboratory with three centrifuges. Module B becomes a dedicated module for human research.

To aid in evaluating these two transition options, timeline analyses were performed for disassembly, transfer, and reassembly of the 13-ft-diameter centrifuges and the 8-ft-diameter centrifuge. These analyses are based on the 13-ft centrifuge design approach illustrated in figure 4.2-2. The 13- and the 8-ft-diameter centrifuge timelines are given in figures 4.2-3 and 4.2-4. The respective crew times to move the centrifuges are 96 hr and 66 hr (including 25% contingency time to cover meals and rest periods). A timeline for transferring racks on orbit from module to module was defined from previous work (Part 2, Indepth Trade Analysis, see fig. 1.1-1), which examined the trade between upgrading and refurbishing an LSRF on orbit versus returning it to Earth with the shuttle-orbiter, refurbishing it, and delivering it back on orbit. The time required for transfer of a rack on orbit, including reverifying, was 1.5 hr per equipment rack (serial

1992 - IOC	1994 - Transition on-orbit	1994 - After transition
Lab module A (SAAX 0307) • $\frac{1}{2}$ module for non-human research (with 8-ft. centrifuge) • $\frac{1}{2}$ module for human research • Contains scars for two 13-ft centrifuges.	Lab module A (SAAX 0307) • Transfer human equipment to module B • Add and assemble two13-ft. centrifuges from Module B • Add additional non-human equipment from module B	Lab module A (SAAX 0302) • Full animal and plant vivarium and laboratory (with 3 centrifuges, one 8-ft. and two 13-ft.)
	1994 - Deliver to orbit and transition Lab module B (SAAX 0302) • Transfer two 13-ft centrifuges to Module A • Transfer non-human equipment to module A • Add human research equipment from module A	1994 - After transition Lab module B (SAAX 0303) • Full human research laboratory

Figure 4.2-1. Option 2 Mission Transition Summary

time) or 3 hr crew time. Figure 4.2-5 compares the on-orbit crew hours involved in transferring the experiment racks and centrifuges for the two transition options.

4.3 CONCLUSIONS

How do these transition approaches compare? On the surface, it would seem that option 2, transitioning the IOC module to a dedicated, nonhuman research facility, would be the way to proceed. As the two options were analyzed, it became increasingly apparent that option 1 is far superior; this is supported by the following:

a. The 8-ft IOC centrifuge is much less involved and less time consuming than the 13-ft centrifuge for disassembly, moving to the growth module (module B), reassembling, and requalifying.

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, repiping, 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.

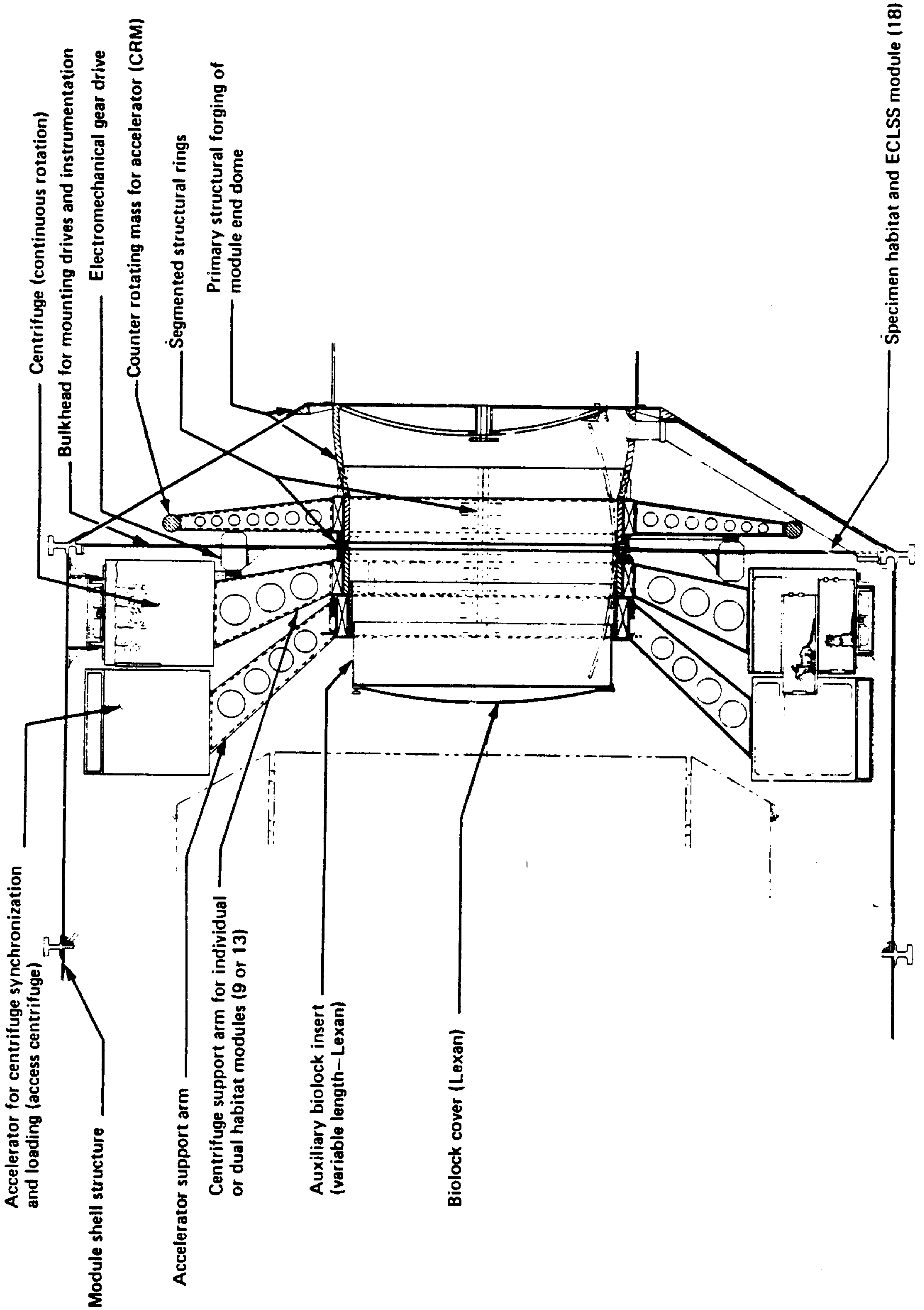

Figure 4.2-2. Details of 13-ft Centrifuge With Access Centrifuge and Counterbalance

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.

TASK	MIN
REVIEW CENTRIFUGE REMOVAL PROCEDURES	240
OBTAIN TOOL KIT	10
OBTAIN PARTS CONTAINERS AND PROTECTIVE COVERS	15
TURN OFF POWER, WATER, DATA, AND ETC.	2
VERIFY POWER OFF	1
PURGE WATER LINES	5
DISCONNECT DATA LINES BETWEEN HABITATS	20
STOW CABLES	1
REMOVE BIOLOCK INSERT	15
REMOVE 2 ACCELERATOR HABITATS	30
REMOVE KEEPER WASHER	5
REMOVE OUTER SEGMENTED RACE AND SUPPORT ARM BASE	10
REMOVE CONTINUOUS INNER RACE	10
REMOVE AND STOW 18 HABITATS	360
REMOVE STATIONARY FECES ENTRAPMENT TRAY	90
REMOVE OUTER SEGMENTED RACE AND SUPPORT ARM BASE	10
DISCONNECT MOTOR ELECTRICAL CONNECTORS & STOW CABLES	12
REMOVE ELECTROMECHANICAL GEAR DRIVE	60
REMOVE DRIVE AND INSTRUMENTATION BULKHEAD	30
REMOVE SEGMENTED STRUCTURAL RINGS	10
REMOVE COUNTER ROTATING MASS	30
REMOVE OUTER SEGMENTED RACE FOR CRM	10
REMOVE BUSHING AND STRUCTURAL FORGING FOR CRM	15
REMOVE AIR FLOW DUCT	30
TRANSLATE AIRFLOW DUCT TO NEW LAB	5
INSTALL AIR FLOW DUCT	30
TRANSLATE STATIONARY FECES ENTRAPMENT TRAY	10
INSTALL STATIONARY FECES ENTRAPMENT TRAY	60
TRANSLATE BUSHING & STRUCTURAL FORGING	7
INSTALL BUSHING AND STRUCTURAL FORGING	30
TRANSLATE COUNTER BALANCE CONTINUOUS INTER RACE	7
INSTALL CRM INTER RACE	15
OBTAIN NEW BEARING LINER INSERT	5
INSTALL NEW BEARING LINER INSERT	5
TRANSLATE CRM	15
INSTALL CRM	30
CHECK BALANCE	10
TRANSLATE BULKHEAD FOR DRIVES AND INSTRUMENTATION	20
INSTALL BULKHEAD	30
TRANSLATE SEGMENTED STRUCTURAL RINGS	5
INSTALL SEGMENTED STRUCTURAL RINGS	15
TRANSLATE ELECTRO MECHANICAL GEAR DRIVES	10
INSTALL ELECTROMECHANICAL GEAR DRIVES	10
CONNECT ELECTRICAL CABLES	12
TRANSLATE CONTINUOUS INTER RACE	7
INSTALL CONTINUOUS INTER RACE	15
OBTAIN NEW BEARING LINER INSERT	5

Figure 4.2-3. Disassembly, Transefer, and Reassemble Timeline for 13-ft. Centrifuge

INSTALL NEW BEARING LINER INSERT	5
TRANSLATE OUTER SEGMENTED RACE AND SUPPORT ARM BASE	10
INSTALL OUTER SEGMENTED RACE	20
VERIFY ELECTRICAL SLIP RING IS IN PLACE	5
TRANSLATE 18 HABITATS	90
INSTALL 18 HABITATS	540
CONNECT CABLES BETWEEN HABITATS	18
TEST CONNECTIONS	20
TRANSLATE ACCELERATOR INTER RACE	7
INSTALL ACCELERATOR INTER RACE	10
OBTAIN BEARING LINER INSERT	5
INSTALL NEW BEARING LINER INSERT	5
TRANSLATE OUTER SEGMENTED RACE	7
INSTALL OUTER SEGMENTED RACE	10
TRANSLATE ACCELERATOR HABITATS	10
INSTALL ACCELERATOR HABITATS	30
INSTALL ACCELERATOR SYNCHRONIZATION BRAKE	15
TRANSLATE KEEPER WASHER	5
INSTALL KEEPER WASHER	15
TRANSLATE BIOLOCK INSERT	10
INSTALL BIOLOCK	15
STOW TOOL KIT	10
TURN ON POWER WATER DATA AND ETC.	5
VERIFY SEALS POWER DATA AND ETC.	20
TEST RUN CENTRIFUGE	10
** TOTAL **	2276 min.
	38 hrs.
CONTINGENCY 25%	10 hrs.
TOTAL (serial time)	48 hrs.
TWO CREW REQUIRED (total crew hours)	96 hrs.

Figure 4.2-3. Disassembly, Transefer, and Reassembly Timeline for 13ft. Centrifuge (Continued)

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TASK	MIN
REVIEW CENTRIFUGE REMOVAL PROCEDURES	240
OBTAIN TOOL KIT	10
OBTAIN PARTS CONTAINERS AND PROTECTIVE COVERS	15
TURN OFF POWER, WATER, DATA, AND ETC.	2
VERIFY POWER OFF	1
PURGE WATER LINES	5
DISCONNECT DATA LINES BETWEEN HABITATS	20
STOW CABLES	1
REMOVE BIOLOCK INSERT	15
REMOVE KEEPER WASHER	5
REMOVE OUTER SEGMENTED RACE AND SUPPORT ARM BASE	10
REMOVE CONTINUOUS INNER RACE	10
REMOVE AND STOW 11 HABITATS	220
REMOVE STATIONARY FECES ENTRAPMENT TRAY	90
REMOVE OUTER SEGMENTED RACE AND SUPPORT ARM BASE	10
DISCONNECT MOTOR ELECTRICAL CONNECTORS & STOW CABLES	12
REMOVE ELECTROMECHANICAL GEAR DRIVE	60
REMOVE DRIVE AND INSTRUMENTATION BULKHEAD	30
REMOVE SEGMENTED STRUCTURAL RINGS	10
REMOVE AIR FLOW DUCT	30
TRANSLATE AIRFLOW DUCT TO NEW LAB	5
INSTALL AIR FLOW DUCT	30
TRANSLATE STATIONARY FECES ENTRAPMENT TRAY	10
INSTALL STATIONARY FECES ENTRAPMENT TRAY	60
TRANSLATE BUSHING & STRUCTURAL FORGING	7
INSTALL BUSHING AND STRUCTURAL FORGING	30
OBTAIN NEW BEARING LINER INSERT	5
INSTALL NEW BEARING LINER INSERT	5
TRANSLATE BULKHEAD FOR DRIVES AND INSTRUMENTATION	20
INSTALL BULKHEAD	30
TRANSLATE SEGMENTED STRUCTURAL RINGS	5
INSTALL SEGMENTED STRUCTURAL RINGS	15
TRANSLATE ELECTRO MECHANICAL GEAR DRIVES	10
INSTALL ELECTROMECHANICAL GEAR DRIVES	10
CONNECT ELECTRICAL CABLES	12
TRANSLATE CONTINUOUS INTER RACE	7
INSTALL CONTINUOUS INTER RACE	15
OBTAIN NEW BEARING LINER INSERT	5
INSTALL NEW BEARING LINER INSERT	5
TRANSLATE OUTER SEGMENTED RACE AND SUPPORT ARM BASE	10
INSTALL OUTER SEGMENTED RACE	20
VERIFY ELECTRICAL SLIP RING IS IN PLACE	5
TRANSLATE 11 HABITATS	55
INSTALL 11 HABITATS	330
CONNECT CABLES BETWEEN HABITATS	18
TEST CONNECTIONS	20
STOW TOOL KIT	10
TURN ON POWER WATER DATA AND ETC.	5
VERIFY SEALS POWER DATA AND ETC.	20
TEST RUN CENTRIFUGE	10
** TOTAL **	1585 min.
26.4 hrs.	
CONTINGENCY 25%	6.6 hrs.
TOTAL (serial time)	33 hrs.
TWO CREW REQUIRED (total crew hours)	66 hrs.

Figure 4.2-4. Disassembly, Transfer, and Reassembly Timeline for 8-ft. Centrifuge

Option 1 Transition

		Crew Hours
12 racks		36
1 centrifuge 8-ft.		66
	TOTAL	102

Rack locations can be preplanned to obtain an optimized arrangement of the growth laboratory (module B).

Option 2 Transition

		Crew Hours
8 racks		24
1 centrifuge 13-ft.		96
	*TOTAL	120

*Additional crew hours and hardware kit provisions required to move existing IOC racks into optimum growth laboratory (module A) positions.

Figure 4.2-5. Timeline Comparison

5.0 MAJOR TRADE ANALYSIS

Based on an indepth review of science requirements (ref. 7), Space Station requirements (ref. 10), and tradeoff analyses previously conducted (appendix B), six major issues were identified as having a significant impact on the system design of a plant and animal research facility. The six issues identified for analysis were—

a. Specimen facility bioisolation.
b. ECLSS closure.
c. Centrifuge configuration.
d. Standardization.
e. Specimen transport facility.
f. Specimen cage cleaning.

This section discusses each of these issues in terms of the specific requirements, the options available for meeting the requirements, an analysis of the options, and preliminary selection of an option for each area of investigation.

Each of these trade areas has been examined to a depth necessary to define the options and the major influence of each option on design and overall costs. As a result of this analysis, a preferred-option set was selected for use in definition of the selected concepts described in section 6.0. Because of their effect on laboratory configuration and cost, it is recommended that each of these trade areas be explored in depth in future LSRF definition studies to fully understand their impact on the LSRF design.

5.1 SPECIMEN FACILITY BIOISOLATION

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.

Several references are made to bioisolation in the requirements document (see appendix D). The major requirement states, "design provisions shall be made for bioisolation to provide positive isolation of the plant and animal vivarium from crew occupied areas of the space station." Another requirement includes protection of the logistics module atmosphere during transport of live specimens to and from orbit. Other sections in the requirements document refer to controlling particle size and levels within given limits and ensuring the laboratory cabin air is maintained at suitable quality for crew use.

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5.1.1 Option Analysis

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. Atmosphere isolation can be achieved by using air filtration techniques, by using separate ECSs, or by constructing partitions (biolocks) to isolate various volumes using cleanroom technology. The following sections discuss the three options chosen for analysis.

5.1.1.1 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 (fig. 5.1-1) depicts the common-module ECS supplying air to the specimen facilities through a 0.3-micron 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. The cabin return air is directed through an activated charcoal odor-control bed and a 0.3-micron microbial filter to provide the required bioisolation.

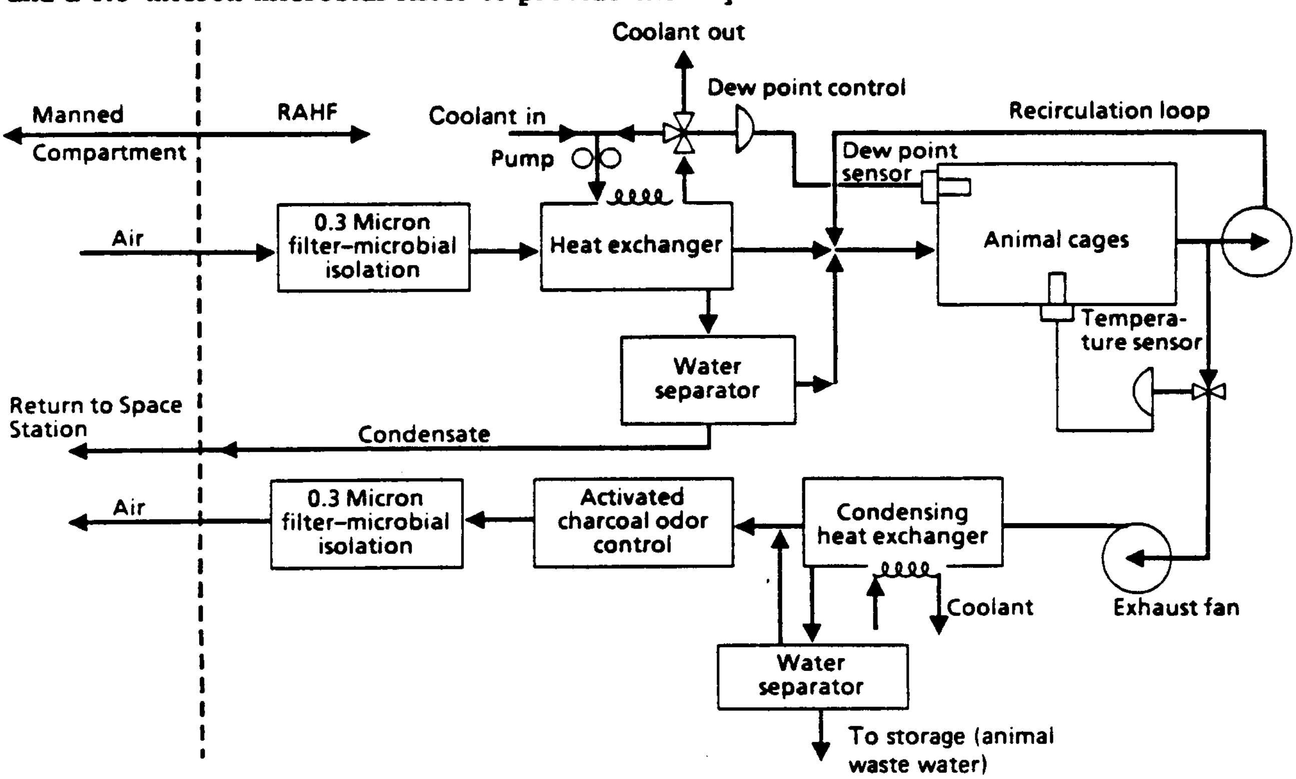

Figure 5.1-1. Specimen Facility ECS—System Shared With Crew Cabin ECS.

Option 1 is the simplest and probably the lowest cost approach because it does not require a separate specimen ECS. The space station common-module system for the crew is used to provide the necessary environmental control. Bioisolation is achieved through microbial and odor filtration before mixing the specimen ECS air with the crew-cabin air. This approach is entirely dependent upon the reliability of maintaining filter integrity over fairly long operating periods.

5.1.1.2 Option 2—Specimen Facilities Recirculate Own Air

Option 2 provides a completely isolated ECS for the specimen holding facilities (fig. 5.1-2) and features water electrolysis for supplying O_2 for the LSRF specimens. The air is exhausted from the specimen cages and processed through a heat exchanger for water recovery. Before return circulation, the air is processed through an activated charcoal bed and a microbial filter, followed by CO_2 removal.

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

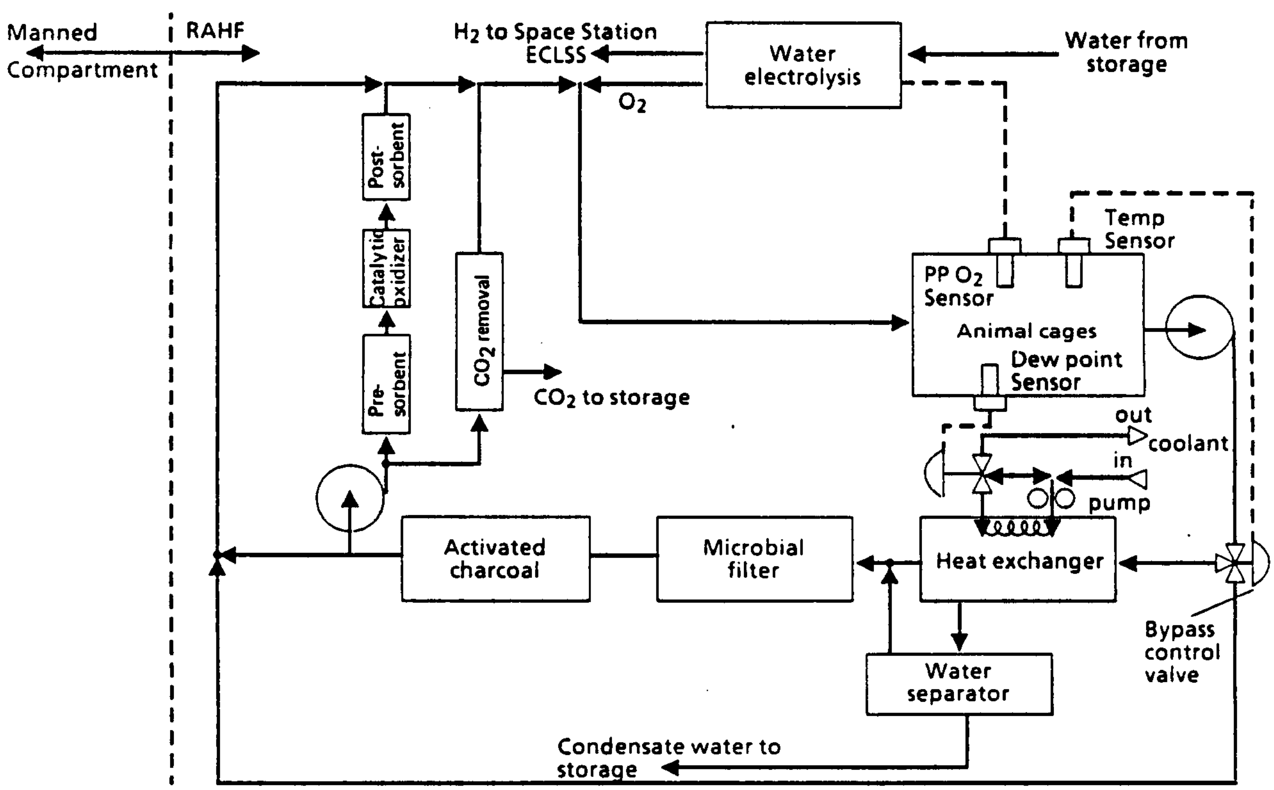

Figure 5.1-2. Specimen Facility ECS—System Isolated From Crew Cabin ECS

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.

5.1.1.3 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.

Several variations of biolocks were analyzed. In the IOC configuration where a module is shared half and half with a human research laboratory, there are two ways of dividing the module: longitudinal and transverse. A longitudinal bulkhead arrangement (fig. 5.1-3) results in two possible passageways, one on each side of the center longitudinal bulkhead with a biolock located in the berthing-port area of the module. Because of the dual passageway, the volumetric efficiency of the arrangement would be reduced. Figure 5.1-4 shows that the passageways have a problem of maintaining the required 50-in diameter access, except for the installation of a flexible center bulkhead. Another option would be to reduce the experiment rack depth; both of these alternatives appear undesirable.

In the case of dividing the laboratory module transversally, a collapsible biolock can be added (fig. 5.1-5). Of the two arrangements, the transverse is preferable. It may be extended into the passageway when needed and collapsed into a narrow storage bulkhead; thus, saving space.

Including biolocks in the system would be the most costly of the three options, not only in designing and building biolocks, but also from the integration impact that would occur with the common-module ECS. The use of biolocks dictate that portions of a module be sealed off, disrupting normal air flow and air-conditioning to the remainder of the module. The sealed-off portion would require additional ECS equipment, thereby adding further costs.

Biolocks would serve mainly as precautionary protection against a contaminating incident. The origin and severity of such an incident can only be determined through failure analyses where failure in procedures as well as hardware are considered.

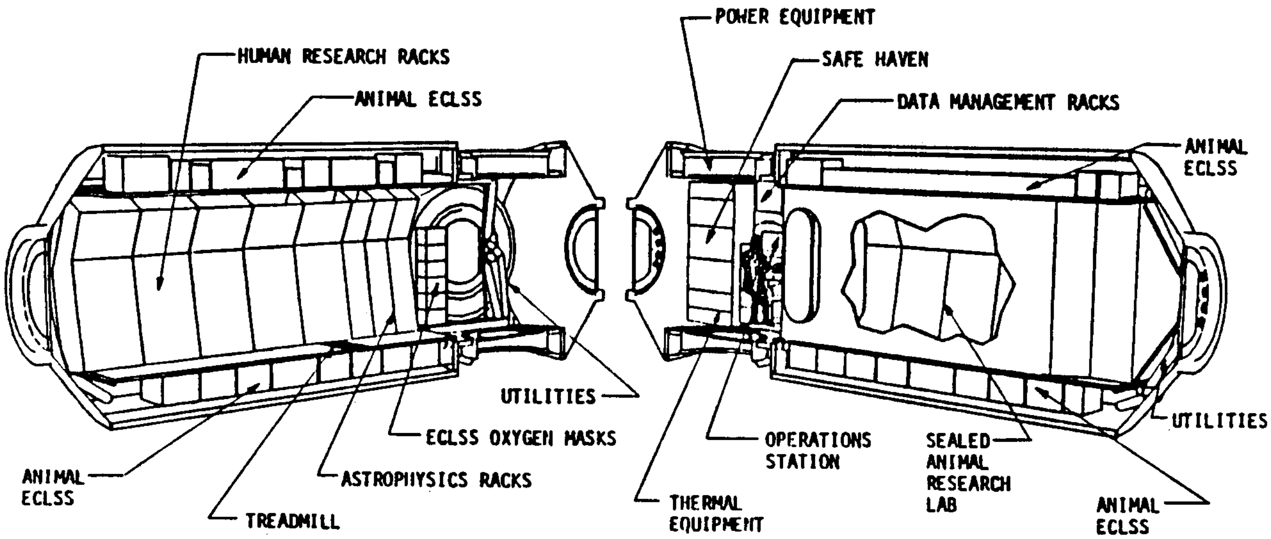

Figure 5.1-3. Longitudinal Bulkhead

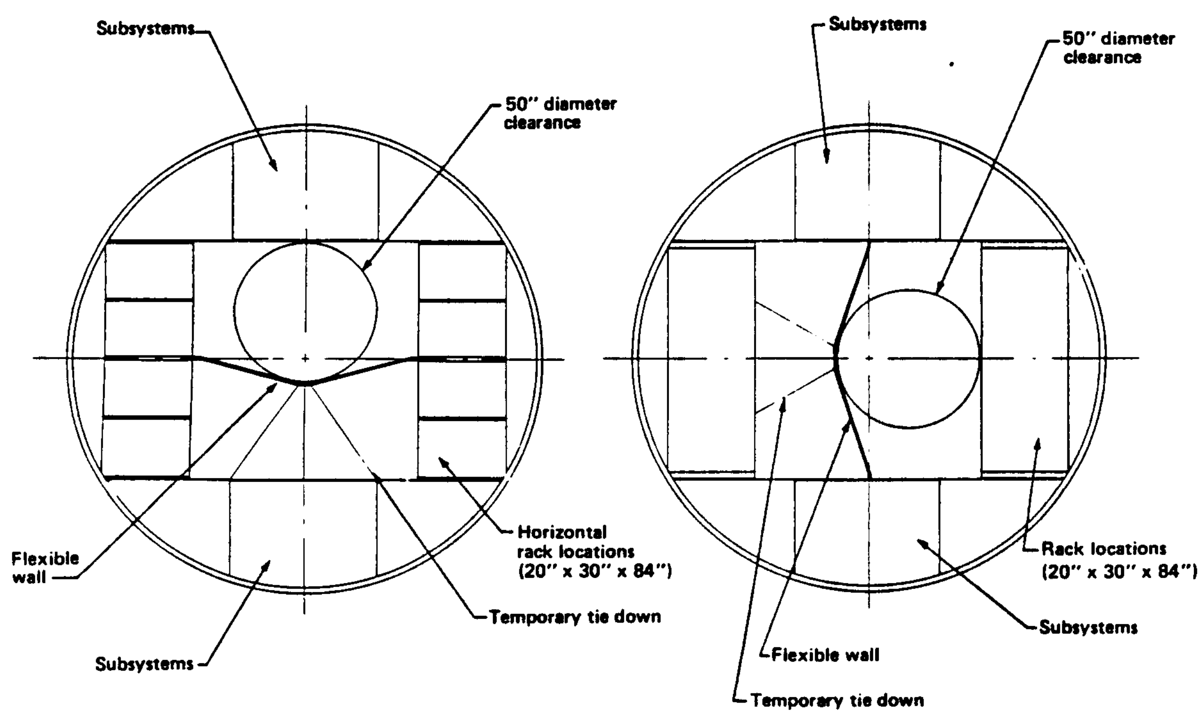

Figure 5.1-4 Cross Section of Longitudinal Bulkhead

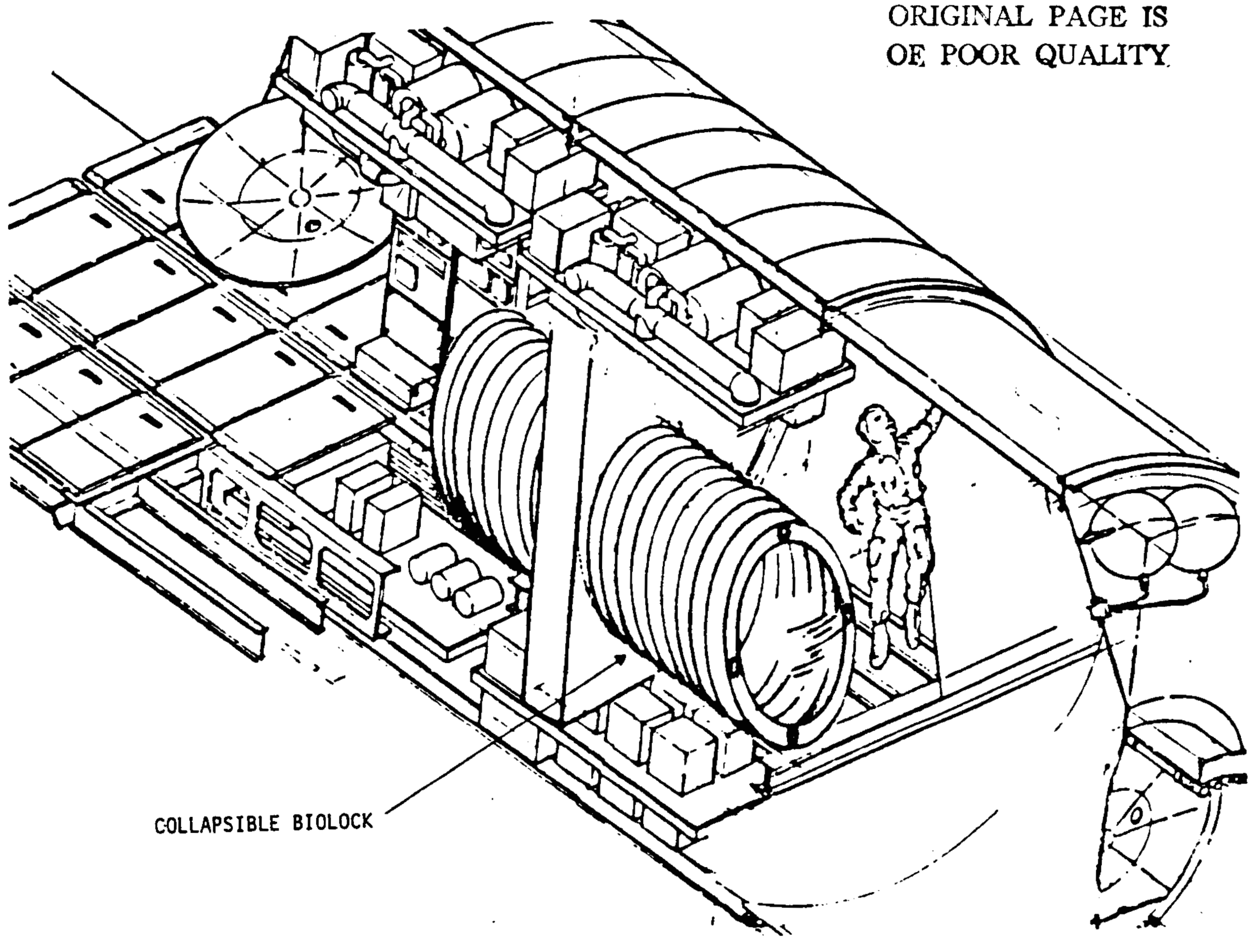

Figure 5.1-5. Colapsible Biolock Concept

5.1.2 Selection

For the purpose of this study, option 2 was selected for both the IOC and growth module conceptual designs. Option 2 provides a reasonable approach to maintaining bioisolation over a long period of time without placing undue design impacts on common-module subsystems.

Option 1 probably does not give the desired level of bioisolation protection. Option 3 was not selected because of the overriding design impacts on the common module. Option 3 may also be very costly without gaining much in lessening the cross-contamination risk.

5.2 ENVIRONMENTAL CONTROL LIFE SUPPORT SYSTEM CLOSURE

In the specimen facility bioisolation discussion, the conclusion was to include separate ECLS equipment for the specimen holding facilities. Major expendables for supplying specimen ECLS would be water and oxygen brought up by the logistics module.

Waste water, feces, and carbon dioxide will accumulate between logistic flights for return to Earth. Resupplying these consumables and returning waste products puts an additional burden on the logistics module. The alternative is to recycle some waste products for reuse on orbit. However, closing the ECLS system requires the addition of process equipment, which increases power usage. The following sections discuss the tradeoff issues involved between an open- and closed-ECLS system for the research specimens in an LSRF.

5.2.1 Option Analysis

Four ECLS subsystems associated with specimen holding facilities were considered for loop closure: oxygen, carbon dioxide, specimen water, and cage washing water.

There are several options for each subsystem to be evaluated and considered for both the IOC and the growth laboratory. One of the principal considerations is the influence of the transition from the IOC laboratory to the growth laboratory. For example, the ECLSS for IOC may not be (1) usable on the growth module because of sizing considerations or (2) practical to consider moving it to the growth module; these are penalty costs that must be taken into account. In general, the principal trade is to compare the resupply support through the space station logistics module with the cost of ECLS equipment and power requirements for loop closure. The options for each of the subsystems are discussed in following sections.

5.2.1.1 Oxygen

Three options were considered for supplying oxygen to the LSRF specimens:

a. Supplied from the space station oxygen generation equipment.
b. Resupplied from the ground by the logistics module.
c. Generated by water electrolysis on orbit.

The simplest and least costly way to supply oxygen to the laboratory specimens would be to use space station oxygen (option a). This option assumes the space station ECLSS can be easily increased to have sufficient oxygen-generating capacity. Oxygen requirement estimates for an IOC and a growth module concept are given in figure 5.2-1. (The numbers and types of specimens for IOC and growth are estimates developed from the conceptual design work discussed in section 6.0.) An estimate of the amount of additional equipment needed to supply the oxygen based on man-equivalent requirements is also shown in figure 5.2-1. For example, supplying the 4 lb/day of oxygen for the IOC specimens will require the same amount of process equipment needed to supply oxygen

IOC OXYGEN		
Specimen and number		lb/day
Small primates	(6)	0.53
Rodents	(63)	3.47
	TOTAL	4.00 *

* Approximately a 2.2 man-equivalent

GROWTH OXYGEN		
Specimen and number		lb/day
Large primate	(1)	0.66
Small primates	(8)	0.70
Rodents	(165)	9.08
	TOTAL	10.44 **

** Approximately a 5.7 man-equivalent

Figure 5.2-1. Specimen Oxygen Requirements

for approximately 2.2 men per day (assuming a requirement of 1.84 lb oxygen per man per day). For growth, the equipment would be about the same as required to support 5.7 men per day.

If oxygen is resupplied from the ground (option b) the major impact is weight that would have to be transported every 90 days. From the concepts developed for this study, the weight of oxygen would be approximately 360 lb for IOC and 940 lb for growth. These weights are for the oxygen only and do not include the containers or any contingency oxygen.

The third option is similar to the first in that additional processing equipment would be necessary. It would be more costly than the first option because it is a system independent of the space station system. It is assumed that the same types of process and hardware used for space station crew oxygen would be used for the specimen system. The additional cost would come from duplicating some of the elements not directly related to capacity (e.g., controllers and monitors).

5.2.1.2 Carbon Dioxide

The options for carbon dioxide removal are—

a. Collect and return to space station subsystem for processing.

b. Collect, store, and return to Earth.

c. Collect and process for reuse.

The first option involves the addition of process equipment to the space station crew ECLSS similar to option a for oxygen generation. In this instance, carbon dioxide would be removed from the specimen air flow (e.g., a solid amine system) and then piped to the space station carbon dioxide reduction equipment to be processed into water. Figure 5.2-2 shows the carbon dioxide loads estimated for the IOC and growth missions. These loads represent approximately a 2.2 man-equivalent system for IOC and a 5.7 man-equivalent system for growth.

IOC CARBON DIOXIDE		
Specimen and number		lb/day
Small primates	(6)	0.67
Rodents	(63)	4.28
	TOTAL	4.95 *

* Approximately a 2.2 man-equivalent

GROWTH CARBON DIOXIDE		
Specimen and number		lb/day
Large primate	(1)	0.77
Small primates	(8)	0.90
Rodents	(165)	11.22
	TOTAL	12.89 **

** Approximately a 5.7 man-equivalent

Figure 5.2-2. Specimen Carbon Dioxide Removal Requirement

Option b, which is to collect, store, and return the carbon dioxide to Earth, could be satisfied by lithium hydroxide canisters, molecular sieve, etc. Because one of the space station requirements is to allow no venting, the collected carbon dioxide would have to be returned to Earth using the logistics module. The loads to be returned every 90 days would be approximately 446 lb of carbon dioxide for IOC and 1168 lb for the growth module. These loads do not include the weight of lithium hydroxide canisters or other transport containers.

The third option considers collecting and processing the carbon dioxide to generate water. Dependent upon what process is used, some waste products are formed that must be returned to Earth. For example, if the Sabatier process is used, some methane is produced in the reduction of carbon dioxide. It is assumed that the same process would be used for the specimen ECLSS as for the space station ECLSS. Options a and c will both require the same amount of processing equipment; however, option c will be more costly because of the duplication of some elements of the system.

5.2.1.3 Specimen Water

Specimen water involves supplying specimens with potable water and recovering waste water, which consists of respiration and perspiration water, and urine.

There are two basic options:

a. Resupply potable water and return waste water to Earth.

b. Collect, process, and reuse waste water for specimens.

Option a is the simplest but may not be the least costly option. To supply potable water every 90 days and return the waste water will put a weight and volume burden on the logistics module. Figure 5.2-3 shows the typical water loads for both an IOC and growth mission. These loads translate to approximately 480 lb drinking water and 566 lb recoverable waste water per 90 days for IOC, and 1358 lb drinking water and 1606 lb recoverable waste water for growth. These loads are not mass balanced; no account is made for water obtained in the food or waste water lost in the feces. Mass balance is discussed in section 6.6.

The second option involves collecting and processing waste water for specimen reuse. The option of using the space station water-processing equipment for specimen water was not considered because of the bioisolation problems involved. All water handling for the specimens should be maintained in separate subsystems.

There are several ways to recycle water within the specimen facilities. For example, respiration and perspiration water can be collected in a humidity-control condenser, treated, and then reused as potable water. Urine can be vaporized and the

IOC

Specimen	Input	Output	
	Drinking H_2O (lb/day)	Urine (lb/day)	Respiration/ Perspiration (lb/day)
Small primates (6)	1.16	0.34	0.91
Rodents (63)	4.16	1.83	3.21
(Plants not included)	-	-	-
Total	5.32	2.17	4.12

GROWTH

Specimen	Input	Output	
	Drinking (lb/day)	Urine (lb/day)	Respiration/ Perspiration (lb/day)
Large primate (1)	2.65	1.85	1.10
Small primates (8)	1.55	0.46	1.22
Rodents (165)	10.89	4.79	8.42
(Plants not included)	-	-	-
Total	15.09	7.10	10.74

Figure 5.2-3. Specimen Input and Output Water Requirements

water recovered by a humidity condenser also. If carbon dioxide is reduced, water will be formed from the process. With these various processes working together, it appears most of the required water can be produced on orbit with very little resupply water required. Estimates are not possible at this time because of unknowns associated with habitat design, ECLS equipment selection, and scientific sampling requirements.

5.2.1.4 Cage-Washing Water

There are two basic options for supplying cage-washing water (1) resupply from the ground and (2) process and reuse it for cage washing.

The conjecture is that cage-washing water can amount to a substantial logistics penalty regardless of which option is selected. There has been no contracted effort related to a cage washer; thus, little is known other than ground laboratory animal-cage experience indicates that rodent feces is very difficult to remove from surfaces after it has dried. It may require high pressure steam with caustic detergents or equivalent cleaning solutions. This could pose a very difficult problem to process this water for reuse, considering the amount of material that will have to be removed. There may be a limited number of cleanup cycles before the water has to be replaced. This could impose high logistic requirements for the transport of water to and from orbit. The other alternative to this problem, returning cages to the ground for cleaning, is discussed in section 5.6.

5.2.2 Selection

ECLSS selections for the IOC and growth missions were based mainly on judgmental decisions, with some quantitative data inputs for consumable weight estimates. Cost numbers were not generated for process equipment versus logistics module costs because of the early stage of Space Station Phase B definition. The selections and rationale are discussed in the following section.

5.2.2.1 IOC Mission

The Selections for the IOC mission were—

a. Oxygen—resupplied by logistics module.
b. Carbon dioxide—collected, stored, and returned to Earth.
c. Specimen water—
    1. Respiration and perspiration water collected as humidity condensate, purified, and reused as potable water.
    2. Urine collected and returned to Earth.
    3. Fecal water returned with feces to Earth.
d. Cage-washing water—no selection because of lack of equipment definition.

The rationale for these selections are—

a. The IOC mission has limited volume; therefore, process equipment should be minimal so as not to reduce the capacity for accommodating specimens.
b. The logistics loads for supplying oxygen and returning carbon dioxide for IOC (see figs. 5.2-1 and 5.2-2) are probably not prohibitive. (However, this must be determined by a total space station logistics analysis.)
c. The humidity-condensate removal system for recovering respiration and perspiration water is required with or without water recycling.
d. The use of crew supplies and crew ECLSS process equipment probably will not be allowed for user needs in the laboratories.
e. The transition from the IOC module to the growth module will require either moving or abandoning the IOC module ECLSS. The less equipment involved, the less costly the transition.

5.2.2.2 Growth Mission

Selections for the growth mission were directed toward closing the specimen ECLSS. These selections are—

a. Oxygen—supplied by water electrolysis.
b. Carbon dioxide—collected and reduced by Sabatier methanation to produce water (hydrogen for this process comes from water electrolysis).
c. Specimen water—
    1. Respiration and perspiration water collected in humidity condensate, purified, and reused as potable water.
    2. Urine collected and processed in wick evaporator, water collected from condenser, purified, and reused as potable water.
    3. Excess water used in electrolytic process (see a and b above).
    4. Fecal water, feces, and urine solids collected and returned to Earth.
d. Cage-washing water—no selection because of lack of equipment definition.

These selections were made based on the following rationale:

a. The growth module can be put into orbit with a full complement of ECLS equipment that is installed and checked out on the ground. No need to transfer ECLS equipment from IOC module.
b. Closing the oxygen, carbon dioxide, and water loops for a full module relieves the amount of logistics support required. (See figs. 5.2-1, 5.2-2, and 5.2-3 for estimates of these logistic loads.)
c. Carbon dioxide reduction and urine recycling produce excess that can be used for the electrolysis process.
d. The air and water loops become intertwined in the recycling process. That is, excess water is used for electrolysis, which in turn produces oxygen for the specimens and hydrogen for use in the carbon dioxide reduction process. It makes more sense to close both loops at the same time rather than close one.

5.3 CENTRIFUGE CONFIGURATION

One of the major science requirements is to provide a specimen centrifuge on board the LSRF. The purpose of a centrifuge is to provide the capability of artificial gravity over a range of the ambient microgravity of low Earth orbit to greater than Earth-normal gravity (i.e., greater than 1-g). Artificial gravity is required to serve two objectives (1) provide on orbit, 1-g experimental control conditions and (2) provide a range of gravity conditions for gravitational biology research.

The types of science experiments, the diversity of species, and the number of research specimens involved are as varied as the scientific disciplines and science objectives to be studied. Exposure of specimens to artificial gravity will be required over varying periods of time (i.e., from hours to days to months). Also, some experiments require specimens to be exposed to continuous gravity conditions (i.e., the centrifuge will have to be operating continuously over the duration of the experiment. The design impacts and options for satisfying these requirements are discussed in following sections.

The effects of centrifuge unbalance and dynamic disturbances on the total space station were not considered in this study. These topics have been covered in detail in other studies, mainly by McDonnell Douglas (ref. 11).

5.3.1 Option Analysis

Major problems associated with providing an artificial gravity capability include (1) accommodating various species—their size, numbers, and life support requirements—and (2) providing the range of gravity loadings that would be required at any one time. These problems lead to a number of design options that require analysis.

a. **Centrifuge diameter.** Centrifuge diameters that could be accommodated inside the space station range from very small up to approximately 13 ft.
   1. The smallest diameter is dictated by the specimen foot-to-head gravity gradients that would be experienced. In the past, 15% has been considered maximum. Figure 5.3-1 shows the 15% gravity gradient relationship of an 8-ft-diameter centrifuge. A 15% gravity gradient would limit the size of specimen that could be accommodated, in this case to approximately 7.2 in in height. Under the 15% guideline, rodents and small plants will not be a problem. Squirrel monkeys will be borderline; their average sitting height is about 10 in. Based on this analysis, an 8-ft-diameter centrifuge would be about the smallest that should be considered for research on small primates.
   2. The largest centrifuge diameter studied, 13 ft, is limited by the space station common-module interior diameter (approximately 14 ft). (Larger sizes have been discussed (e.g., a 25-ft-diameter centrifuge using the shuttle external tank aft cargo carrier). These larger diameters were not considered as a part of this study.) The gravity gradient relationship (fig. 5.3-2) for a 13-ft centrifuge is approximately 12-in specimen height. This size centrifuge could accommodate plants, rodents, and squirrel monkeys; however, a rhesus monkey

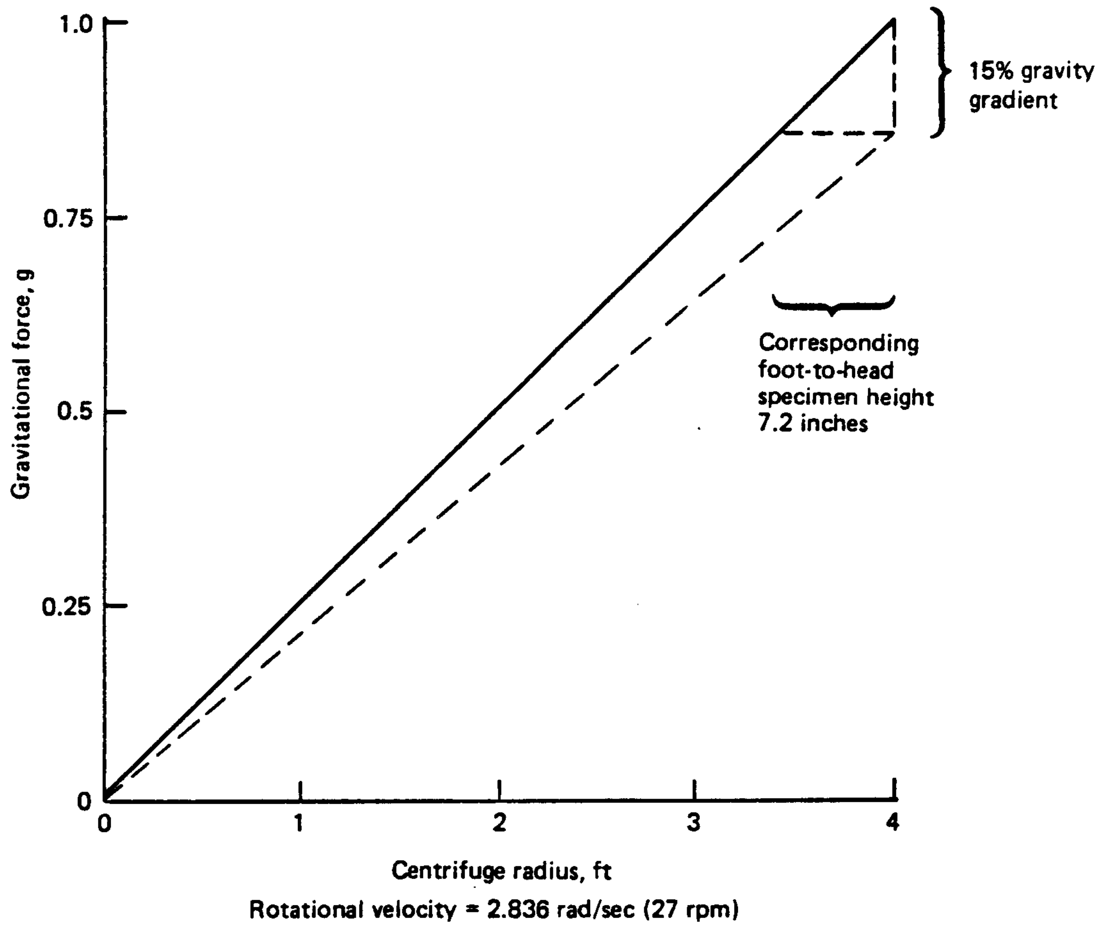

Figure 5.3-1. Gravity Gradient Relationship for 8-ft Diameter Centrifuge

(approximately 24-in sitting height) would experience about 31% gravity gradient.

3. 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 is discussed further in section 5.4.
4. More specimens can also be accommodated on a centrifuge by placing habitats on shorter radii than those located at the periphery of the centrifuge. This will also change the gravitational force. If the outer specimens are subjected to one-g, then those on a shorter radius will be subjected to some fractional-g. There are limitations as to what can be accomplished (e.g., gravity gradient

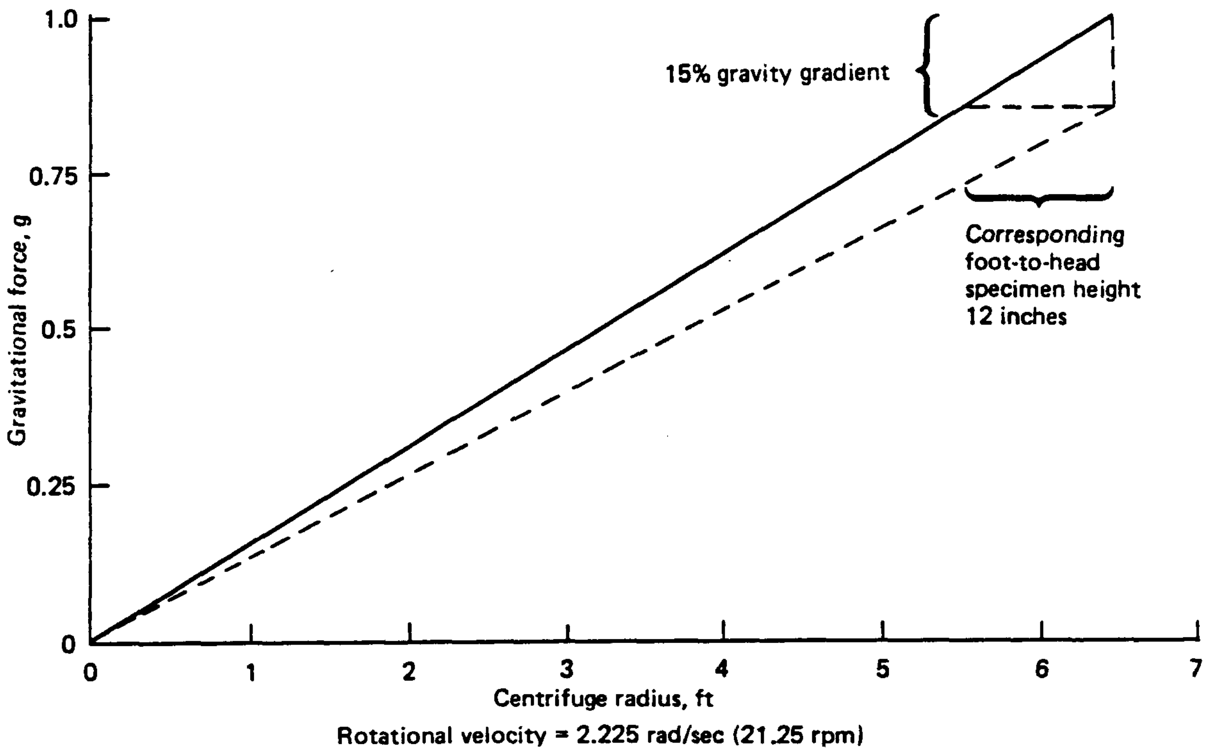

Figure 5.3-2. Gravity Gradient Relationship for 13-ft Diameter Centrifuge

relationships will change as shown in figs. 5.3-1 and 5.3-2). Using the gravity gradient relationship for an 8-ft-diameter centrifuge, fig. 5.3-1, specimens placed on a 2-ft radius will experience a gravity force of 0.5 and the maximum specimen height will be 3.6 in, based on a 15% gravity gradient.

b. **Centrifuge operation.** 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 conditions.

It is not clear at this time if there is a solid requirement for a continuously running centrifuge or if periodic stopping and starting is acceptable. If a continuously running centrifuge is required, it can be achieved by configuring two centrifuges running on the same axis. One centrifuge is continuously running, the other centrifuge is designated a variable-g centrifuge with the capability to access the cages on the continuously running centrifuge. A configuration with these characteristics is illustrated in figure 5.3-3. This particular centrifuge arrangement has 18 specimen-holding units for the 1-g continuously running centrifuge and 16 specimen-holding units for the variable-g access centrifuge.

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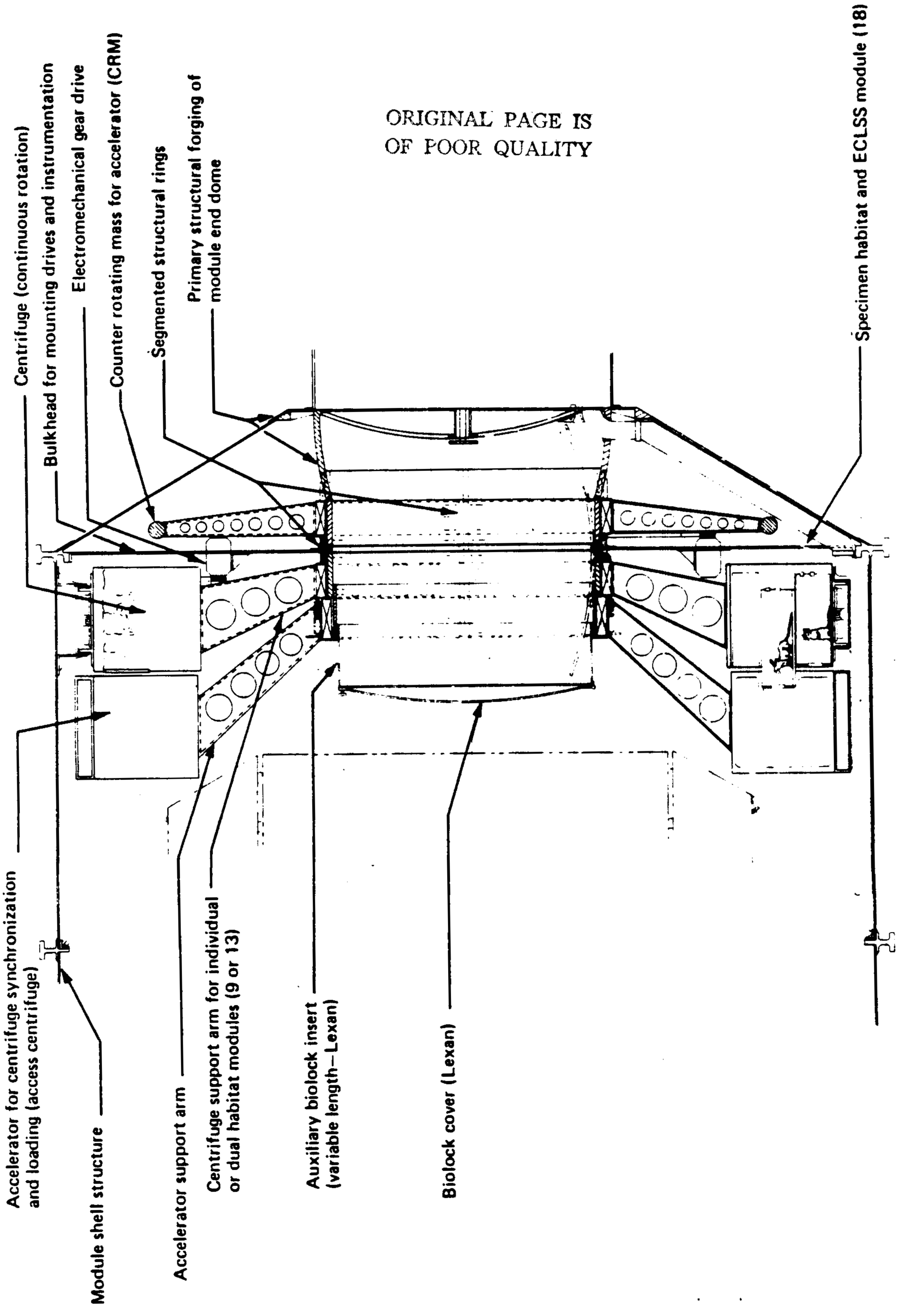

Figure 5.3-3. Details of 13-ft Centrifuge With Access Centrifuge and Counterbalance

This trade is involved in evaluating the scientific value versus implementation cost for a continuously running centrifuge versus the frequent start-stop centrifuge.

5.3.2 Selection

Selections were made for both the IOC and growth mission modules. These selections are discussed in following sections, with the rationale stated for each selection.

5.3.2.1 IOC Mission

At IOC, the nonhuman research facilities are assumed to be shared with the human research facility on a 50/50 split. This condition severely limits the available volume for equipment. Therefore, one 8-ft centrifuge was selected for the IOC configuration. This centrifuge will satisfy a minimal requirement for the 1-g control environment. It will provide very little capability in the fractional-g range and no capability above 1-g, assuming the rotational velocity provides 1-g at the periphery.

For the 1-g controls, the centrifuge will accommodate small plants and rodents. The accommodation of squirrel monkeys will be borderline if gravity gradient levels are limited to 15%; however, they have been included for the IOC concept considered in this study. Rodents and very small plants (less than 4 in high) could also be exposed to gravitational forces between 0.5 and 1.0 for limited, fractional-g research.

Another consideration for an 8-ft centrifuge at IOC is transition accomplishment when the growth module is delivered. A small, single centrifuge would be less crew intensive and less costly to move from one module to another.

5.3.2.2 Growth Mission

For the growth mission, it was assumed that a continuously running centrifuge will be required. With the advent of full-module availability for plant and animal research, it was considered appropriate to satisfy all of the requirements for simulated gravity; three centrifuges are required. The continuously running, 13-ft-diameter centrifuge for 1-g controls and some long-duration fractional-g studies. The 13-ft access centrifuge is to access specimens on the continuously running one and also to provide additional fractional-g conditions. By moving the 8-ft centrifuge to the growth module, g levels greater than 1 could be studied.

5.4 STANDARDIZATION

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

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) contaminant scrubber, and (5) waste management. These interfaces, particularly with 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. 15.) Figure 5.4-1 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 this basic unit installs on an 8-ft centrifuge where nine standard habitat units are installed. Figure 5.4-2 shows how the proposed unit might be configured for adaptation to a rack-type facility.

It is important to achieve this degree of standardization to minimize long term operating costs and provide flexibility for on-orbit changeout and maintenance. Standardized units were considered the choice for both IOC and growth missions.

5.5 SPECIMEN TRANSPORT FACILITY

The life sciences experiment program will require replacement specimens (animals) every 90 days. The transport of these rodents and primates necessarily requires containment and life support. The space station logistics module, as defined by the Boeing proposal configuration, does not include ECLS. 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 orbiter payload bay.

These facilities are envisioned to be several experiment racks containing the transport facility, including the ECLSS, specimen holding units, and provisions for animal transfer to the on-orbit laboratory specimen holding facilities. There are two basic options—

a. Option 1—Specimen life support restricted duration.
b. Option 2—Specimen life support extended duration.

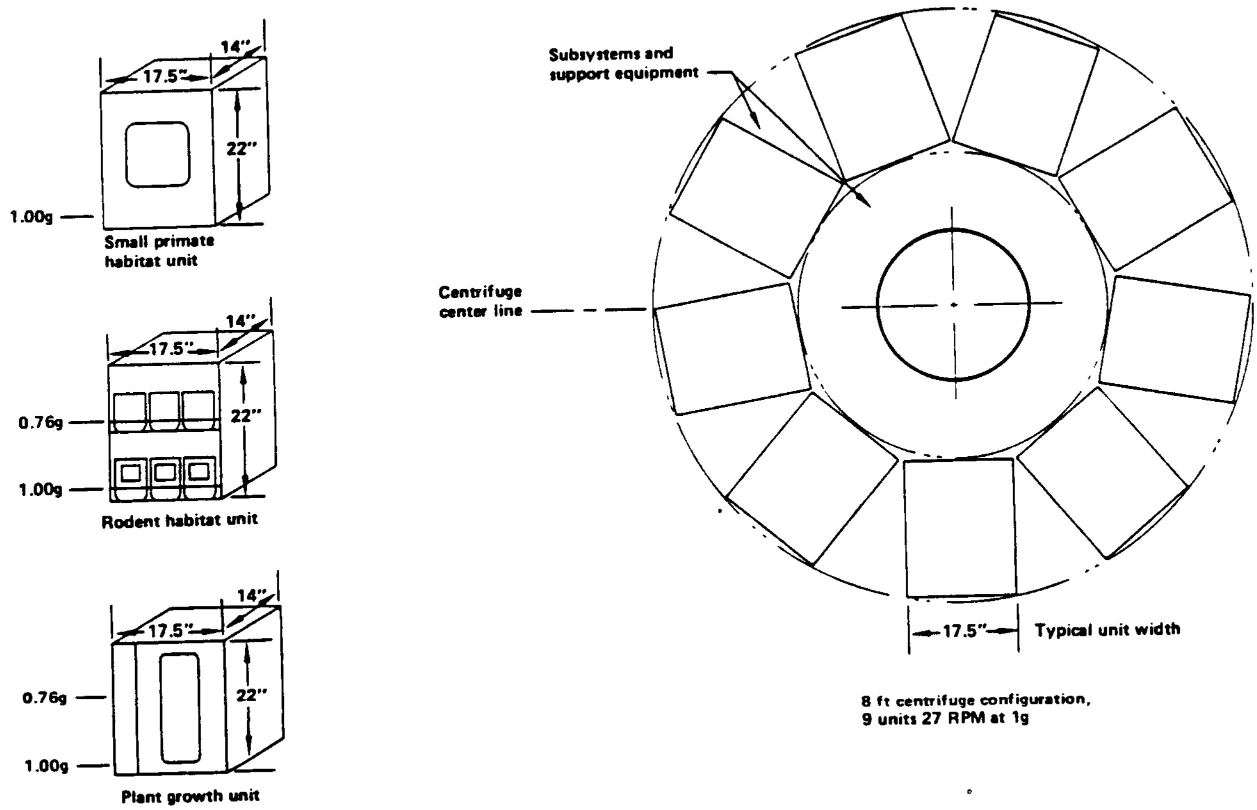

Figure 5.4-1. Common Habitat Unit Concept

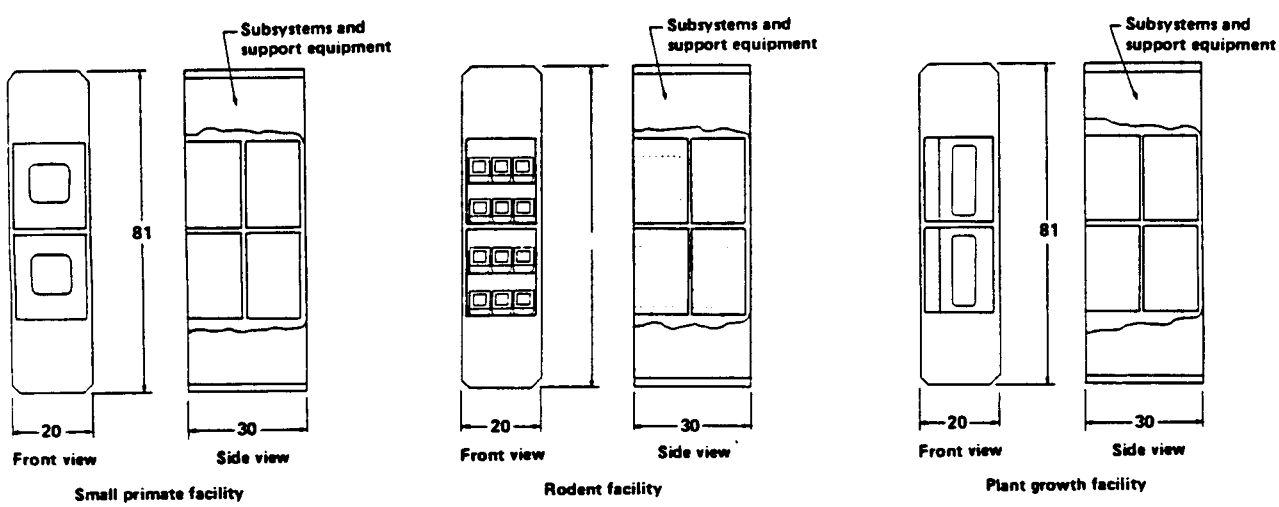

Figure 5.4-2. Common Habitat Facility Concept

Option 1 life support would depend on the logistics module having sufficient trapped air, pressurization, thermal rejection, and electrical power at launch. The specimen transport facility would provide some temperature control, air circulation, and microbial filter isolation. The CO_2 levels would be allowed to build over the total launch sequence (i.e., from loading specimens on the ground to removing them at the space station). This option would provide ECLS for limited duration, dependent on the available air capacity (volume) of the logistics module.

Option 2 involves incorporating the required ECLS equipment within the specimen transport facility and assumes the logistics module is pressurized and can supply electrical power and heat rejection. This option would provide the necessary ECLS for live specimens for some extended duration; however, it would add weight to the logistics module.

No selection was made for the specimen transport facility in this study because adequate data are not available. Indepth analyses need to be conducted in the future with emphasis on the interfaces involved with the logistics module. The transport facility must also be analyzed in conjunction with the micro-g habitats in the LSRF. Standardization should be a strong consideration for developing conceptual designs.

5.6 CAGE CLEANING

Cage cleaning is a major task in the care of specimens on orbit. 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 resuse. This does not appear to be a demanding task until the numbers are considered. If the cages are washed every 7 days, the growth laboratory, with 165 rodents, will require 2121 washing operations every 90 days. This equates to approximately 1/hr, night and day for the life of the laboratory—a sizeable on-orbit task.

5.6.1 Option Analysis

There are two basic options—

a. Option 1—wash and sterilize cages on orbit.
b. Option 2—return dirty cages to Earth.

5.6.1.1 On-Orbit Cage Washing

To wash and sterilize cages on orbit will require (1) a washing device that operates in 0-g, (2) a sterilization unit (may use dry heat, moist heat (steam), or chemicals to kill microorganisms), and (3) a waste-water processing unit to allow reusing the wash water. To date, none of this equipment has been designed for space use. Considerable trade analyses and design and development work will be required to determine optimum washing and sterilizing processes. Once these are understood, waste-water processing requirements and methods can be defined. On-orbit cage washing has been identified as one of the critical areas requiring technology development.

5.6.1.2 Return Dirty Cages to Earth

The second option for achieving clean cages on orbit is simply to transport clean cages to orbit, replace the dirty cages, and transport dirty ones back to Earth. To facilitate this option, some type of replaceable cage liner with high-density packaging capability will be 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 packaging 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 5.6-1 defines a collapsible cage concept for rodents.

The number of liners and their mass and storage volume for this concept are represented by the data given in figure 5.6-2. These data indicate that when the

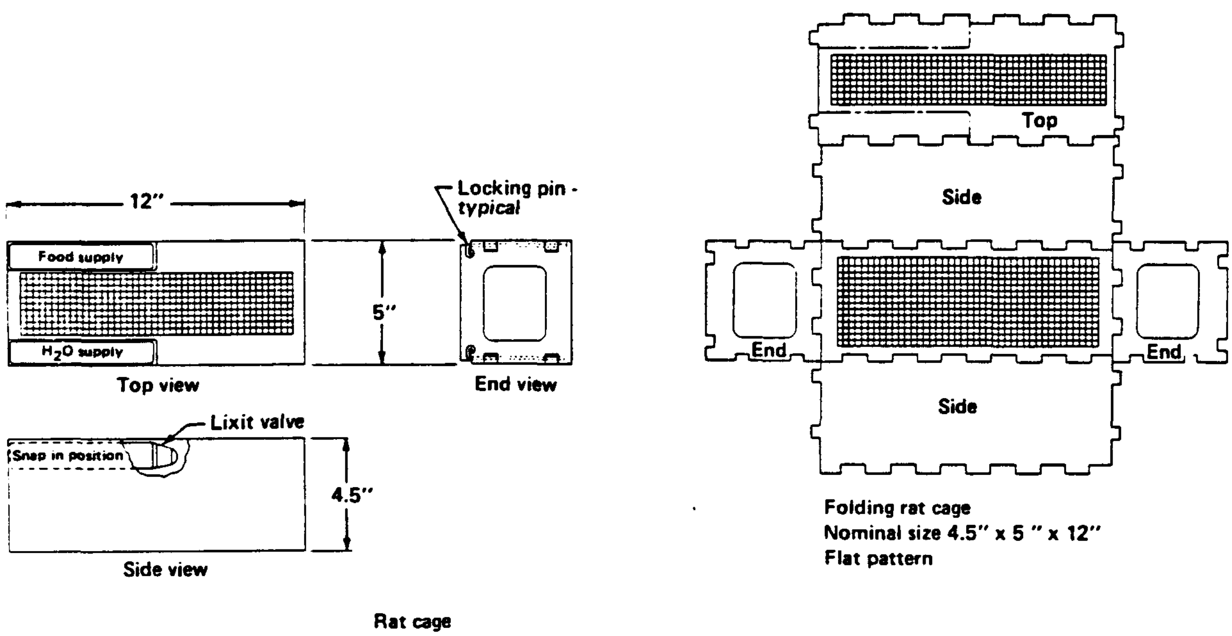

Figure 5.6-1. Collapsible Cage Concept

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Returnable liners (90 days)	IOC Number	IOC Mass (lb)	IOC 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	**Growth Mass (lb)**	**Growth 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 5.6-2. Returnable Cage Logistics

specimen population approaches the numbers represented by the growth concept, the ground cage-cleaning concept is no longer practical.

5.6.2 Selection

The selections made for cage cleaning are to have returnable cage liners for IOC and to develop an on-orbit cage washer for the growth module. The underlying reason is based on the state of development for a cage washer. It is probably not realistic to expect a cage washer and sterilizer to be developed for IOC. Based on this assumption, returnable cage liners would have to be used. The weight associated with transporting cage liners to and from orbit, figure 5.6-2, is probably not prohibitive for IOC. It is highly recommended that technology efforts be initiated as soon as possible to develop a cage washer, sterilizer, and the associated process equipment for water recycling.

6.0 CONCEPT DEVELOPMENT AND EVALUATION

This section describes the recommended IOC and growth concepts, their development, and supporting evaluations. The section concludes with on-orbit resource requirements and logistics analysis, which indicate the required degree of support required from the space station logistics module based upon a 90-day resupply period.

6.1 APPROACH

Both the IOC and the growth life sciences research laboratory configuration concepts were developed interactively with requirements developed in section 3.0, trades defined in section 5.0, and mission transition analysis discussed in section 4.0. The selected IOC and growth concepts were developed to meet the program and mission requirements and minimize the IOC cost impacts. Inherently, they are strongly influenced by cost and experiment requirements, and by the space station common-module configuration and design approach.

Common Module Concept. The Boeing common-module configuration submitted in the Space Station Phase B proposal for work package 1 was used as the baseline for developing life sciences laboratory conceptual layouts. A conceptual drawing of this common module is shown in figure 6.1-1 and in the module cross section (fig. 6.1-2). A module, 27.5 ft long (excluding endcaps) with a 14-ft inside diameter, was assumed for this study. Some of the relevant features of the module include (1) longitudinal floor and ceiling concept that houses subsystem equipment in tilt-out panels; (2) floor and ceiling panels house ECLS, data management, communications, electrical power, and thermal subsystems; (3) common equipment racks with nominal dimensions of 20-in width by 30-in depth by 80-in height that are available for laboratory user equipment; (4) racks tilt out for maintenance and pressure-shell access; (5) racks can be disconnected and rotated for intermodule transport; and (6) utility interfaces in floor and ceiling with easy access for rack connections.

A variety of conceptual layouts were developed and evaluated for the IOC and growth missions. These evaluations resulted in selecting a conceptual design and set of options, previously discussed, for each mission. The selected designs and option sets are described in the following sections.

6.2 IOC CONCEPT DEVELOPMENT AND EVALUATION

6.2.1 IOC Concept Options

The IOC mission is a shared-laboratory module. It was assumed that the module would be divided vertically (see sec. 5.1) with some length taken up by the radial

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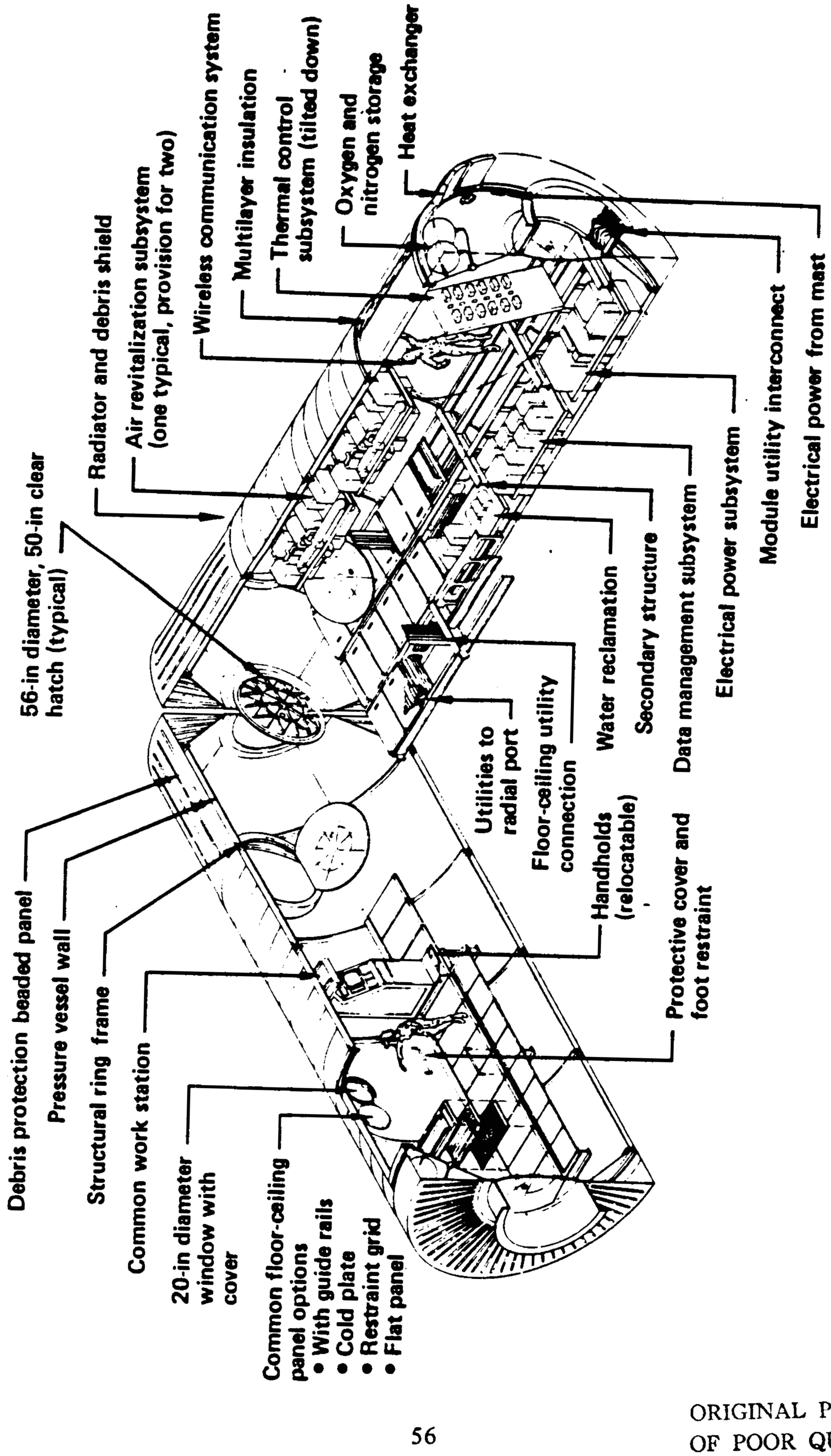

Figure 6.1-1. Typical Common Module

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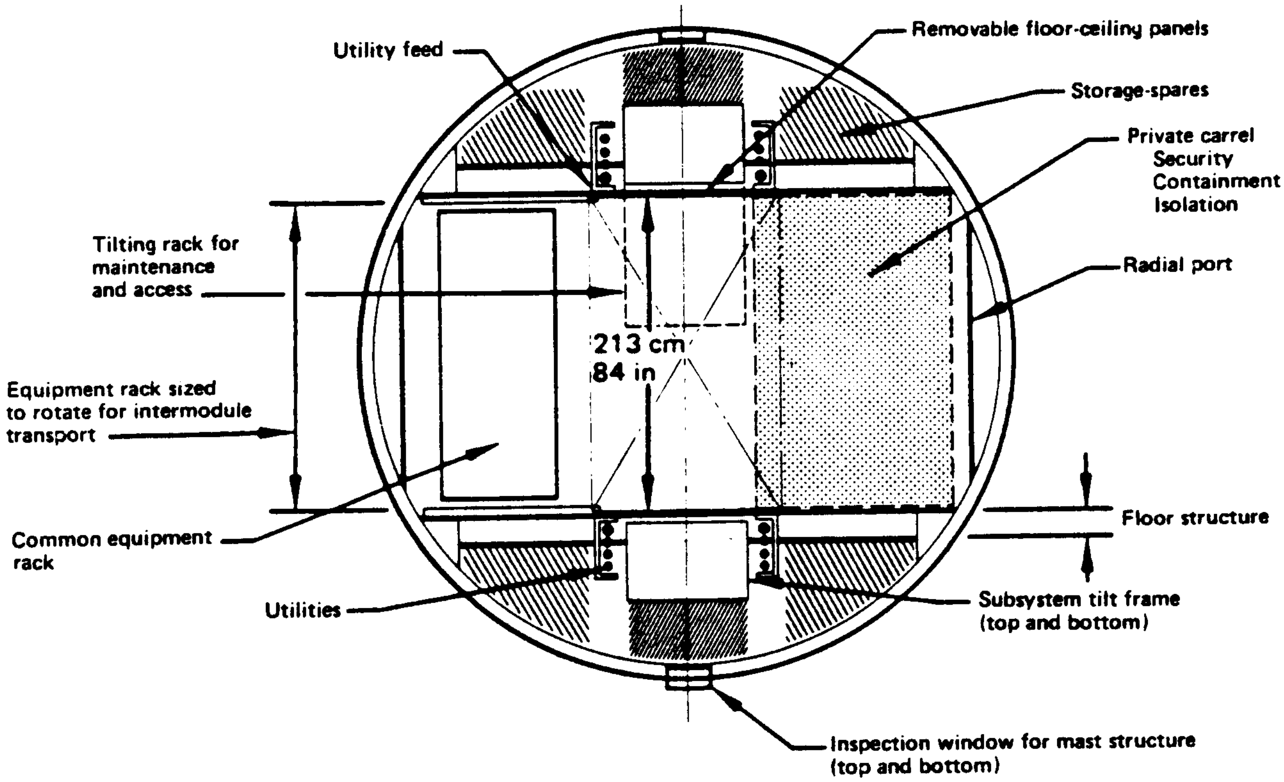


Figure 6.1-2. Typical Common Module Cross Section

berthing ports and the remaining length divided 50/50 between human research and nonhuman research. Assuming a 27.5-ft module, length allocations were assigned as follows:

a. Berthing-port area, 7.5 ft.
b. Human research facility, 10 ft.
c. Nonhuman research facility, 10 ft.

In developing the IOC concepts, eight basic configurations were evaluated. They are mainly variations in size, number, and placement of centrifuges, which impact the module and experiment rack placement in various ways, some severely. The eight basic configurations are—

1. No centrifuge.
2. One 8-ft centrifuge perpendicular to centerline.
3. One 8-ft centrifuge parallel to centerline, in rack area.
4. One 8-ft centrifuge parallel to centerline, on centerline.
5. One 8-ft centrifuge parallel to centerline, in berthing-port area.
6. One 13-ft centrifuge perpendicular to centerline.
7. Two 13-ft centrifuges perpendicular to centerline.
8. One 13-ft centrifuge parallel to centerline, on centerline.

6.2.2 IOC Concept Evaluation

The eight centrifuge options were evaluated for their impact on laboratory configurations and requirements. The evaluation included impact on module primary and secondary structure, laboratory equipment space, subsystem and storage volume, and 50-in access clearance. Figure 6.2-1 summarizes the effects.

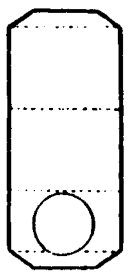
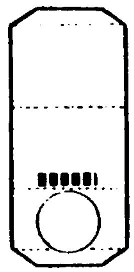
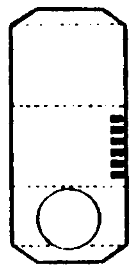
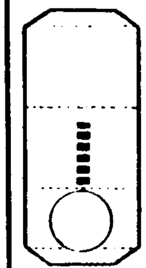
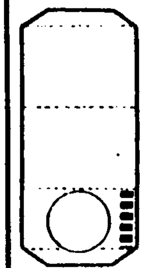
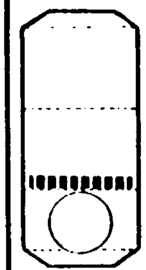
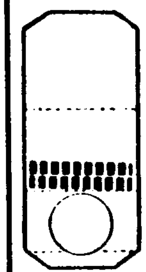
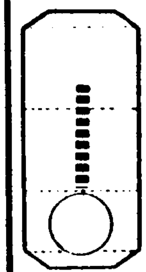
The only option that does not impact the module is option 1, no centrifuge; however, this option is not valid and, therefore, was discarded because it does not satisfy the science requirements. Options 4 and 8 place the centrifuge on the centerline, parallel to the centerline. These options were discarded because the 50-in access clearance requirement is violated and is critical to module operations. Options 2, 3, 6, and 7 all have major impacts on experiment and subsystem equipment volume. Volume is a critical factor for the IOC mission; therefore, these options are not the most desirable. However, they are not as limiting as options 1, 4, and 8.

Option 5 appears to be the most promising and was selected for the IOC configuration. This option places an 8-ft centrifuge in the berthing-port area and, therefore, does not impact equipment volume. However, it does assume that limiting the radial berthing ports to three will not be critical to space station operations. Placing the centrifuge in the berthing-port area of the module appears to have the least impact on the common module and the science and mission requirements.

6.2.3 Selected IOC Concept

It has been concluded that an 8-ft-diameter centrifuge is desirable 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 figures 6.2-2 through 6.2-4, which show 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. The equipment selection is based on the McDonnell Douglas experiments list (ref. 7), equipment catalog (ref. 13), and on a prioritized equipment list furnished by NASA/Ames personnel. This prioritized list is broken into three sets of equipment (figures 6.2-5 through 6.2-7). Each set adds capability to the laboratory in terms of additional support equipment for added species and number of specimens. Using these three sources of data, equipment was selected to fill the IOC equipment racks. This selection is only one of many that could be made and serves only as an indication of the amount of capability available. It should also be pointed out (assuming equipment

Impact	Centrifuge Options							
								
	1	2	3	4	5	6	7	8
Primary structure scarred		X	X	X	X	X	X	X
Floor/ceiling modification		X	X	X		X	X	X
2 equipment racks displaced		X				X		
4 equipment racks displaced							X	
5 equipment racks displaced			X					
Subsystem equipment volume displaced		X	X	X		X	X	X
Limits module radial ports to 3					X			
50-inch access clearance violated or additional racks displaced				X				X

X denotes impact

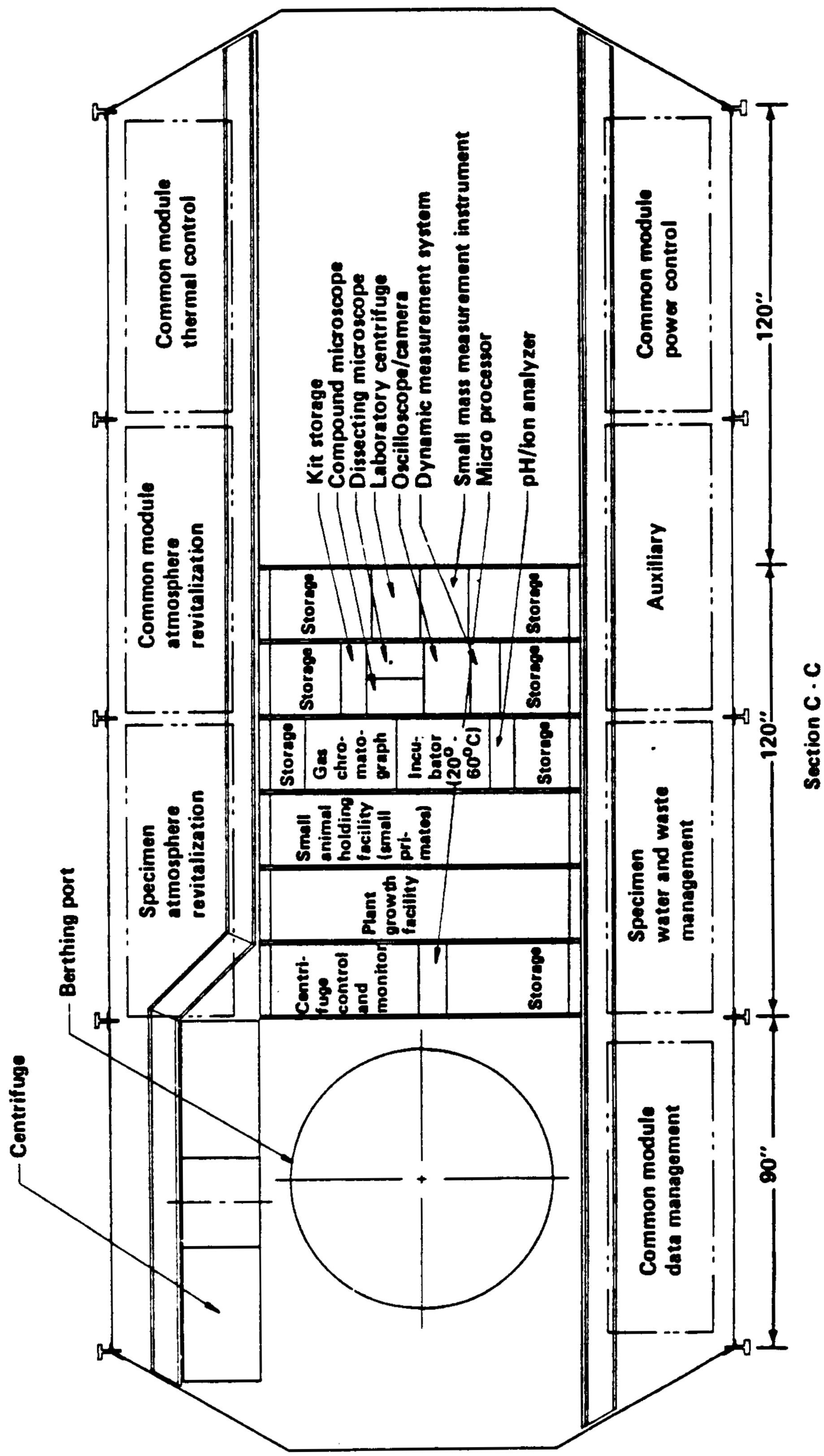


Figure 6.2-2. Selected IOC Module Concept—View A

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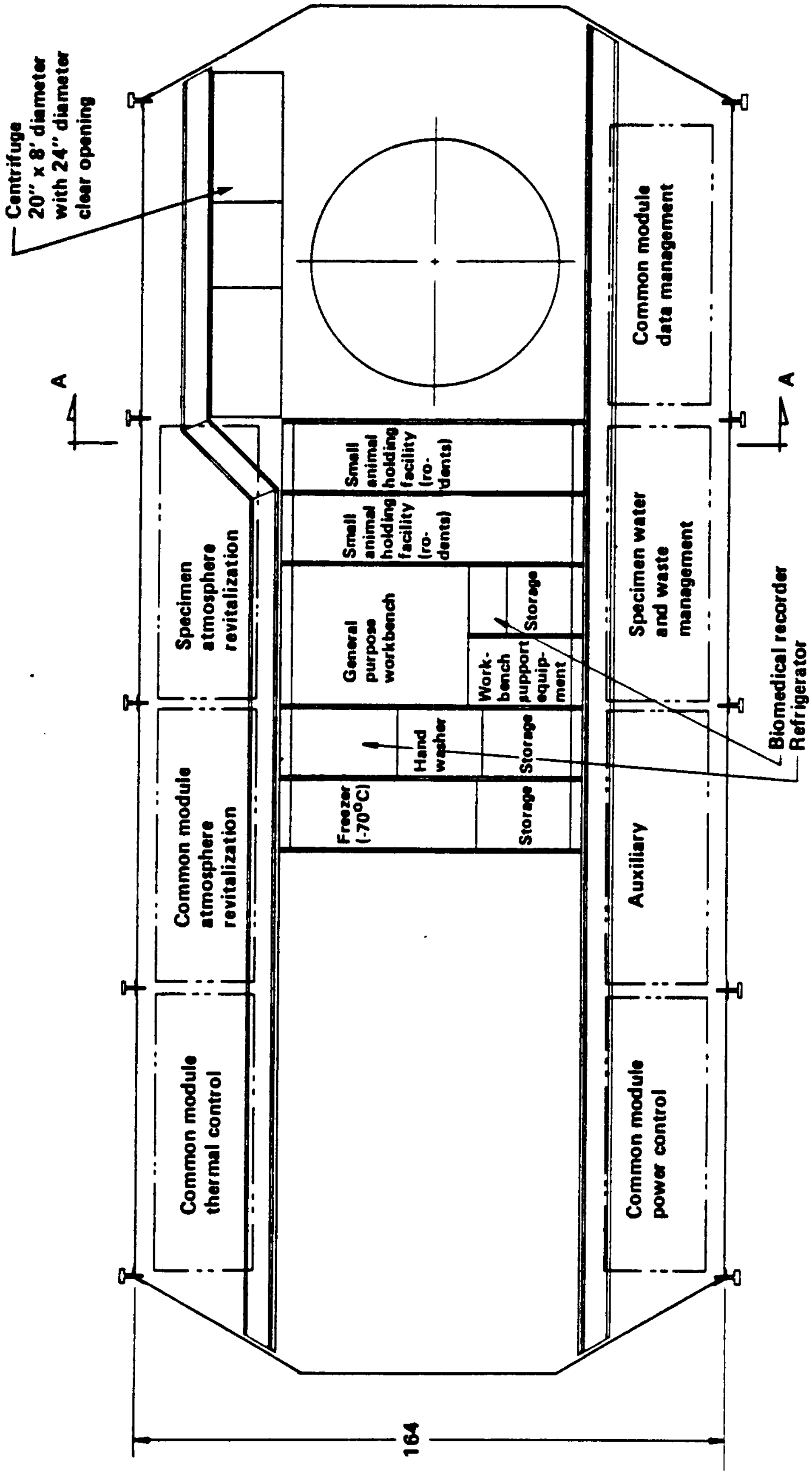

Section B - B

Figure 6.2-3. Selected IOC Module Concept—View B

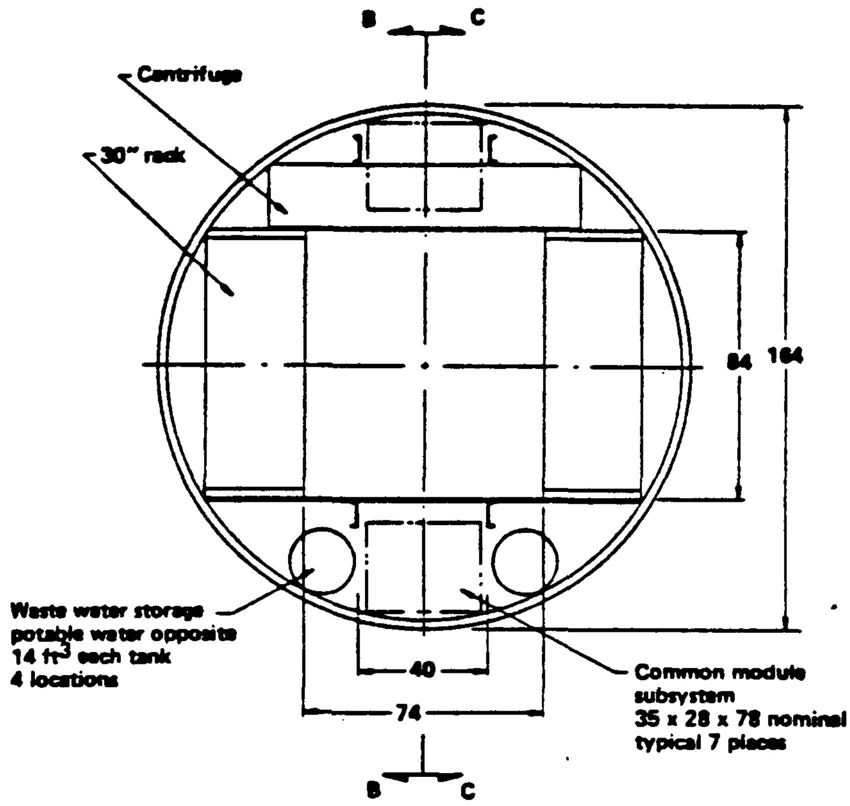

Figure 6.2-4. Selected IOC Module Concept—View C

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 6.2-5. Prioritized Equipment List - Set 1

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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 6.2-6. 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 6.2-7. Prioritized Equipment List—Set 3 will be transferred to and from orbit) that any equipment assignments made now are only indicative and not necessarily recommendations.

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 6.2-8 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 plants and four plant units with 172 wheat plants per standard equipment rack.

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 6.2-8. Specimen Totals for IOC Module

6.2.4 Subsystems and Interfaces for IOC Concept

The IOC laboratory-unique subsystem features are summarized in figure 6.2-9. The principal feature is the approach to bioisolation for isolating the crew from the animal specimens. The common module provides cabin ECLS for the crew. The LSRF provides a mechanically isolated specimen ECLS to prevent any mixing of cabin air with laboratory specimen air. Wherever there is a possibility of mixing (e.g., during cage cleaning and specimen exchange) microbial filters and laminar flow techniques are recommended.

Because the laboratory module has two ECLS systems, one for specimens and the other supplying the crew cabin, subsystem floor/ceiling tilt-down rack space is near saturation. This has bearing on (1) space available for laboratory storage and (2) all-up module weight. The latter involves possible offloading of some equipment racks during the initial launch of the laboratory module. If the laboratory module were overweight for launch, the offloaded equipment racks would be transported to orbit in the logistics module and installed on orbit. The laboratory concept is flexible and can accommodate this situation with no significant disruptions.

Figure 6.2-10 summarizes the utility interfaces for the experiment racks keyed to the rack layouts in figures 6.2-2 and 6.2-3. The utility interface concept is that the common module interface will be located (including disconnects) at the base and top of each experiment rack location. The LSRF-unique interfaces (specimen air, potable water, and laboratory data bus) are available as follows:

a. Specimen air entering and exiting ports available for connection.
b. Potable water, waste water, and laboratory data bus connectors are available at each rack.

This interface approach provides complete flexibility for placement of experiment racks. It also accommodates the on-orbit transition from the IOC laboratory to the growth laboratory, and supports changes in configuration through transport of experiment equipment racks with the space station logistics module.

6.3 GROWTH CONCEPT DEVELOPMENT AND EVALUATION

6.3.1 Growth Concept Options

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 dedicated entirely to nonhuman research. This concept features outfitting the new

STRUCTURES

- o Readily interchangeable rack locations.
- o Bio-isolation supported by mechanical seals between the specimen habitats and the crew cabin. Microbial filters used where applicable.

DATA MANAGEMENT

- o Experiment monitor and control.
- o Data storage and retrieval.

ECLSS

- o Specimen pressure and air composition control.
- o Specimen temperature and humidity control.
- o Specimen atmosphere revitalization.
- o Specimen tissue, urine, fecal waste storage for return.
- o Consumable waste storage for return.
- o Metabolic water recovery and processing.

ELECTRICAL POWER

- o Experiment peculiar power conditioning and protection.
- o Experiment peculiar electrical power distribution and control.
- o Experiment lighting and control.

THERMAL CONTROL

- o Experiment rack (cabin air fans, cold plates, and heat exchangers).

COMMUNICATIONS

- o Experiment peculiar special crew communications.

EXPERIMENT

- o Artificial gravity equipment.
- o Specimen holding facilities.
- o Plant/animal analysis capability.
- o Specimen refrigeration.
- o Specimen transport facilities to and from orbit.

CREW

- o Handholds, pushoffs, restraints and orientation cues.

Figure 6.2-9. IOC Subsystem Features

Equipment rack	Cabin air	Specimen air	Potable water	Lab data bus	Fire det. and suppres.	* S.S. data bus	* Thermal bus	* Electrical power	* Video bus
Lab centrifuge Small mass measurement instrument				X	X		X	X	
Compound microscope Dissecting microscope Oscilloscope camera Dynamic measur. system	X			X	X	X		X	X
Gas chromatograph Incubator pH/ion analyzer	X	X			X	X	X	X	
Small animal holding facility		X	X	X	X	X	X	X	X
Plant growth facility		X	X	X	X	X	X	X	X
Centrifuge control and monitor Microprocessor				X	X	X	X	X	
8-ft, 1-g centrifuge		X	X	X	X	X	X	X	X
Freezer				X	X		X	X	
Refrigerator Hand washer	X		X	X	X		X	X	
(Double rack) General purpose workbench Workbench support equip. Biomedical recorder	X	X	X	X	X	X	X	X	X
Small animal holding facility		X	X	X	X	X	X	X	X
Small animal holding facility		X	X	X	X	X	X	X	X

*Common module utility interface

Figure 6.2-10. Equipment Rack Utility Interfaces—IOC 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 described for IOC (sec. 6.2.1), were used for the growth options. The major difference in configurations is the additional space available in the growth module.

6.3.2 Growth Concept Evaluation

The same evaluation factors and impact analysis were used as for the IOC evaluation (fig. 6.2-1). Options 1, 4, and 8 were again discarded for the reasons given in section 6.2.1. Options 2, 3, 6, and 7 were considered for the growth module. Since rack space is not as critical on the growth module any of these options are viable choices. Considering that since option 5 was selected for IOC, it was assumed it could be transferred to the growth module on-orbit. Two 13-ft centrifuges were also selected for the growth module concept to satisfy science requirements for increased capability. Therefore, options 5 and 7 were combined for the growth module concept.

6.3.3 Selected Growth Concept

The concept selected for the growth mission is depicted in figures 6.3-1 through 6.3-3. The selected concept features (1) the design accommodation for the IOC equipment, including the 8-ft centrifuge, option 5, (2) two 13-ft centrifuges, option 7 (one continuously running and one for access), (3) eight additional rack spaces (20 total), (4) six single racks available for specimen holding facilities, (5) one doublewide rack for large-primate facility, (6) cage washing and sterilization on orbit, (7) specimen ECLS isolated from crew cabin, and (8) regenerative ECLS concepts.

The IOC 8-ft-diameter centrifuge located in the berthing-port area is transferred to the growth laboratory to provide a greater degree of flexibility for variable-g testing. It is a variable speed device that can produce an artificial-g environment of 0.1g to 2.0g with a variation in revolutions per minute (rpm) from approximately 8 to 39 rpm. It is not practical to reduce the centrifuge diameter below 8 ft because the head-to-foot gravity gradients on the specimen exceed the accepted variation of 15%. For example, a 6-in plant will encounter a variation of 12.5% on an 8-ft centrifuge; the same plant on a 13-ft centrifuge varies 8%.

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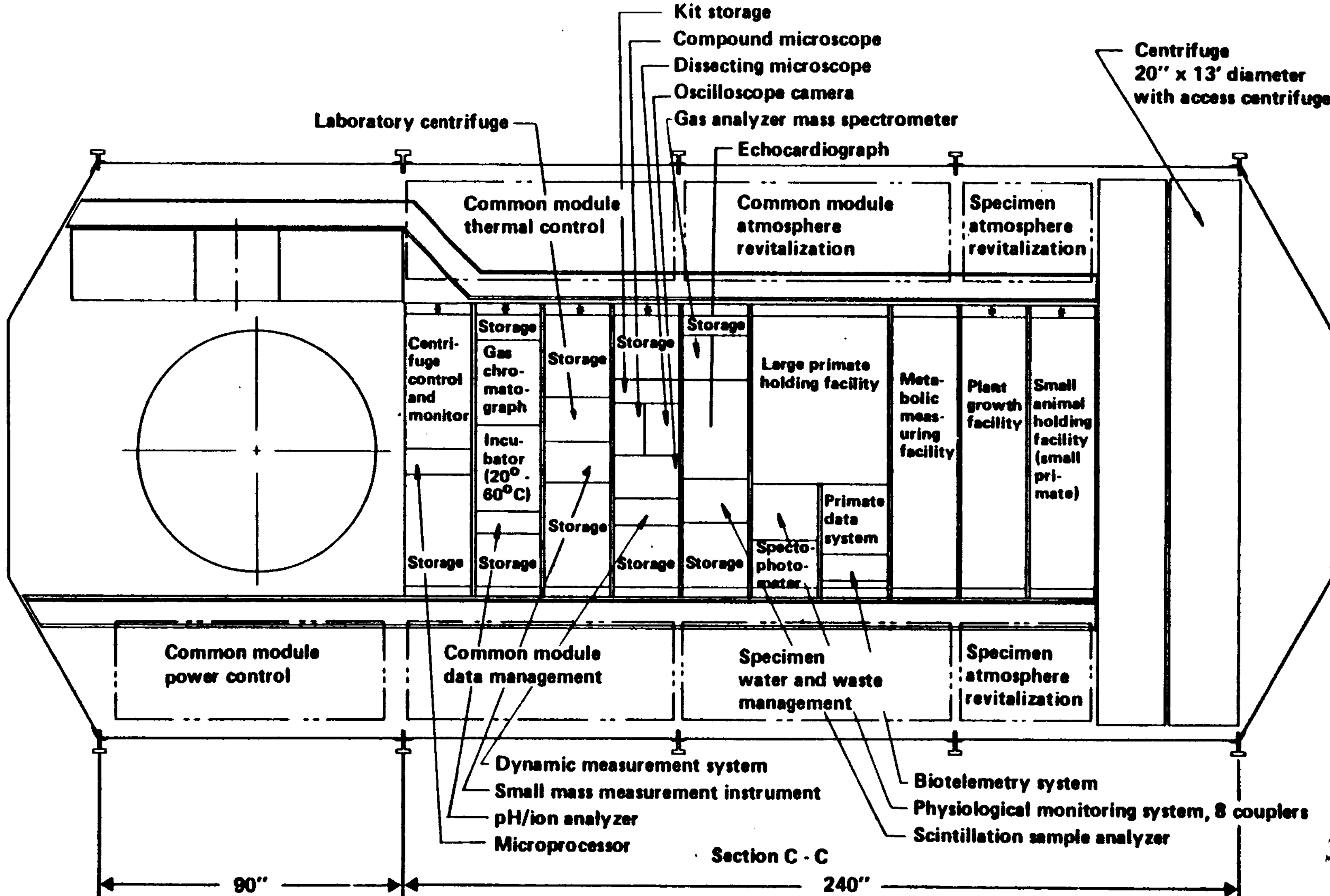
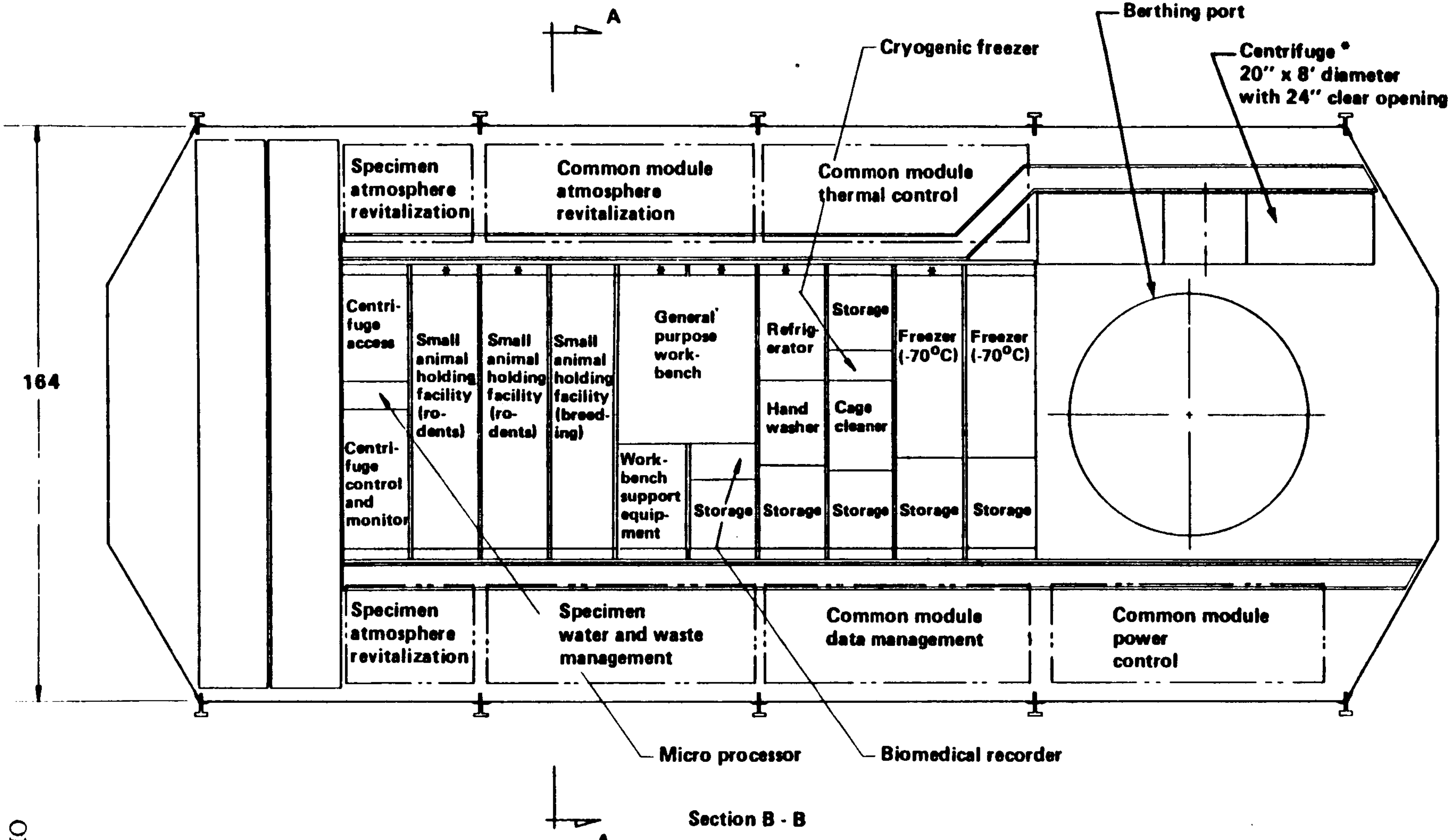


* Equipment racks transferred from IOC module

Figure 6.3-1. Selected Growth Module Concept—View A



* Equipment racks transferred from IOC module

Figure 6.3-2. Selected Growth Module Concept—View B

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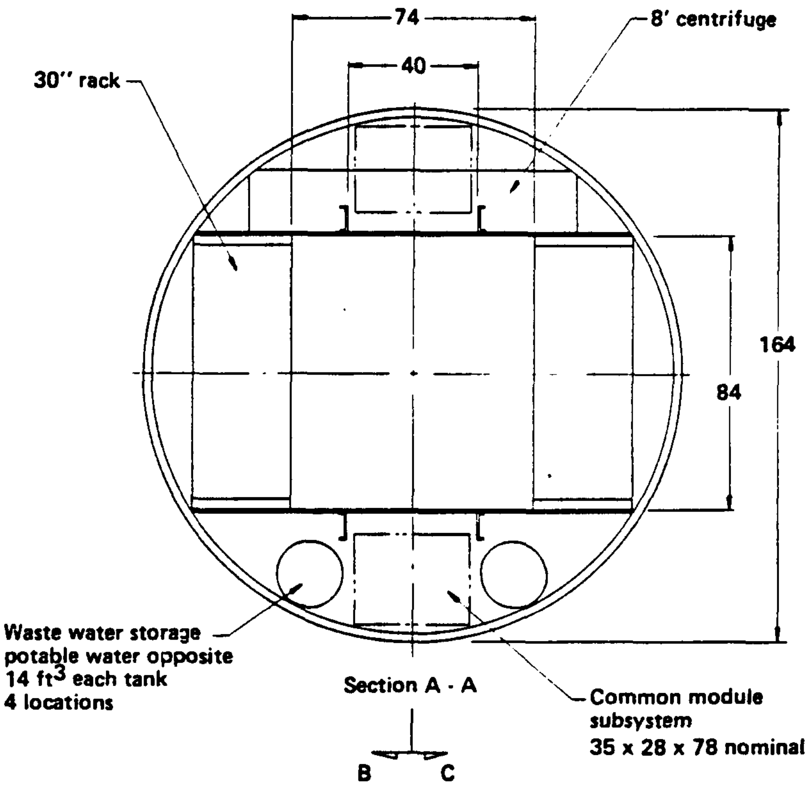

Figure 6.3-3. Selected Growth Module Concept - View C

The 13-ft centrifuges are efficient in volume and performance. They supply the means for 1-g control specimens where the control centrifuge is continuously running. Its companion 13-ft-diameter access centrifuge is dual purpose; it allows access to the continuously running control centrifuge by having the capability for synchronizing with the control centrifuge for the transfer of plant and 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, or 48 rodents, or 16 plant growth units). The 13-ft centrifuges displace four experiment racks. If the displaced racks are animal holding facilities, they would have the capacity for 24 rodents each, or a total of 96 rodents. The 13-ft centrifuges have the capacity for 34 (18 plus 16) habitat units containing 3 rodents each, or 102 rodents total.

The three centrifuges each have their unique capabilities that give the laboratory flexibility for concurrently conducting several groups of test objectives with a variety of test specimens. This flexibility would probably not be used in an IOC laboratory but in the growth laboratory where considerable supporting equipment is available. The ability to carry on several test programs concurrently will improve the efficiency and performance of the life sciences laboratory.

Access to the common-module skin for inspection is considered in each installation. For the 8-ft centrifuge, a center opening of 24 in is provided for inspection access to the common-module skin. Inspection access for the 13-ft centrifuges is gained at either side, around their periphery. The common-module equipment arrangement features all of the specimen holding facilities located adjacent to the 1-g control and access centrifuges. This concentrates the contamination isolation problem to a localized area of the module, except the 8-ft centrifuge specimens located in the berthing-port area. The ECLS interfaces are simplified, and hardware and installation costs minimized.

All other equipment rack locations are completely interchangeable, which provides flexibility of changing configurations with a minimum of on orbit costs involved. The freezers, refrigerators, and rack storage units are located along one side near the berthing ports to allow easy, clear access to the space station logistics module. The general-purpose workbench is located adjacent to the specimen holding facilities. The arrangement allows two crewmen to work different tasks with a minimum of interference.

On-orbit resource requirements were derived from the equipment set shown in figures 6.3-1 and 6.3-2. These resources are approximately 12.2 kW of power; the required volume is 36.6 m^3 for equipment, with an additional 11 m^3 for storage.

The growth module specimen capability is contained within an 8-ft variable-g centrifuge, a 13-ft controlled 1-g centrifuge, a 13-ft variable-g access centrifuge, six single racks available for specimen holding facilities, and one doublewide rack for a large-primate facility. This capability is summarized in figure 6.3-4.

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 6.3-4. Specimen Totals For Growth Module

6.3.4 Subsystems and Interfaces for Growth Concept

The growth laboratory unique subsystem features are the same as those for the IOC subsystems (fig. 6.2-6) with the following ECLS additions:

a. Specimen O_2 generation and storage.

b. Specimen CO_2 collection and processing.

c. Urine processed and recycled.

d. Cage-wash water storage and processing.

The IOC concept involves one ECLS loop closure, which is specimen metabolic water that was recovered, filtered, and treated to supply potable water. Makeup water was transported by the logistics module; this is also included in growth. In addition, O_2 will be produced by water electrolysis with the H_2 byproduct supplied to the CO_2 reduction process. The CO_2 will be collected and reduced with an output of methane and water. The methane will be supplied to the space station for use, or returned, and the water supplied to the water electrolysis for production of specimen O_2. Urine will be recovered and processed to potable water. Cage-wash water will be reprocessed for reuse. This may require frequent resupply of wash water because of the complexity of processing the water repeatedly for reuse.

The growth utility interfaces for the equipment racks are summarized in figure 6.3-5. The common-module interface is indicated as well as the laboratory unique interfaces. The IOC racks are also noted. The growth module rack interfaces are compatible with the IOC rack interfaces. The approach of moving the IOC equipment to the growth module on orbit appears feasible.

In the preliminary development of the concepts selected, cost was a strong consideration. Wherever mission requirements could be met in a variety of ways, the most cost-effective method was selected. The development phasing of these concepts is presented and discussed in section 7.0.

Equipment rack	Cabin air	Specimen air	Potable water	Lab data bus	Fire det. and suppres.	* S.S. data bus	* Thermal bus	* Electrical power	* Video bus
**Small animal holding facility		X	X	X	X	X	X	X	X
**Plant growth facility		X	X	X	X	X	X	X	X
Metabolic measuring facility		X		X	X	X	X	X	X
(Double rack) Large primate holding facility Primate data system Physiological monitoring sys. Spectrophotometer	X	X	X	X	X	X	X	X	X
Gas analyzer mass spec Echocandiograph Scintillation sample analyzer	X			X	X	X		X	
**Compound microscope Dissecting microscope Oscilloscope camera Dynamic measur. system	X			X	X	X		X	X
**Laboratory centrifuge Small mass measur. instr.				X	X		X	X	
**Gas chromatograph Incubator pH/ion analyzer	X	X		X	X	X		X	
**Centrifuge control and monitor Microprocessor				X	X	X	X	X	
**8-ft centrifuge		X	X	X	X	X	X	X	X
Two 13-ft centrifuges		X	X	X	X	X	X	X	X
Microprocessor Centrifuge control and monitor				X	X	X	X	X	
**Small animal holding facility		X	X	X	X	X	X	X	X
**Small animal holding facility		X	X	X	X	X	X	X	X
Small animal holding facility		X	X	X	X	X	X	X	X
**(Double rack) General purpose work bench Work bench support equip. Biomedical recorder	X	X	X	X	X	X	X	X	X
**Refrigerator Hand washer	X		X	X	X		X	X	
Cryogenic freezer Cage cleaner		X		X	X		X	X	
**Freezer				X	X		X	X	
Freezer				X	X		X	X	

* Common module utility interface
**Rack transferred from IOC module

Figure 6.3-5. Equipment Rack Utility Interfaces - Growth

6.4 FUNCTIONAL INTERFACES

The on-orbit life sciences laboratory may be divided into three functional groups (as related to interfaces) (1) LSRF accommodation as supplied by the outfitter, (2) the common-module accommodation, and (3) the space station logistics module direct support. These respective functions are shown in figures 6.4-1 through 6.4-3. By comparing these functions by subsystem, a functional interface may be described between the common module and the outfitter supplied functions. A support interface also exists between the other two functions to operate the laboratory on orbit. This support is supplied by the space station logistics module. To achieve the benefit of this support, the life sciences laboratory must provide live-specimen life support and transport carrier capability and specimen-sample freezers for the logistics module. This allows the logistics module to fully support the transport of consumables, specimens, experiment equipment, and maintenance orbital replacement units (ORU).

- Structure and mechanism
  - Equipment installation
  - Laboratory storage accommodation
  - Bio-isolation compartmentation

- Electrical power
  - Laboratory power distribution and control
  - Power conditioning and protection

- Data management
  - Experiment monitoring and control
  - Data storage and retrieval
  - Video monitoring and storage

- Habitability/man systems
  - Mobility and restraints
  - Hand holds and pushoffs
  - Housekeeping provisions
  - Contamination detection and control

- Environmental control and life support
  - Specimen atmosphere pressure and composition control
  - Specimen temperature and humidity control
  - Specimen air revitalization
  - Laboratory water collection, processing and dispensing
  - Laboratory waste collection, treatment and disposal

- Thermal control
  - Air circulation
  - Heat exchanger

Figure 6.4-1. LSRF Accommodation Functional Interfaces

- Structure and mechanism
  - Primary structure
  - Secondary structure (floor, ceiling and rack attach points)
- Electrical power
  - Power distribution
  - Load control and circuit protection
- Data management
  - Subsystems monitor and control
  - Data acquisition and handling
  - Operation and control command processing
  - Timing reference
- Communications
  - Audio utility distribution
  - Video utility distribution
  - Intercommunications
- Habitability/man systems
  - Hand washer
  - Interior lighting
  - Stowage containers
- Environmental control and life science
  - Atmosphere, pressure, and composition control
  - Temperature and humidity control
  - Atmosphere revitalization
  - Waste control and disposal
  - Water management
- Thermal control
  - Thermal bus
  - Thermal bus interface

Figure 6.4-2. Common Module Functional Interfaces

- LSRF supplied
  - Live specimen carrier transporters
  - Live specimen life support
  - Specimen freezers

- Logistics support
  - Consumables transport and storage
  - Transport (to orbit and return) live specimen carrier transporters
  - Transport freezers for sacrificed specimens and sample return
  - Transport LSRF upgrade equipment
  - Transport LSRF maintenance ORU's

Figure 6.4-3. Logistics Module Functional Interfaces

6.5 LOGISTICS ANALYSIS

This section summarizes the LSRF resupply logistics requirements for both the IOC and the growth concepts. The logistics requirements provide a basis for updating the Space Station Mission Data Base.

Figure 6.5-1 defines the input consumption and output production of each specimen group for IOC and growth. These data were the basis for the ECLSS mass balance analysis that is discussed for the IOC and the growth configurations.

IOC

Specimen	Pounds per day							
	Food	Water	Oxygen	Carbon dioxide	Urine	Feces	Respiration and Perspiration	Water of transpira-tion
Small primates (6)	0.92	1.16	0.53	0.67	0.34	0.20	0.91	-
Rodents (63)	3.47	4.16	3.47	4.28	1.83	0.69	3.21	-
Plants (258)	-	4.27	- 0.05	- 0.05	-	-	-	4.27
Total	4.39	9.59	3.95	4.90	2.17	0.89	4.12	4.27

GROWTH

Specimen	Food	Water	Oxygen	Carbon dioxide	Urine	Feces	Respiration and Perspiration	Water of transpira-tion
Large primate (1)	0.47	2.65	0.66	0.77	1.85	0.19	1.10	-
Small primates (8)	1.23	1.55	0.70	0.90	0.46	0.26	1.22	-
Rodents (165)	9.08	10.89	9.08	11.22	4.79	1.82	8.42	-
Plants (516)	-	8.53	- 0.10	- 0.10	-	-	-	8.53
Total	10.78	23.62	10.34	12.79	7.10	2.27	10.74	8.53

Figure 6.5-1. Specimen Input / Output Summary

6.5.1 IOC Logistics Requirements

The IOC logistics requirements were developed based the following assumptions and conditions:

a. Specimen cage liners are replaced every 7 days and are stored and returned every 90 days in the space station logistics module.

b. Humidity condensate water is recovered, processed, and reused as specimen potable water.

c. Specimen oxygen is transported and stored on orbit by the logistics module.

d. Carbon dioxide is recovered and liquified and returned in the the logistics module.
e. Specimen urine is collected and returned as waste.
f. Feces is recovered and returned as waste.
g. Experiment equipment is transported to and from space station in standard equipment rack units.
h. Live-specimen transport equipment will be supplied for installation in the logistics module for live-specimen transport to and from orbit.
i. Sacrificed specimens and tissue samples will be transported from orbit in freezer units. These freezers will be supplied in the logistics module for installation in the laboratory.

An ECLSS mass balance was performed to derive logistics requirements. Using specimen food, water, and oxygen as inputs, outputs of CO_2, urine, and fecal waste were determined. This mass balance was sized for 6 small primates, 63 rodents, and 258 wheat plants. The metabolic water (perspiration and respiration) is recovered and recycled. Carbon dioxide is removed by a molecular sieve process, collected, compressed, and stored. Metabolic wastes (urine and feces) are collected and stored. This analysis is summarized in the schematic in figure 6.5-2. The IOC logistics requirements are shown in figure 6.5-3.

It has been assumed that two replacement experiment racks will be transported to the LSRF to replace two existing racks every 90 days. This allows flexibility in experiment planning and operations. One specimen freezer (-70°C) will be provided in the logistics module. It presumably will be unpowered during launch and powered for the return flight. It will store and transport sacrificed specimens and tissue samples back to the ground.

The following areas of requirements were left to be determined (TBD).

a. Specimen transport facilities.
b. ECLSS expendables.
c. Laboratory expendables.

The specimen transport facilities require a limited-duration life support capability that is dependent on the utility supply capability of the logistics module. Many other factors have influence (e.g., the ability to gain access on the launch pad, and ability to supply continuous electrical power and heat rejection after installation on the ground and upon return). ECLSS expendables are composed principally of replacement filter devices, brine tanks, etc. The laboratory expendables are composed of absorbent odor control and waste collection materials, disposable analysis kits, cleanup wipe materials, etc.

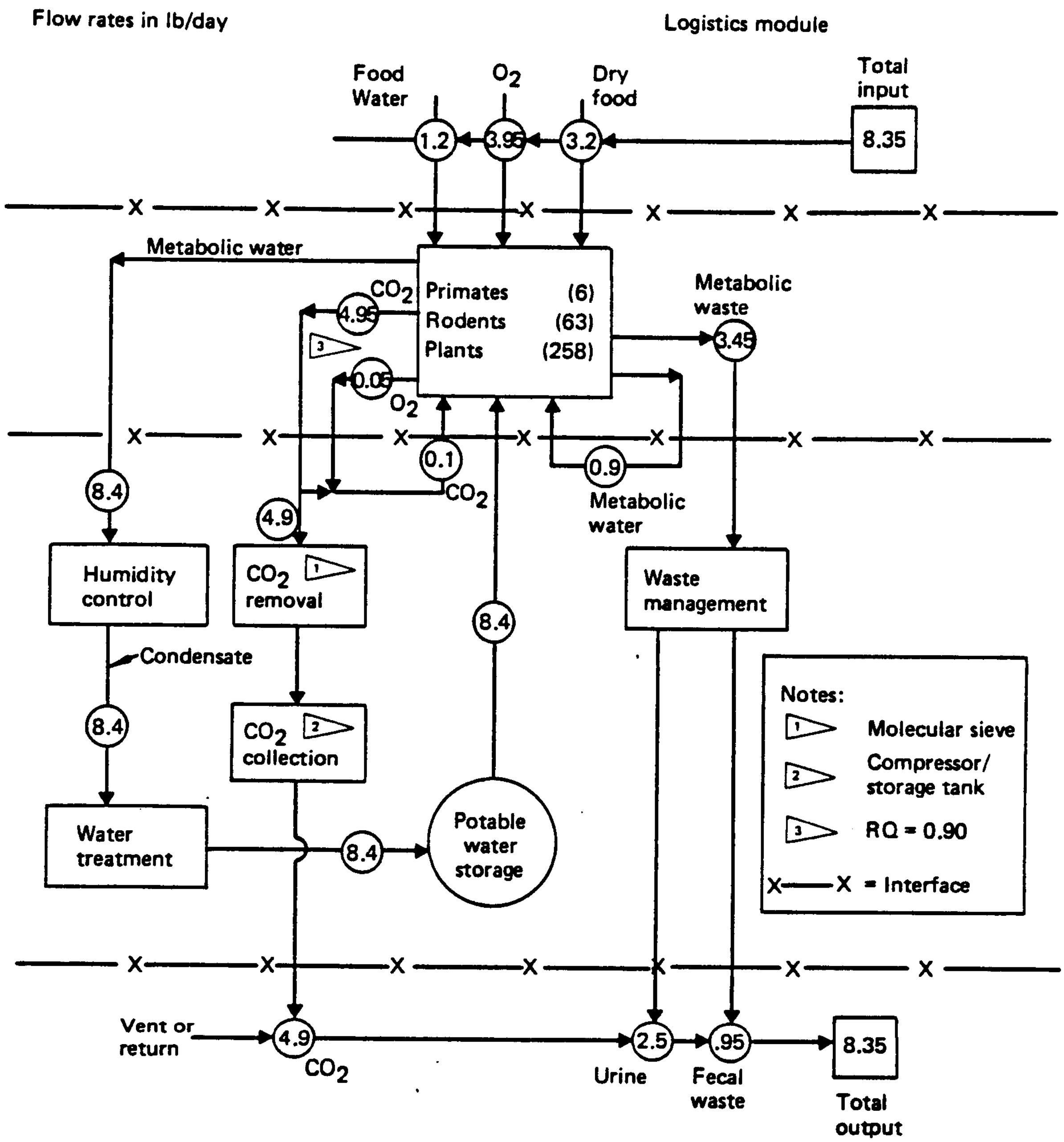

Figure 6.5-2. Specimen ECLS Material Balance – IOC Module

Manifest Item	Up Load, lb	Down Load, lb
• Specimen food (25% H_2O)	396	-
• Oxygen (0_2)	356	-
• CO_2 (waste)	-	441
• Water (resupply)	0	-
• Urine (waste)	-	225
• Feces (waste)	-	86
• Cage liners	4,647	4,647
• Experiment equipment racks (2)	1,400	1,400
• Specimen freezer	300	300
• Specimen transport racks	TBD	TBD
• ECLS expendables	TBD	TBD
• Lab expendables	TBD	TBD
Total	7,099 + TBD	7,099 + TBD

Figure 6.5-3. IOC Logistics Transport Requirement (90-Day Supply)

6.5.2 Growth Logistics Requirements

The growth logistics requirements were developed based upon the following assumptions:

a. Specimen cages are washed on orbit. Cage-washing water is recovered, processed, and reused on orbit.
b. Humidity recovery water is processed and reused as potable water.
c. Specimen oxygen is generated by electrolysis.
d. Carbon dioxide (CO_2) is recovered and processed to produce water and methane using the hydrogen byproduct from water electrolysis. The excess methane/CO_2 will be supplied to the space station for propulsion use.
e. Specimen urine is recovered through a wick evaporator process.
f. Specimen feces is collected and returned by the logistics module.
g. Experiment equipment is transported to and from orbit in standard equipment rack units.
h. Live-specimen transport equipment will be supplied for installation in the logistics module for live-specimen transport to orbit.
i. Sacrificed specimens and tissue samples will be transported from orbit in freezer units. These freezers will be supplied for installation in the logistics module.

The life support logistics items were determined by performing an ECLSS mass balance (shown schematically in fig. 6.5-4). The balance was performed based on 8 small primates, 1 large primate, 165 rodents, and 516 wheat plants. Metabolic water (perspiration and respiration) and water vapor generated by wick evaporation for recycling urine are recovered by the humidity condenser and recycled after treatment. Carbon dioxide is collected by a molecular sieve and then reduced to methane (Sabatier process) to the extent possible by the hydrogen supplied by the electrolytic cell producing oxygen. Fecal waste is collected and stored. The growth logistics requirements are summarized in figure 6.5-5.

As in the IOC logistics module, two experiment racks are transported to the laboratory for exchange with existing racks. This provides a continual capability for upgrading and support of evolving experiment programs. Because of the increased specimen capability, the logistics module requires increased freezer capacity. Two -70°C freezers are provided. These freezers will require 1 kW of power during the return trip. They would be powered down for the launch-delivery flight. It appears not to be practical to supply replaceable cage liners for specimen cage cleaning because of the excessive weight and volume involved. A cage washer will be provided on-orbit and the

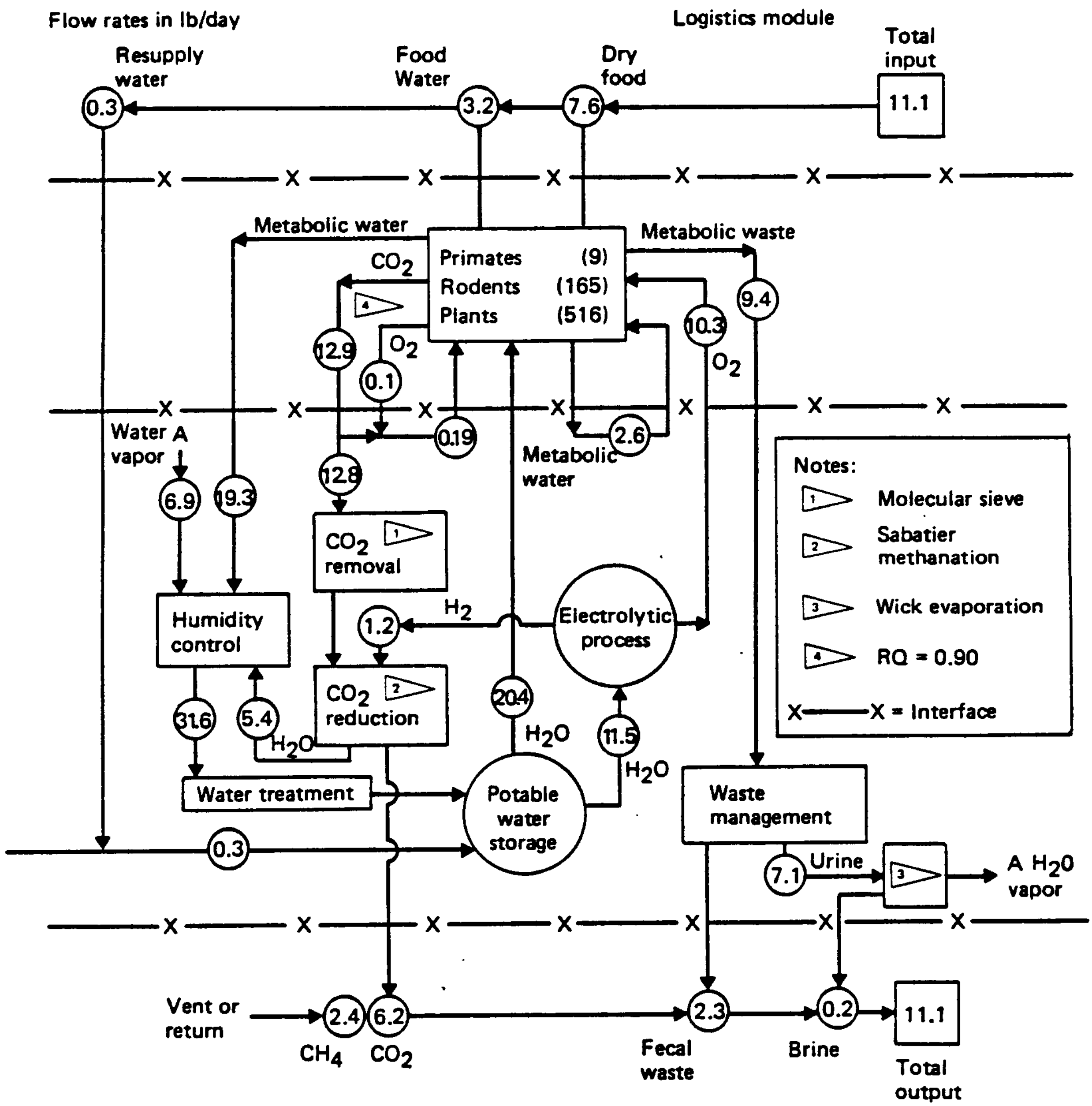

Figure 6.5-4. Specimen ECLS Material Balance — Growth Module

Manifest Item	Up Load, lb	Down Load, lb
• Specimen food (25% H_2O)	972	-
• CH_4 (waste)	-	216
• CO_2 (waste)	-	558
• Water (resupply)	·27	-
• Urine (brine) (waste)	-	18
• Feces (waste)	-	207
• Experiment equipment racks (2)	1,400	1,400
• Specimen freezers (2) (-70 deg,C)	600	600
• Specimen transport racks	TBD	TBD
• Cage wash water	TBD	TBD
• Lab expendables	TBD	TBD
Total	2,999 + TBD	2,999 + TBD

Figure 6.5-5. Growth Logistics Transport Requirements (90-Day supply)

additional function for processing cage-washing water is added to the ECLSS. Because of the severe requirements for processing the cage-washing water, it is assumed that the water will periodically require replacement because of excessive contamination.

The growth logistics total appears to be lower than for IOC. This is a misconception because the cage liners are no longer provided for growth and cage-washing water has taken its place (TBD for now). The expendables for growth will be higher and the ECLSS inputs and products are higher. The resulting growth logistics total will ultimately be higher than IOC.

7.0 PROGRAMMATICS

This section defines the LSRF programmatic factors that 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 summarized in section 6.0.

7.1 WORK BREAKDOWN STRUCTURE

The WBS and WBS dictionary were developed to provide the framework for task planning and control. It 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 life sciences program WBS elements are defined to level 5. The WBS was developed around the concept of a module outfitting contractor. A common module is supplied at level 3 as a builtup 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 7.1-1. The complete WBS and dictionary are documented in appendix E.

7.2 SCHEDULE

A program schedule was developed in accordance with the WBS. The schedule (fig. 7.2-1) 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 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^{o}C to -195^{o}C). Another critical item is a specimen cage-washer and sterilizer. The washer may not be required for IOC but will certainly be needed for growth.

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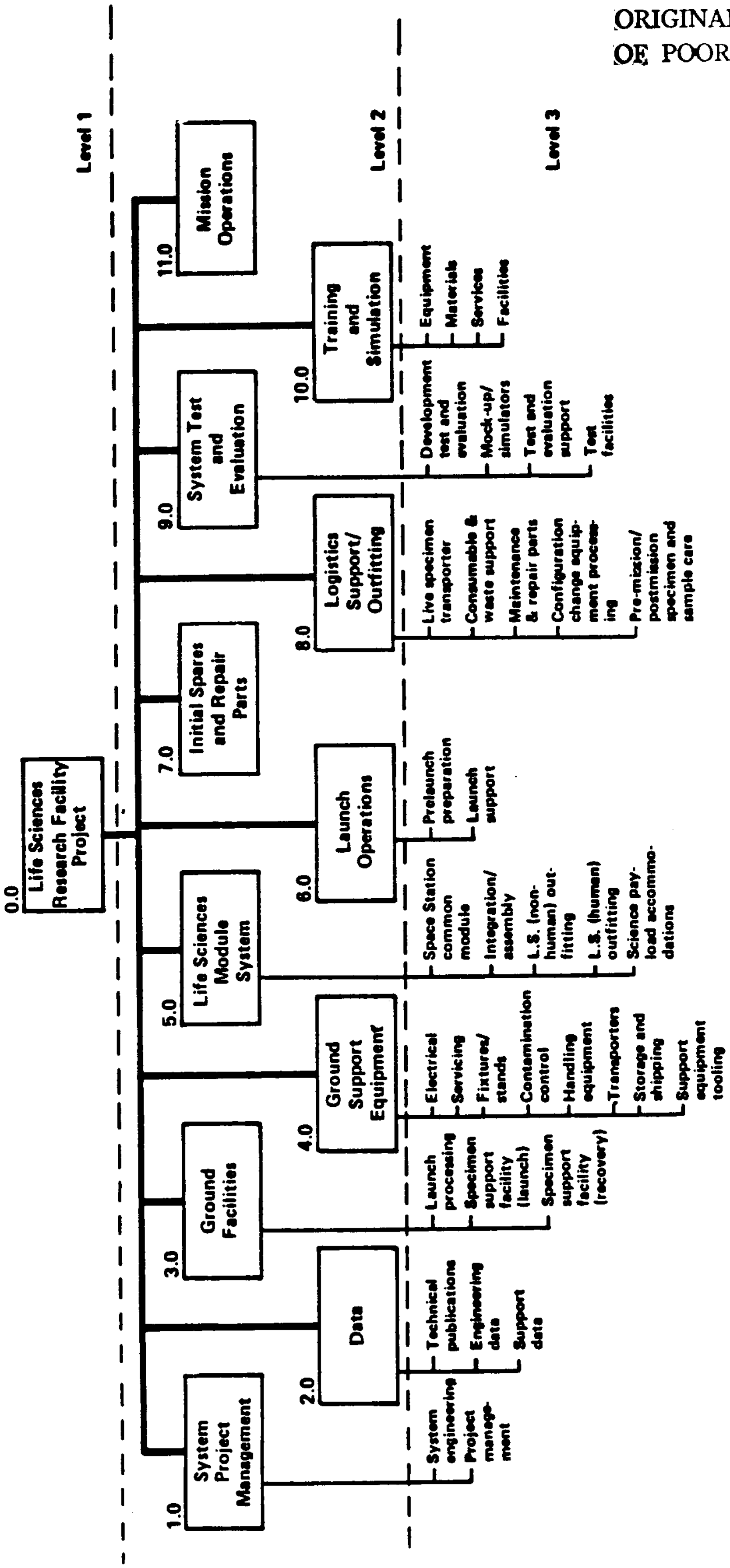

Figure 7.1-1. Work Breakdown Structure for the LSRF Project

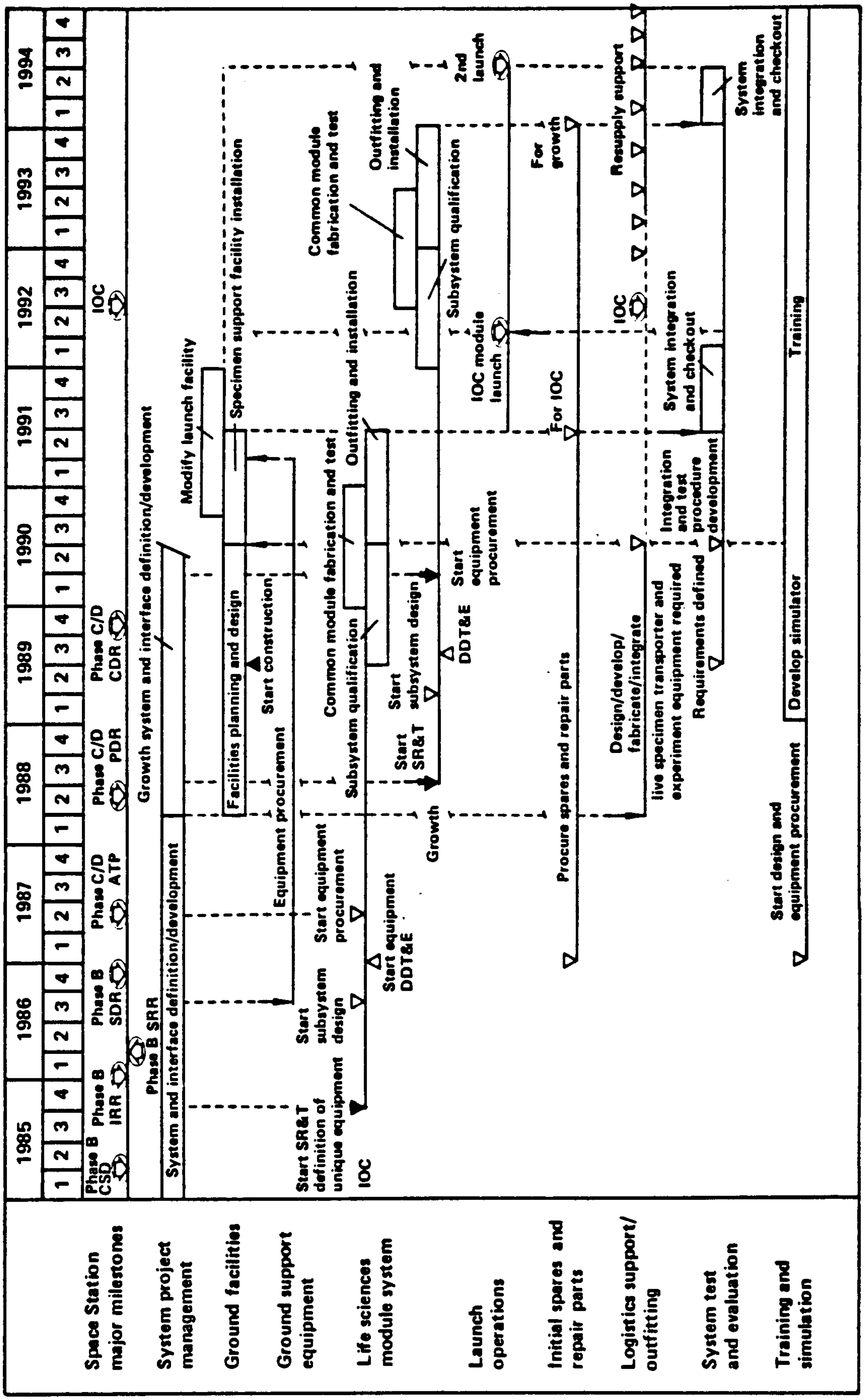

Figure 7.2-1. Life Sciences Research Facility Development and Operations Schedule

7.3 COST

Program costs were developed for the outfitted IOC and growth module concepts described in section 6.0. 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 models. The Boeing-developed, parametric cost model (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 model was used to estimate the cost of electronics.

The following ground rules and assumptions were used to estimate costs for all three module concepts:

a. The cost estimate is in constant 1985 dollars.

b. The estimate does not include costs for the following items:

   1. Ground facilities.
   2. Launch operations.
   3. Logistics support and outfitting.
   4. Training and simulation.
   5. Mission operations.
   6. Life sciences human research module outfitting.
   7. Attached exterior science payload accommodations.
   8. Laboratory common module nonrecurring costs.

c. The estimate assumes additional ECLSS and structures are necessary to outfit the nonhuman section of the laboratory module.

d. Laboratory equipment costs were derived from McDonnell Douglas technology assessment and development plan, 1983 (ref. 12).

e. The additional ECLSS needed to outfit the laboratory module was assumed to be 100% off the shelf.

f. Subcontract and Boeing spares were estimated to be 5% of hardware costs.

g. One set of peculiar support equipment.

h. Common module software costs are not included. Additional software requirements for outfitting the laboratory module are included.

i. The program schedule was assumed to be nominal.

j. The LSRF has a separate water system.

k. The LSRF laboratory equipment will be packaged in tilt-down racks.

l. The laboratory experiment equipment includes heat exchangers and cold plates, as required to tie into the common module thermal bus.
m. The life sciences module outfitting includes both recurring and nonrecurring costs.

7.3.1 IOC Costs

In addition to the above ground rules, the IOC costs assume that specimen oxygen will be supplied by the logistics module. Condensate will be collected from the dehumidifier units, processed, and reused. Makeup water will be supplied by the logistics module. Specimen CO_2 will be collected, liquified, and returned by the logistics module. The IOC configuration includes an 8-ft-diameter centrifuge and 12 racks for experiment equipment.

The estimated cost for the IOC module and LSRF outfitting is $273.3 million, as shown in figure 7.3-1. 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 (listed in fig. 6.2-7).

7.3.2 Growth Costs

Additional assumptions for the growth module cost include provisions for transferring the 8-ft centrifuge and 12 loaded equipment racks from the IOC module to the growth module. Eight additional racks of equipment will be delivered in the growth module for a total of 20 equipment racks. Specimen oxygen will be generated by water electrolysis. Condensate will be collected from the dehumidifier units, processed, and reused. The carbon dioxide (CO_2) will be collected and processed to produce water and methane (CH_4). The cage-washing water will be collected, processed, and reused. The growth configuration assumes provisions for three centrifuges as follows:

a. An 8-ft diameter variable-g centrifuge (located in berthing-port area).
b. A 13-ft diameter 1-g control centrifuge (occupying 2 rack spaces).
c. A 13-ft diameter variable-g, access centrifuge (occupying 2 rack spaces).

Figure 7.3-2 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 the growth capability. This additional equipment includes two 13-ft centrifuges and eight additional racks of equipment as previously identified in figure 6.3-5.

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 7.3-1. IOC Configuration Cost Summary

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 7.3-2. Growth Configuration Cost Summary

7.3.3 Unique Growth Costs

The unique growth module concept assumes there is no shared laboratory capability (i.e., a dedicated growth module for nonhuman research would be the first LSRF module). The costs for this concept are shown in figure 7.3-3. Some savings could be realized from this concept (i.e., $378.5 million for the unique growth module as compared to $584.9 million, which is the combined cost of buying the IOC and growth modules).

The assumptions for estimating these costs are the same as those given in section 7.3.2; however, since an IOC module is not involved, no equipment transfers are made. The module is delivered to orbit fully outfitted. The laboratory equipment costs include all three centrifuges and the 20 racks of equipment listed in figure 6.3-5.

7.3.4 Annual Funding Projection

Annual funding projections were developed based on the module costs and the program schedule presented above. These projections are for the IOC module followed by a growth module; the unique growth concept was not included. Figure 7.3-4 shows a breakdown of the costs over a 9-year cycle. Figure 7.3-5 is a graphic representation of these costs.

Assuming the budget is available as shown in the cost projections, the immediate steps that should be initiated in FY 1986 are—

a. Initiate Phase B definition and development for the LSRF project. The major drivers include—
    1. Bioisolation policy.
    2. Live-specimen transport system and logistics module interface.
    3. Extent of on-orbit sample analysis.
    4. Specimen ECLS definition, with emphasis on waste management.
b. Initiate supporting research and technology on the following critical items:
    1. Specimen holding facilities for long-duration, 0-g habitation.
    2. Specimen centrifuge.
    3. Specimen cage washer, sterilizer, and water-processing unit.
    4. Sample preservation system (-70°C to -195°C).

It is of utmost importance that the LSRF project gets immediate attention and that the schedule shown in figure 7.2-1 be maintained and tracked with the space station milestones.

Items		Cost $ million
Laboratory common module*		$162.8
Life Sciences module outfitting (non-human)**		215.7
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	123.1	
Project management	12.5	
Data	3.6	
Final assembly and checkout	9.5	
Initial spares	3.9	
Peculiar support equipment	4.5	
Tooling and special test equipment	1.3	
System test	8.4	
Software	2.1	
System engineering and integration	6.1	
Liaison engineering	2.1	
Total cost		$378.5

* 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 growth option assumes there is no longer an IOC configuration.

Figure 7.3-3. Unique Growth Configuration Cost Summary

LSRF-843

Year	IOC millions $	Growth millions $	Total Program millions $
1986	7		7
1987	32		32
1988	62	4	66
1989	75	29	104
1990	67	67	134
1991	30	90	120
1992		81	81
1993		39	39
1994		1	1
Total	273	311	584

Notes:
- Includes estimated cost to build one laboratory common module including management, tooling, and support equipment costs.
- Excludes common module non-recurring design costs.
- Includes both non-recurring and recurring costs for module outfitting.
- Assumes transfer of IOC laboratory equipment to growth module.

Figure 7.3-4. Annual Funding Requirements

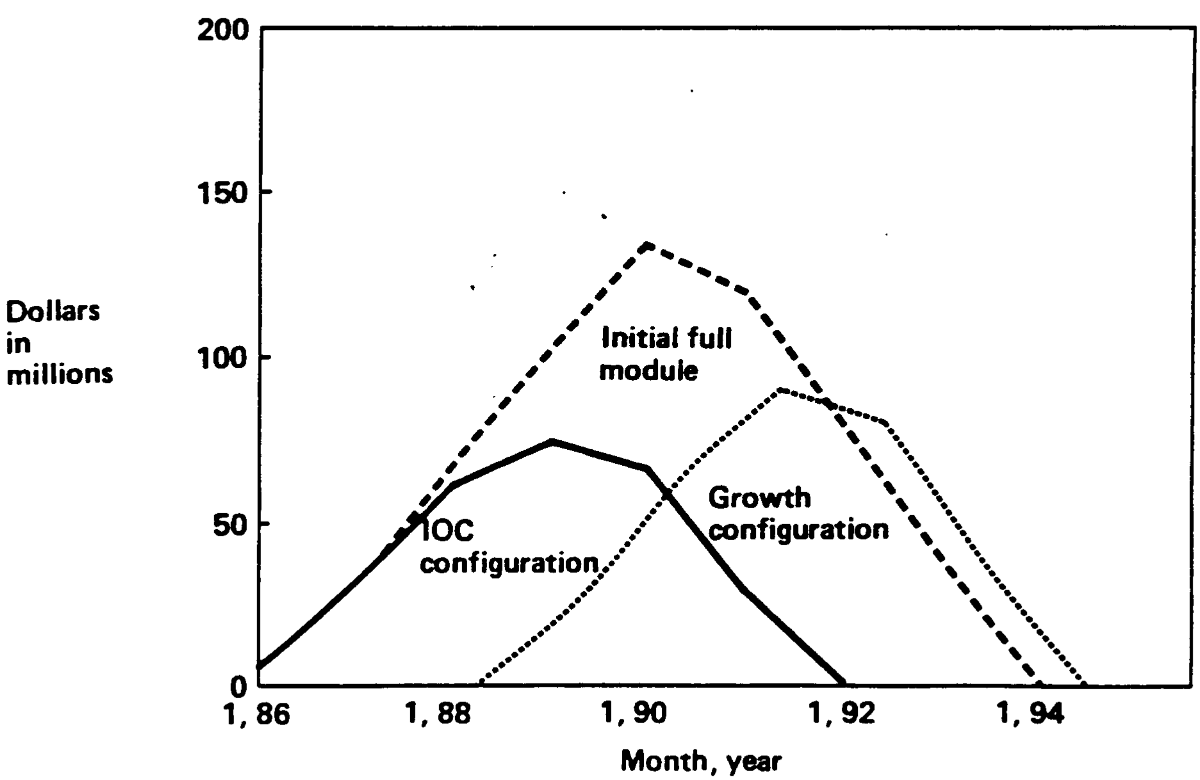

Figure 7.3-5. Annual Funding Projections

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