FINAL REPORT - VOL. II STUDY RESULTS

SPACE STATION ACCOMMODATIONS
FOR
LIFE SCIENCES RESEARCH FACILITIES

PHASE A CONCEPTUAL DESIGN & PROGRAMMATICS STUDIES
FOR MISSIONS SAAX0307, SAAX0302, AND THE TRANSITION FROM
SAAX0307 TO SAAX0302

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FOREWORD

This report has been prepared under NASA Marshall Space Flight Center contract NAS8-35472. It provides the supplemental report pages called for by Change Orders 5 and 7 for the Final Report - Volume II Study Results. This constitutes the completion of Data Requirement 5.

Prior reports in the series under contract NAS8-35472 include:

- Task 1. Parameter Analysis Data Package - LMSC/D914350 - August 1983
- Task 2. Tradeoff/Analysis Data Package - LMSC/D914366 - October 1983
- Task 3. Preliminary Conceptual Design Requirements Data Package - LMSC/D914369 - January 1984
- Final Review. July 1985
- Change Order 3 Special Report - LSRF Bioisolation Study - LMSC/D962181 - August 1985

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure		Page

LIST OF TABLES

ACRONYMS & ABBREVIATIONS

AC	Alternating Current
ADU	Advanced Development Unit
AN	Applications Notice
AO	Announcement of Opportunity
ARC	Ames Research Center
BMVP	Bone, Muscle, Vestibular, Plant
Ca	Calcium
CELSS	Controlled Ecological Life Support System
CER	Cost Estimating Relationship
CFVP	Cardiovascular, Fluids, Vestibular, Plants
CO2	Carbon Dioxide
CV	Cardiovascular
DDT&E	Design, Development, Test, & Evaluation
ECLSS	Environmental Control and Life Support System
EDO	Engineering Development Unit
EKG	Electrocardiograph
EMC	Electromagnetic Capability
EMI	Electromagnetic Interference
EUE	Experiment Unique Equipment
EVA	Extra-Vehicular Activity
FC	Factor of Complexity
FOC	Follow-on (also Final) Orbital Configuration
FY	Fiscal Year
g	Earth Gravity
GPWS	General Purpose Work Station
GSFC	Goddard Space Flight Center
HRF	Human Research Facility
IOC	Initial Orbital Configuration (also Capability)
IVA	Intra-Vehicular Activity
JSC	Johnson Space Center
kg	Kilogram
KSC	Kennedy Space Center
kw	Kilowatt
LMSC	Lockheed Missiles & Space Company, Inc.
LSLE	Life Sciences Laboratory Equipment
LSRF	Life Sciences Research Facilities
m	Meter
MF	Muscle, Fluids
MFRP	Metabolism, Fluids, Reproduction, Plants
MIL-STD	Military Standard
MMS	Metabolic Measurement System
MPC	Mission Production Center
mps	Meter Per Second
MSFC	George C. Marshall Space Flight Center
NASA	National Aeronautics & Space Administration
O_2	Oxygen
OPS	Operations
ORU	Orbital Replacement Unit
PD	Preliminary Design
PI	Principle Investigator

ACRONYMS & ABBREVIATIONS

POCC	Payload Operations Control Center
RAHF	Research Animal Holding Facility
RFI	Radio Frequency Interference
RFP	Request For Proposal
RTOP	Research/Technology Operations Plan
SAAX0302	Science Mission of a Full Laboratory Module for Nonhuman Life Sciences
SAAX0307	Science Mission of a Half Laboratory Module for Nonhuman Life Sciences and Half for Human Life Sciences
SASP	Science Applications Space Platform
SLM	Science Laboratory Module
SPF	Specific Pathogen Free
SS	Space Station
SSPE	Space Station Program Element
SSSC	Space Station Support Center
SSST	Space Station Systems Trainer
STS	Space Transportation System
UV	Ultra-Violet
VGRC	Variable Gravity Research Centrifuge
WBS	Work Breakdown Structure
Yr	Year
$K	Thousand of Dollars
$M	Millions of Dollars

SECTION 1
INTRODUCTION

This study presents Lockheed Missiles & Space Company's (LMSC's) conceptual designs and programmatics for a Space Station Nonhuman Life Sciences Research Facility (LSRF). Conceptual designs and programmatics encompass an Initial Orbital Capability (IOC) LSRF, a growth or Follow-on Orbital Capability (FOC), and the transitional process required to modify the IOC LSRF to the FOC LSRF. The IOC and FOC LSRFs correspond to missions SAAX0307 and SAAX0302 of the Space Station Mission Requirements Database, respectively. The study final report is organized with this introduction, a technical summary, and project results from subtasks 3.1 Requirements, 3.2 Concepts and 3.3 Programmatics.

1.1 BACKGROUND

1.1.1 Previous Contract Work

LMSC began studies of Life Sciences Research Facilities under contract NAS8-35472 from the George C. Marshall Space Flight Center (MSFC) in May 1983. Initial work focused on data base building plus a limited overall concept description. This work produced the following reports:

1. Orientation Briefing - June 8, 1983
2. Task 1 Parameter Analysis Data Package - LMSC/D914350 - August 3, 1983
3. Midterm Review - August 16, 1983
4. Task 2 Tradeoff Analysis Data Package - LMSC/D914366 - October 31, 1983
5. Task 3 Preliminary Conceptual Design Requirements Data Package - LMSC /D914369 - January 1984
6. Final Executive Review - May 1984

Subsequently, the contract was extended to conduct an in-depth tradeoff analysis dealing with isolation between crew and nonhuman specimens. This resulted in the report:

7. LSRF Bioisolation Study - LMSC/D962181 - August 1985

Finally the contract was amended to develop a "Preliminary Conceptual Design Requirements" data package. This report is the culmination of that work. It also included:

8. Study Midterm Review - May 3, 1985
9. Study Final Review - July 24, 1985

1.1.2 NASA Relationships

The work described in the background above was guided by MSFC under the technical direction of Dr. John D. Hilchey. Parallel studies were conducted by the Boeing Company during the same time period. Program direction was provided by the NASA Ames Research Center (ARC) on behalf of NASA headquaters Life Sciences Division. The ARC program manager is Roger Arno.

ARC also managed directly related efforts by McDonnell Douglas which focused first on a technology assessment of life sciences equipment and on describing the science protocols of NASA ARC's strawman list of 54 representative expeirments. LMSC work has been based on these experiments as a reference. More recently, McDonnell Douglas has been conducting studies of research centrifuges and automation.

In addition to the above studies related to nonhuman life sciences, NASA's Johnson Space Center (JSC) has been managing studies of a Human Research Facility (HRF). LMSC participated in this work as a subcontractor to Lockheed Engineering and Management Services Company. The HRF would share facilities with the LSRF under the initial Space Station life sciences mission, SAAX 0307. Later, these missions would separate as the nonhuman LSRF would grow into its own module under mission SAAX 0302.

1.1.3 Relationship to Space Station Program

The original work under this contract considered both a manned Space Station and an unmanned Science and Applications Space Platform (SASP) as the potential carriers for LSRF. As the project continued, NASA announced its intention to develop a permanently manned Space Station and the studies focused sharply on this carrier.

Under Phase B Definition and Preliminary Design studies, NASA Headquarters assigned the Goddard Space Flight Center (GSFC) to manage the outfitting of a Science Laboratory Module (SLM) for the station. Missions SAAX 0307 and SAAX 0302 were assigned to this module. LMSC is conducting one of the GSFC Phase B SLM studies under subcontract to RCA. Data or tradeoff results from that work have been taken into account under this LSRF study for MSFC. Likewise, LSRF results have influenced the direction of the GSFC work.

1.2 STUDY OBJECTIVES AND APPROACH

The study was conducted following the flow diagram shown in Fig. 1-1. The overall objective was to focus on conceptual design options and to recommend the best choice based on an evaluation against the science and engineering requirements. The approach to this objective included a brief review of science, an update of selected key trades from the earlier studies, and a layout of the engineering and mission design requirements structure for reference. In addition, four sample mission scenarios were established to test the concepts for their ability to be reconfigured on orbit and to transition to a complete LSRF module.

A second objective was to achieve an understanding of selected programmatics data associated with the conceptual design. The approach here was to develop a work breakdown structure for the LSRF on the basis of the entire job of converting a space station common module into a functioning lab. No effort was made to distinguish between the roles of the different NASA centers, eg, GSFC and MSFC or ARC, or the different NASA divisions, eg., Life Sciences, Code E or Space Station, Code S. This was followed by a definition of technology requirements. All of the above fed into cost estimates and schedule estimates and requirements relative to the overall space station schedule.

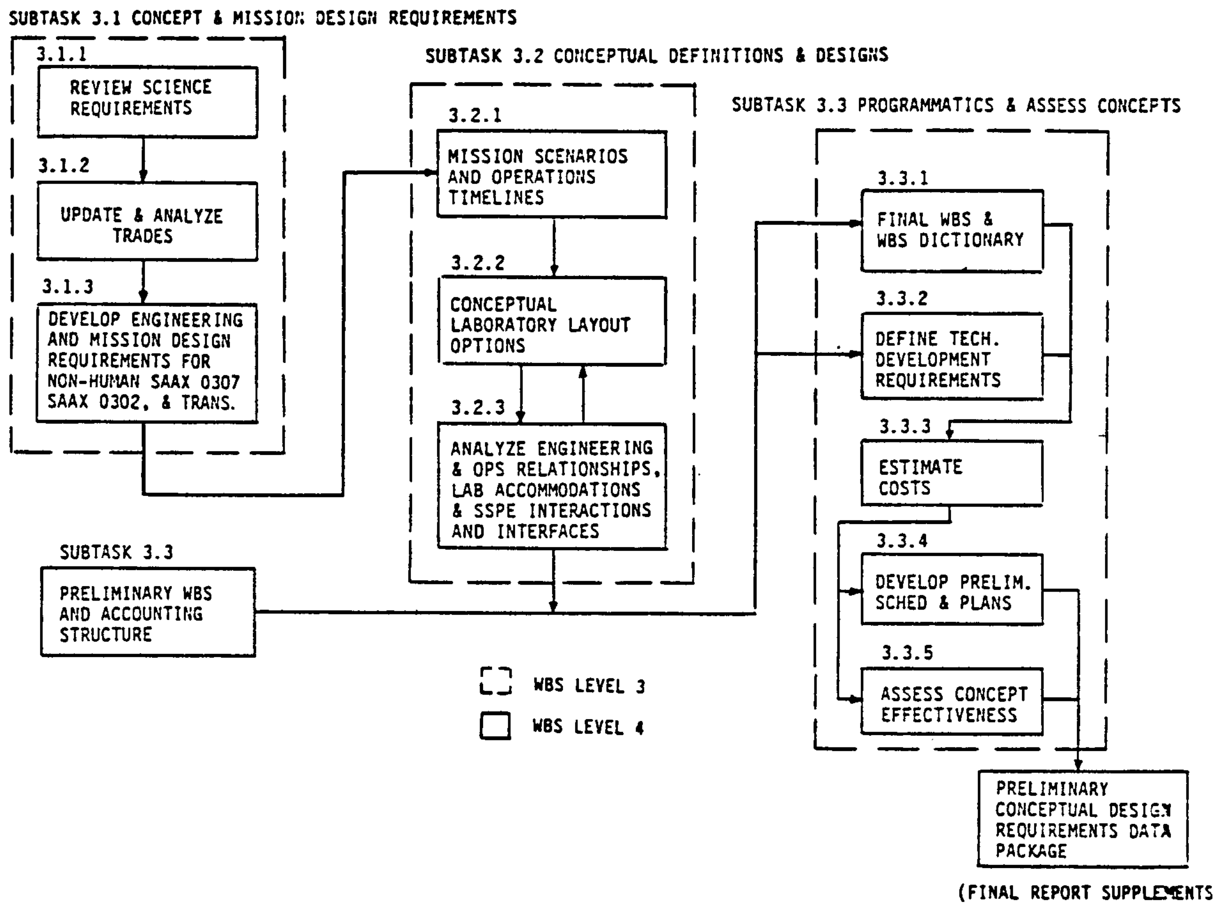

Figure 1-1 Study Flow Diagram

1.3 ASSUMPTIONS

The main assumptions of this project were:

- The LSRF would use the Space Station permanently manned concept as its carrier
- The LSRF housing would be the common module including its associated minimum subsystems such as thermal, environmental control, power, and data management
- The missions of interest are US life sciences missions SAAX 0307 and 0302 of the Space Station Mission Requirements Data Base
- Strawman science experiments are the list of 54 from NASA ARC
- Prioritized equipment list is from the proposed study plan.

SECTION 2
SUMMARY

This Summary presents the highlights of the three projects subtasks reported on in Sections 3, 4, and 5.

2.1 REQUIREMENTS

The requirements section addresses science, mission, engineering, and operations considerations.

Science. Space Station Life Sciences Research Facilities (LSRFs) are needed to meet the objectives of the NASA Headquarters Life Sciences Division program plan. The LSRF accommodates nonhuman specimens (plants and animals) to meet these objectives. The biomedical experiments typically planned would be coordinated with research on the human crew. The plant experiments will support the future development of CELSS (Controlled Ecological Life Support Systems), needed for extended lunar and orbital colonies and Mars missions, as well as gravitional biology.

The studies with highest priority are those which relate to understanding the biomedical problems of weightlessness. Those studies are also of great interest to basic biologists, because they address the questions of how gravity is sensed, how the sensor output is translated into tissue responses, and the series of physiological changes that result. Understanding the process and designing countermeasures will require two approaches: collecting data from crewmembers and studying the mechanisms of the changes in animals. The importance of animal studies is that they allow more stringent procedures, including extensive use of tissue analyses. Some of the biomedical changes in weightlessness which are thought to be most important include the decrease in bone mass and strength, decrease in muscle mass, cardiovascular changes, and altered vestibular function. Studies in those areas, therefore, will be among the earliest on the Space Station.

Most life sciences experiments will need to be repeated many times. Repetition of an experiment unchanged would be for the purpose of confirming the results. In most cases an experiment would be modified when repeated, to extend the information obtained the previous time. Some experiments may be repeated one or more times during a 90-day mission. Other studies will require holding specimens on the station for multiples of 90 days; examples are long-term radiation effects, and multi-generation studies on mammals.

A prioritized list of strawman experiments is provided in Section 3, Table 3-1. Data sheets have been developed for all of the 54 experiments in the list; these were updated from earlier work and four are shown in this report (Figures 3-1 thru 3-4). The experiment data are used in defining core equipment (basic items generic to life sciences research) to be accommodated in the LSRF.

Mission. There are no requirements for particular orbital altitude or inclination, viewing angles, attached payloads, or EVA servicing (at IOC or near-term). Life Sciences missions do have special requirements related to the use of live specimens, however. These include:

- Animal and plant holding facilities, with bioisolation to prevent transfer of microbes between these facilities and the surrounding laboratory, and temperature/humidity control which is more accurate than that of the laboratory module.
- Closed or laminar flow work bench(es) for carrying out research procedures on plants and animals without danger of contamination of the specimens or lab. Procedures include use of chemicals, mass determinations, examination, testing, transfer, dissection, analysis, and preservation of specimens.
- Refrigerators and freezers to maintain unstable chemicals, and especially for preserving biological specimens for return and ground analysis. Because many of the constituents of interest are extremely labile, cryogenic temperatures are necessary for some samples.

- Laboratory equipment for testing, injecting, handling, and dissecting specimens; for blood and urine collection and analysis; and for specialized studies in electrophysiology, cardiology, vestibular activity, radiology, and other areas.

- A large-diameter centrifuge to apply 1g to groups of animals and plants for up to 90 days. These specimens will serve as 1g ("normal") controls for similar specimens maintained at 0g. The centrifuge will also be capable of providing fractional g, and more than 1g, to study the g-thresholds at which physiologycal changes occur or can be prevented.

Because each 90-day mission will begin with the supply of new specimens and some equipment items, all missions may be considered as reconfigurations. Several reconfiguration scenarios are shown in Sec. 3.2.1 as examples of logical groupings of experiments.

Engineering. The LSRF is a multi-mission facility in an enclosure outfitted with a set of essentially independent general purpose subsystems and equipment items analogous to the Spacelab Life Sciences Laboratory Equipment (LSLE). The lab is at the disposal of various users, each with a particular mission. The LSRF also has identifiable subsystems (ECLSS, power distribution, etc.) that are in support of the primary equipment complement and the users.

Bioisolation was identified as a key driver, perhaps the dominant issue in LSRF design. Because of its importance, the bioisolation issues were the main focus of a contract extension study, change order #5. The results of this study were published in a separate report (LMSC/D962181, August 85) and are summarized briefly in Sec. 3.3.2.1.

The study concluded that using SPF animals is the prefered approach; unscreened animals (primates specifically) present too much of a health risk to the crew, while the very strict aseptic technique required of gnotobiotes reduces the productivity of the on-board life scientist. In addition, gnotobiotic primates are very expensive and virtually impossible to obtain.

As for the proper placement of isolation, the study concluded that cage level isolation is both much more effective a measure than the use of module partitions, and is much less disruptive of routine activity.

Other tradeoffs have been reported in earlier documents. Important issues which have been taken into account in the conceptual design (section 4) include the following:

- Equipment Sharing & Commonality
- Vivarium location (in lab vs. logistics module vs. special module)
- Centrifuge
  - Location
  - Architecture
- Waste storage
- Logistics (animal re-supply)

Operations. LSRF reconfiguration scenarios and internal layouts are the primary drivers influencing lab operations and support facilities. Elements in the operational sequence include pre-mission, on-orbit, post-mission support, and ground-based facility support activities. These activities must be fully integrated to handle all experiments in various phases of the operational sequence at anytime. Section 3.4 provides an overview of the operational sequence for a typical LSRF mission.

2.2 CONCEPTUAL DEFINITION AND DESIGNS

Layouts. Eight module arrangement conceptual layouts were developed (see Table 2-1) with nonhuman equipment outfitting volumes equal to either half of a module or a full module. Prioritized equipment lists were developed by NASA Ames Research Center that were used in equipping the halflab and full lab options.

The Space Station Common Module is the carrier for the LSRF layouts. It provides basic services such as environmental control, thermal control, power distribution, and a link to the communications and data systems.

Module length is constant at 13.7 meters. The options are based on the use of a 2.75m diameter centrifuge combined with a horizontal or vertical layout or a 3.75m diameter double rotor centrifuge combined with a horizontal or vertical layout.

TABLE 2-1 LAYOUT OPTIONS CONSIDERED

Half Module (SAAX0307)	Horizontal	Small Centrifuge	Figs. 4-1 and 4-2	#1
		Large Centrifuge	Figs. 4-3 and 4-4	#2
	Vertical	Small Centrifuge	Figs. 4-5 and 4-6	#3
		Large Centrifuge	Figs. 4-7 and 4-8	#4
Full Module (SAAX0302)	Horizontal	Small Centrifuge	Figs. 4-9 and 4-10	#5
		Large Centrifuge	Figs. 4-11 and 4-12	#6
	Vertical	Small Centrifuge	Figs. 4-13 and 4-14	#7
		Minilab Option	Figs. 4-15 and 4-16	#7A
		Large Centrifuge	Figs. 4-17 and 4-18	#8

Internal layout options directly influence the number and type of experiments to be done and the ability of the crew to complete the experiments that are flown. Vertical arrangements are the preferred internal layout because with similar equipment volumes vertical arrangements are simpler and more uniform with a greater degree of commonality possible. Vertical module packaging also is more simply arranged allowing more crew working space and higher packaging efficiency resulting in more desirable equipment accommodation than horizontal arrangements. Thus, for the SAAX0307 mission, option #4 is the best and for SAAX0302 option #8 is best. The latter is shown in Figs. 2-1 and 2-2.

Operationally, transitioning from the combined laboratory (SAAX 0307) to the dedicated plant-animal lab (SAAX0302) should minimize equipment changeout. It is recommended that the combined lab grow to the dedicated animal-plant lab leaving the centrifuge in place. The newly-launched module then would become a human research facility.

Subsystems. The common module contains secondary structure and network distribution system for life support, data management, electrical power

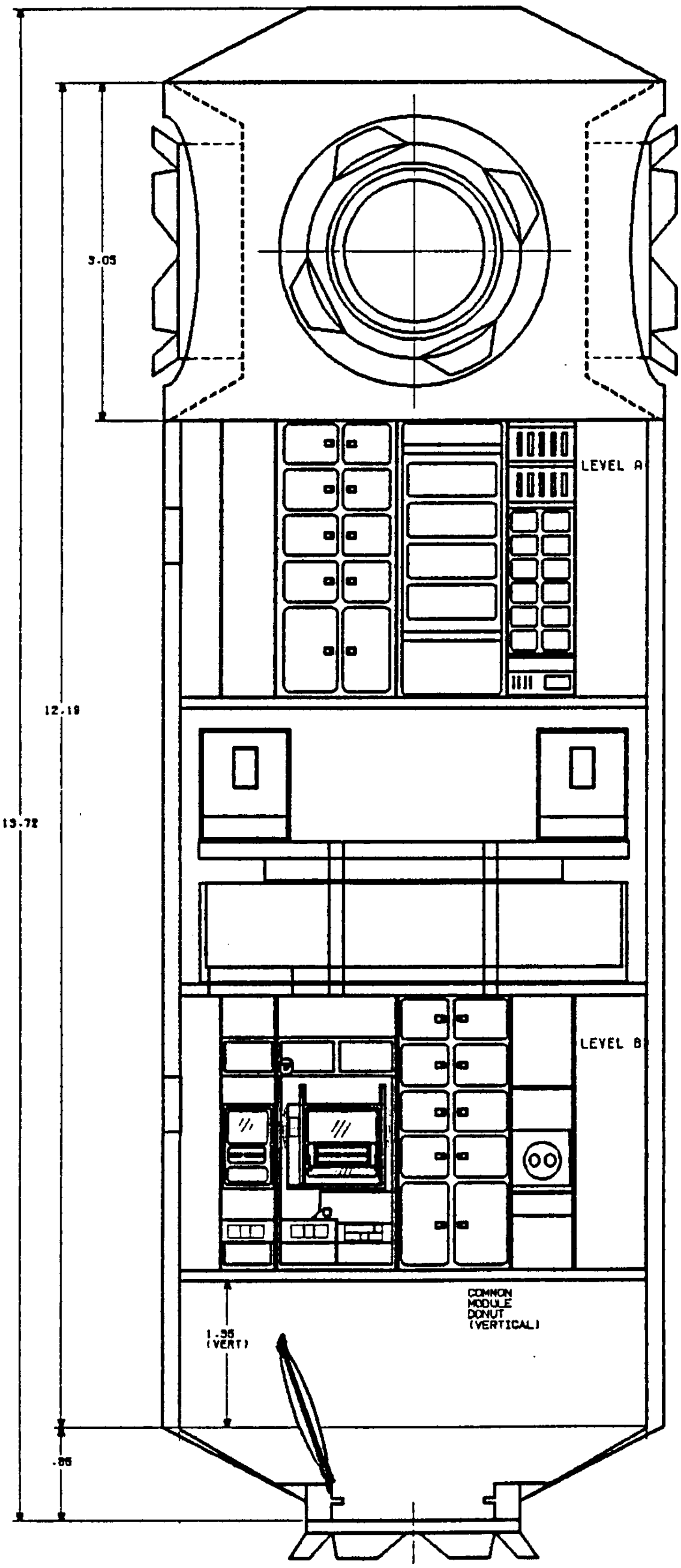

Figure 2-1 Full Lab Concept With Large Centrifuge (Option #8)

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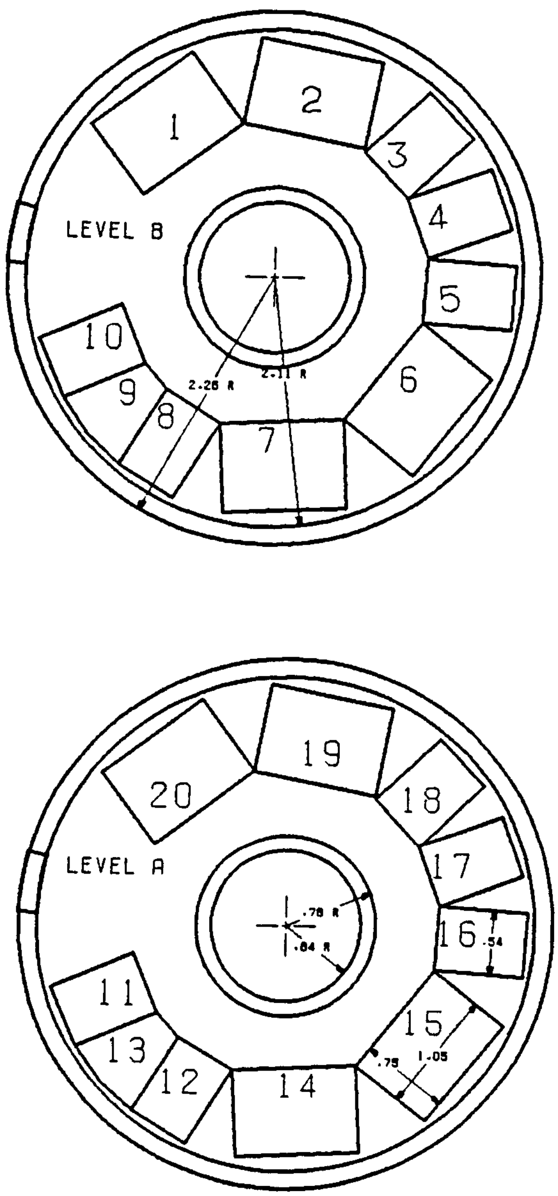

RACK NUMBER	RACK VOLUME (CUBIC M)	EQUIPMENT
1	2	GENERAL PURPOSE WORK STATION (#11). DISSECTION KIT(#124). SPECTROPHOTOMETER (#206). MASS SPEC/GAS ANALYZER (#183). ANIMAL MONITORING (#203).
2	2	STORAGE.
3	1	HAND WASHER (#100).
4	1	INCUBATOR CO2(#202). EGG INCUBATOR (#78). CELSS (#90). FREEZER(#45A).LABORATORY CENTRIFUGE (#28).
5	1	PLANT RESEARCH FACILITY (#81).
6	2	DATA SYSTEM (#33-38). COMPUTER (#51). STRIP CHART RECORDER (#182). MICROPROCESSOR (#209). VIDEO CAMERA AND RECORDER (#141).
7	2	CAGE WASHER (#88). SPECIMEN FOOD AND WATER (#96.97). STORAGE.
8	1	RODENT STANDARD HOLDING FACILITY (#52A).
9	1	STORAGE. PH/ION ANALYZER (#208). OSCILLOSCOPE (#207). MICROSCOPES (#). PRIMATE KIT (#205).
10	1	RODENT STANDARD HOLDING FACILITY (#52B).
XX	14	3.75 METER DIAMETER SPECIMEN RESEARCH CENTRIFUGE.
11	1	CENTRIFUGE CONTROLS (#65). STORAGE.
12	1	PLANT RESEARCH FACILITY (#81A).
13	1	REFRIGERATOR/FREEZER (#44A). ENVIRONMENTAL MONITOR (#142). PHYSIOLOGICAL AMPLIFIER (#134). DOSIMETER (#125). SMALL MASS MEASUREMENT (#112).
14	2	STORAGE.
15	2	RODENT BREEDING HOLDING FACILITY (#153).
16	1	REFRIGERATOR/FREEZERS(#44B.45B). SPECIMEN FOOD AND WATER(#96A.97A).
17	1	METABOLIC HOLDING FACILITY.
18	1	RODENT STANDARD HOLDING FACILITY (#52C).
19	2	LARGE PRIMATE HOLDING FACILITY (#58). STORAGE.
20	2	STORAGE.
	42	TOTAL VOLUME

Figure 2-2 Equipment Identificatin by Rack Location for Option #8

distribution and final conditioning, thermal management and communications. Internal LSRF outfitting must be compatible with external structural features to facilitate: equipment/specimens/supplies transfer from Space Transportation System (STS) (Shuttle) orbiter into the lab, earth viewing, power, ECLSS, thermal and data management interfaces with the logistics module, and safety egress requirements for crew in emergency situations.

LSRF internal arrangements also must be compatible with common module interior characteristics to ensure proper interface during ground and on-orbit assembly activities.

The equipment mounting system is the means for integrating the laboratory elements into laboratory arrangements. To complete this integration, the mounting system concepts investigated by LMSC were designed to provide the following:

- o Interfaces for laboratory equipment: common elements which support operation of laboratory equipment and user equipment.
- o Structural integrity for applicable loads and environments.
- o Easy reconfiguration and change-out of Orbital Replacement Units (ORUs).
- o Accessibility for maintenance, service, and repair of laboratory equipment and of module elements.
- o Commonality with other Space Station elements.

2.3 PROGRAMMATICS

Work Breakdown Structure. The WBS was updated version from the December 1984 report to correspond to the Space Station RFP. WBS elements 1.0 through 7.0 address common module end items from Work Package 01 that must be enhanced to achieve an operational LSRF by IOC. Items 8.0 through 21.0 address LSRF operational activities and associated hardware required for IOC. The WBS was developed to level 5 and a definition for each WBS level 4 and 5 element is provided in Sec. 5.1.1.

Technology Development. Technology development activities play an integral part in the development of a fully operational LSRF that is compatible with other Space Station elements. Section 5.2 provides detailed discussions of a Variable Gravity Research Centrifuge (VGRC), Metabolic Measurement System (MMS), and a Cage Washer including:

- o specific areas within each technology requiring additional study
- o advances required to fully develop the technology

These technology development areas were selected for study after an evaluation of experimental protocols and equipment lists expected to be representative of LSRF work.

Cost Estimates. The cost estimates presented in Sec. 5.3 address design, development, test and evaluation (DDT&E) and operations costs for IOC (SAAX0307) and FOC (SAAX0302) LSRF. The SAAX0307 represents the LSRF portion or one-half of a Science Laboratory Module (SLM) at IOC. The SAAX0302 estimate is for a dedicated animal-plant vivarium lab which becomes operational two years after IOC. Assumptions and groundrules used to generate cost estimates include the following:

- o Costs are in constant year FY 1987 million dollars
- o Estimates are for a 45 foot module in a racetrack configuration
- o Development approach is protoflight program
- o Costs for WBS functional elements and non-flight hardware are generated by applying factors arrived at by engineering judgement
- o Weights for life science flight hardware are based on earlier LSRF work, adjusted in some cases to reflect current to reflect current thinking

Cost Estimating Relationships (CERs) for equipment items are computed on the basis of weight, a complexity factor, and state of development. Cost adjustments within each CER can be made by assigning a complexity factor (FC) for each equipment item. The normal factor is unity. An equipment item deemed to be lower or higher in complexity should be assigned a complexity factor lower or higher than unity.

Equipment costs also can be adjusted relative to development status of the item. For example, an item that has already been developed or exists as flight qualified hardware should not be charged for full development costs. Each equipment item, therefore, was assigned a number that reflected its development status as it will exist at the start of Phase C/D.

Funding profiles for LSRF Missions SAAX0307 and SAAX0302 were constructed to evaluate funding requirements from program initiation through first launch. The profiles (Fig. 2.3) are generated based upon a 7.5 year program. It was assumed that program start commenced in FY 1986 and that the program ends with a launch in mid FY 1993 (March 1993). The profiles are based upon the DDT&E costs detailed in Sec. 5.2.1.

Annual operations costs for pre-launch, on-orbit, and post-return operational activities involving the LSRF portion of the combined lab (SAAX0307) and the dedicated animal-plant vivarium lab (SAAX0302) are presented in Sec. 5.3.2.

Program Plan. The LSRF program plan encompasses a phased approach, consistent with the Space Station phasing, to accomplish the requirements definition, design, development, assembly, verification, integration and all aspects of mission support.

The plan appears in Sec. 5.4 and addresses: science management, development and implementation engineering LSRF operation and mission planning, equipment changeout and resupply and training; a project summary of activities associated with LSRF developmental phases; and LSRF project project schedules that are phased with the overall SS schedule. These sections, taken together, provide a generalized overview of an end-to-end LSRF system.

SECTION 3
Subtask 3.1 REQUIREMENTS

This section develops the requirements for Space Station Life Sciences Research Facilities. First, the stage is set with an overview of the scientific needs and a discussion of the characteristics of life science experiments. Then the mission requirements are developed, including four hypothesized mission-reconfiguration scenarios which would correspond to the 90-day-interval logistics flights to the station.

Engineering requirements follow. These include functional needs and an update of key life sciences compatibility analyses in the areas of bioisolation and the environmental control system. Engineering requirements documentation is described. The section concludes with discussion of LSRF operations requirements including premission, on-orbit, post-mission, and ground-based facility support

3.1 SCIENCE REQUIREMENTS

The official list of Life Sciences experiments in both the animal and plant areas is provided from the LMSC study plan and reproduced here as Table 3-1. This list was confirmed later in the "SLM Quick Look Data Base", ORI report of April 10, 1985. In the Lockheed Midterm Report of April 1985, the experiment priorities were reassessed according to a perception of the most important scientific questions, and the practicality of the experiments on Space Station.

The priorities suggested in Table 3-1 remained the same, although it is realized that those priorities are highly subjective, and that another group or individual would produce a different list.

NASA Headquarters (Life Sciences Division) organized a scientific workshop in June 1985 to discuss Space Station experiments in several life sciences disciplines. The scientists outlined objectives for each area and prioritized experiments directed toward those objectives. The results have been issued as the "Red Book" of 8/29/85, containing human, plant, and animal

TABLE 3-1 LIST OF STRAWMAN EXPERIMENTS

PROPOSED PRIORITY[1]	REFERENCE PRIORITY[2]	MDAC NO.[3]	LMSC NO.[4]	TITLE
1	B1	(A) BL 1a	1	Calcium/Bone Mineral balance on rats
2	B2	(A) ML 1a	6	Nitrogen balance and change in rat muscle structure
3	B3	(A) MB 1a	15	Metabolic balance changes in rats
4	B4	(W) MB 4	19	Respiratory quotient (O_2/CO_2) changes in rats
5	B5	(W) BL 4	5	Calcium/Mineral balance in rats using nonradioactive tracers
6	B7	(A) FE 1a	12	Fluid/electrolyte changes in rats
7	L1	(A) BL 1b	2	Calcium/Mineral balance on squirrel monkeys
8	L2	(A) ML 1b	7	Nitrogen balance and change in squirrel monkey muscle structure
9	B16	(A) VP 1	23	Vestibular organ structural change in rats
10	B17	(A) VP 2a	24	Vestibular system operation changes in rats
11	L5	(A) VP 2b	25	Vestibular system function changes in squirrel monkeys
12	B8(L7)	(A) PC 1	44	Plant development following sprouting
13	B9(L8)	(A) PC 3	46	Plant growth in 0g
14	B10(L9)	(W) PC 8	51	Multiple generation plant growth
15	B11(L10)	(W) PC 9	52	Gas balance on plants
16	B12(L11)	(A) PC 2	45	Gravitational strength and orientation effects on plant development
17	B13(L12)	(W) PC 6	49	Weightlessness effects on microscopic plants
18	B14(L13)	(W) PC 7	50	Geotropism threshold experiments
19	B15(L14)	(A) PC 4	47	Prototype CELSS plant unit
20	L15	(A) FE 1b	13	Fluid/electrolyte changes in squirrel monkeys
21	L3	(A) CV 1	9	Cardiovascular function changes in restrained Rhesus monkeys
22	L4	(W) CV 2	10	Cardiovascular system changes in restrained Rhesus monkeys
23	L6	(A) VP 2c	26	Vestibular system function changes in Rhesus monkeys
24	L16	(W) FE 2	14	Fluid shifts in restrained Rhesus monkeys
25	L17	(A) MB 1b	16	Metabolic balance in squirrel monkeys
26	L18	(W) MB 5	20	Respiratory quotient (O_2/CO_2) in squirrel monkeys
27	L19	(W) MB 6	21	Energy expenditure/CO_2 production in squirrel monkeys
28	L20	(W) MB 7	22	Time-dependent glucose metabolism changes in squirrel monkeys
29	L21	(A) VP 2d	27	Vestibular system operation changes in cats
30	L22	(A) VP 2e	28	Vestibular system function changes in pigeons
31	L23	(A) VP 2f	29	Vestibular system function changes in frogs
32	L24	(A) VP 2g	30	Vestibular system function changes in goldfish
33	L25	(W) VP 3	31	Vestibular system function changes in squirrel monkeys
34	B18	(W) BL 2	3	Bone development in early stages of rat fetuses
35	B19	(W) BL 3	4	Bone development in early pregnancy over multiple rat generations
36	B20	(W) CV 3	11	Development of rat CV reflexes, sensors
37	B21	(A) RD 3	36	Multigeneration changes in rat reprod. behavior and develop.
38	B22	(W) RD 5	38	Rat development
39	B23	(W) RD 6	39	Rat post natal development at 19 days
40	B24	(A) RD 1	32	Multiple generation mouse development
41	B25	(A) RD 2c	35	Mouse development
42	B26	(W) RD 7	40	Rat development cycle following birth in 0g
43	B27	(W) RD 8	41	Determine gravity threshold for development changes in rats
44	B28	(A) RD 2b	34	Early development in chickens
45	B29	(A) RD 4	37	Chicken development and hatching
46	B30	(A) RD 2a	33	Early development in frogs
47	B31	(W) MB 2	17	Changes in mouse metabolism
48	B32	(W) MB 3	18	Recovery in mouse metabolism to 1g
49	B33(L26)	(A) PC 5	48	Prototype algae CELSS unit
50	B34(L27)	(W) PC 10	53	Plant lignification
51	B35(L28)	(W) PC 11	54	Plant growth rate changes due to light/dark cycle
53	B36	(A) RB 1	42	Passive radiation dosage in mice
53	B37	(A) RB 2	43	Passive radiation dosage in mice
54	B6	(W) ML 2	8	Nitrogen balance and rat muscle structure changes with tracers

[1] Proposed priority: LMSC recommended starting point for use of experiments in trade studies based on a blending of reference priorities

[2] Reference priority: Prioritized list of experiments specified in Hilchey memorandum dated October 12, 1983
B=Boeing; L=Lockheed

[3] MDAC No: (A) Ames Research Center report "Life Sciences Research and the Science and Applications Space Platform"
(W) "Experiments Derived from the 1982 Life Science Workshops" by Heinrich (ARC)

PC= plant growth	RB= radiation
BL= bone loss	RD= animal development
CV= cardiovascular	VP= vestibular system
FE= fluid/electrolyte	MB= metabolic balance
ML= muscle loss	

[4] LMSC No.: Lockheed experiment numerical listing specified in Appendix 1 - Parameter Analysis Data Package - Life Sciences Research Facility System analysis Study

studies. The selection of experiments to be done on Space Station will be the responsibility of NASA and its advisory committees and is still pending.

3.1.1 Life Science Experiment Characteristics

In terms of science requirement definition life sciences studies have several characteristics which distinguish them from studies in other areas. The physiological changes found in microgravity exhibit different rates and durations. Cardiovascular and vestibular changes occur rapidly relative to bone and muscle changes. Studies of these systems, therefore, require sampling of specimens at intervals during the time-course of the changes. If the specimens are large animals, they would be examined and tested at intervals. If the subjects are rodents, small groups of specimens (to provide statistically significant results) would be sacrificed at intervals, dissected, and tissues preserved. In most cases it will be desirable to return some specimens to ground the requirements for food, water, and storage space in freezers or refrigerators.

Each experiment does not require a separate group of specimens. Many observations can be made on one animal and many analyses on a blood sample, e.g. in the case of sacrificed specimens, all tissues should be available, and should be used in a variety of studies. The tissues will require different procedures for freezing, fixation, analysis, etc., depending on the experiment.

The NASA list of experiments calls for many species. Obviously not all species can be provided in sufficient number on one mission. Selection of species for a mission will depend on the numbers required, types and size of holding facilities available, utility of specimens for several experiments, equipment required, and crew time and skills required, and crew time and skills available among other factors.

The Science Requirements discussed above are used to define the Life Sciences Research Facility. It is important to emphasize that this is a permanent space laboraroty which will operate much like life sciences laboratories on the ground. There will be continuing research programs in many different disciplines over periods of years. Facilities are required to accommodate standard laboratory procedures (modified for 0g operation), and to provide maintenance of live animals and plants for at least 90 days. Selection of the laboratory equipment is driven by the experiments to be done. Because specific experiments have not yet been selected for IOC or later commencement by NASA, it is necessary to design the facilities based on requirements for "typical" or "generic" experiments. Representative experiments have been provided by studies at Ames Research Center, Johnson Space Center, and a number of workshops of life scientists (see 3.1).

The studies with highest priority are those which relate to understanding the biomedical problems of weightlessness. Those studies are also of great interest to basic biologists, because they address the questions of how gravity is sensed, how the sensor output is translated into tissue responses, and the series of physiological changes that result. Understanding the process and designing countermeasures will require two approaches: collecting data from crewmembers and studying the mechanisms of the changes in animals. The importance of animal studies is that they allow more stringent procedures, including extensive use of tissue analyses. Some of the biomedical changes in weightlessness which are thought to be most important include the decrease in bone mass and strength, decrease in muscle mass, cardiovascular changes, and altered vestibular function. Studies in those areas, therefore, will be among the earliest on the Space Station.

Plant studies are included in the planning because of fundamental interest in the mechanisms of their gravity sensors and responses, and because it is appreciated that plants will be an essential renewable food source for extended missions (e.g., lunar base or interplanetary mission). The latter experiments are directed toward eventually achieving a Controlled Ecological Life Support System (CELSS) in which food plants can be grwon efficiently by recycling.

Operation of the LSRF at IOC and beyond can be described in a series of steps:

1. Selection of experiments for a series of 90-day missions. NASA, with assistance of peer groups of scientists, will select experiments by a procedure not yet detailed.

2. Transport of equipment, specimens, and consumables require for a 90-day mission to Space Station in Logistics Module A.

3. Change-out of equipment and specimens. Return of replaced equipment (max. 10%), remaining live specimens, and tissue samples to ground in Logistics module B.

4. In the LSRF, conduct the planned experiments, collect data and samples. Life scientist astronauts will be in active communication with scientists in ground POCC, to describe and consult, and to modify procedures if required. Data and video will be down-linked.

Steps 2, 3, and 4 will be repeated every 90 days, with the opportunity to carry out new experiments and replace specimens and some equipment with each cycle. For more details on Ground and Resupply Operations see sec. 5.4

Most life sciences experiments will be repeated many times. Repetition of an experiment unchanged would be for the purpose of confirming the results. In most cases an experiment would be modified when repeated, to extend the information obtained the previous time. Some experiments may be repeated one or more times during a 90-day mission. Other studies will require holding specimens on the station for multiples of 90 days; examples are long-term radiation effects, and multi-generation studies on mammals.

3.1.2 Updated Experiment Data Sheets

Many of the current experiments have been updated to conform to present Space Station planning. Updated information on four candidate IOC LSRF experiments is presented in Figs. 3-1 through 3-4. The experiments are prioritized based upon NASA "Red Book" results and recent design decisions for the SLM originating from GSFC. The information contained in these figures constitutes the science requirements for a minimal LSRF facility under current NASA guidelines. The complete catalogue of data sheets is found in the task 1 Data package, LMSC/D913250, August 1983.

Reference is made in some of the data sheets to a "core list" of equipment. These are the basic items of generic laboratory equipment identified by LMSC as follows:

Research Animal Holding Facility	Surgical Tools
Centrifuge	Cage Washer
Transfer Cage	Metabolic Measurement System
General Purpose Work Station	Spectro Photometer
Specimen Mass Measuring Device	Plant Growth Chamber
Specimen restraint	Mass Spectrometer
Surgical Workbench	Data Station
Lab Centrifuge	Hand Washer
Cryogenic Freezer	Physiological Monitoring System
Freezer (-70°C)	Guillotine
Refrigerator-Cooler	Oven
Blood Kit	Mill
Dissecting Kit	HPLC
Food Storage	Nutrient Storage
Water Storage	Gas Storage (O_2, CO_2)
Containers	pH meter
Voice Recorder	Log Books

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Experiment No. BL1A

EXPERIMENT TITLE: BONE LOSS IN RATS
OBJECTIVE: Determine Effects of Microgravity on Calcium/Mineral Balance in Rats; Radiology, Histology, Biomechanics, Osteoblast Differentiation, Tooth Eruption Rate, Joints, Calcium Metabolism.

SPECIES: Rat, Mature Males	SIZE: 400-600 g	DURATION: 90 Days
SUGGESTED NUMBER: 90	STATION G LEVEL FRACT G (Centrifuge) 1 G (Centrifuge)	45 (50%) 45 (50%)

TASK	FREQUENCY	POTENTIAL FOR AUTOMATION
Vivarium: Urine/Feces Sample	2 days/week	X
RAHF/VGRF Maintenance	Every 7 days	X
Support Lab:		
Weigh Specimens	Every 7 days	
Blood Samples/Preserve	Every 7 days	
Sacrifice/Dissect/Preserve	6 each at 2, 10, 20, 30, 50, 85 days	
X-Ray	Every 14 days	
Bone thin sections & U-V Microscopy	At sacrifice	

EQUIPMENT - VIVARIUM	DATA
RAHF/Rodent Environment, Food & Water Consumption, Activity	DL
VGRF/Rodent Environment, Food & Water Consumption, Activity	DL
Solid & Liquid Waste Storage	-
Hand Wash Facility Cage Cleaning Facility	-

EQUIPMENT - SUPPORT LAB		DATA
Surgical Workbench	Chemical Storage (opt)	-
Mass Measurement Device (Small)	Dry Storage (opt)	-
Sacrifice Kit	Freeze Dryer (opt)	-
Blood Collection Kit	Thin Section Saw	-
Laboratory Centrifuge		-
Wet Trash Storage	X-Ray & Developer	
	X-Ray Digitizer	-
Freezer		-
Quick Freeze Unit		-
Hand Wash Facility	Binoc. Microscope	-

SAMPLE STORAGE & RETURN NO./TYPE SAMPLES	FREEZE DRY	REFRIG.	FREEZE	FIX
Bone			X	X (opt)
Feces			X	
Urine			X	
Blood			X	
Carcasses	X (opt)		X	X (opt)

SPECIMEN RETURN/SACRIFICE
20% (18) returned live
80% (72) returned sacrificed

SPECIAL ENVIRONMENTAL REQUIREMENTS (IF ANY)

None

Figure 3-1 Bone Loss Experiment Data Sheet

EXPERIMENT TITLE: CARDIOPULMONARY FUNCTION IN 0 G IN RESTRAINED SMALL PRIMATES
OBJECTIVE: Study the cardiopulmonary changes that result from exposure to zero G and to study the return to normal following return to one G

SPECIES: Mature Squirrel Monkeys | SIZE: 1 kg | DURATION: 90 days

SUGGESTED NUMBER: 16 | STATION G LEVEL 8 (50%)
FRACT G
1 G 8 (50%)

TASK	FREQUENCY	POTENTIAL FOR AUTOMATION
Vivarium: Urine/Feces Samples	Every 5 days	X
RAHF/VGRF Maintenance	Every 7 days	X
Support Lab:		
Blood Samples/Preserve	Every 7 days	
Weigh Specimens	Every 7 days	
Surgical Procedures	1 at beginning	
Echo & EKG	Every 7 days (w/blood samples) for first 6 weeks; every 2 weeks thereafter	
Expiratory gas analysis & air flow	Same as above	
Arterial blood gas	Same as above	

EQUIPMENT

Core List

Experiment Specifics:
- Sensors (implanted)
- SPSMF (Microprocess)
- CRT
- Digital Display
- Strip Chart Recorder
- Echo, Imaging, Display & Recording System
- Pulmonary Function Analyser
- Blood Gas Analyser
- Anesthesia Unit
- Surgical Prep. Kit

SAMPLE STORAGE & RETURN	FREEZE DRY	REFRIG.	FREEZE	FIX
Urine			X	
Feces			X	
Blood		X	X	
Carcasses (if die)	X (opt)		X	

SPECIMEN RETURN

100% returned alive

SPECIAL ENVIRONMENTAL REQUIREMENTS (IF ANY)

None

Figure 3-2 Cardiopulmonary Function Data Sheet

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EXPERIMENT TITLE: FLUID BALANCE IN RATS IN 0 G
OBJECTIVE: Study changes in fluid balance and shifts in rats exposed to 0 G

SPECIES: Mature male rats	SIZE: 400-600 g	DURATION: 90 days
SUGGESTED NUMBER: 72	STATION G LEVEL	36 (50%)
	FRACT G	
(1 G recommended to be on the ground)	1 G	36 (50%)

TASK	FREQUENCY	POTENTIAL FOR AUTOMATION
Vivarium: Urine/Feces Measurements (Volume)	1 day prior to fluid measurement	X
RAHF/VGRF Maintenance	Every 7 days	X
Support Lab:		
Fluid measurements	6 each at 2,7,14,30,60,85 days	
Weigh	Every 7 days	

EQUIPMENT

Core List

Experiment Specifics:
- Infusion pump
- Surgical tools
- Injection kit
- Inulin, D_2O, Evans Blue Dye
- Protein precipitation chemicals

SAMPLE STORAGE & RETURN	FREEZE DRY	REFRIG.	FREEZE	FIX
Urine (Na^+)			X	
Feces			X	
Blood		X	X	X (opt)

SPECIMEN RETURN

100% alive or sent to other experiment (e.g., bone loss in rats)

SPECIAL ENVIRONMENTAL REQUIREMENTS (IF ANY)

1 G at ground rather than on station centrifuge due to rapidity of fluid shifts and therefore inability to remove subject from centrifuge and take measurements

Figure 3-3 Fluid Balance Data Sheet

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EXPERIMENT TITLE: PLANT GROWTH IN 0 G
OBJECTIVE: Study the effects of 0 G on plant structure, growth, and function

SPECIES: Plant seeds of various types — DURATION: 90 days

TASK		FREQUENCY	POTENTIAL FOR AUTOMATION
Vivarium:	Vivarium calibration	Every 6 days	
	Replenish Vivarium	Every 6 days	
	Prepare cuvette	1	
	Sow seeds	1	X
	Germinate seeds (plants)	1	X
Support Lab:			
Dry specimens		Bunch each at	
Analyze specimens		5, 10, 20, 30, 45, 60, 90 days	
Store specimens			

EQUIPMENT

Core List

- Experiment Specifics:

pH Meter	Tissue-Mill	Gas Storage
Ion Chromatograph	HPLC	
Oven	Nutrient Storage	

SAMPLE STORAGE & RETURN	OVEN DRY	FREEZE DRY	REFRIG.	FREEZE	FIX
Plant material	X	X			X

SPECIMEN RETURN

100% sacrificed

SPECIAL ENVIRONMENTAL REQUIREMENTS (IF ANY)

Monitored and controlled in humidity, T°, light, airflow

Figure 3-4 Plant Growth Data Sheet

3.2 MISSION REQUIREMENTS

The basic requirements of Life Sciences missions include:

- Pressurized volume
- Normal earth atmosphere
- Standard utilities
- A gravity level of 10^{-5}g
- A data management system

There are no requirements for particular orbital altitude or inclination, viewing angles, attached payloads, or EVA servicing (at IOC or near-term).

Life Sciences missions do have special requirements related to the use of live specimens, however. These include:

- Animal and plant holding facilities, with bioisolation to prevent transfer of microbes between these facilities and the surrounding SLM in either direction, and temperature/humidity control which is more accurate than that of the SLM.

- Closed or laminar flow work bench(es) for carrying out research procedures on plants and animals without danger of contamination of the specimens or SLM. Procedures include use of chemicals; mass determinations, examination, testing, transfer, dissection, analysis, and preservation of specimens.

- Refrigerators and freezers to maintain unstable chemicals, and especially for preserving biological specimens for return and ground analysis. Because many of the constituents of interest are extremely labile, cryogenic temperatures are necessary for some samples.

- Laboratory equipment for testing, injecting, handling, and dissecting specimens; for blood and urine collection and analysis; and for specialized studies in electrophysiology, cardiology, vestibular activity, radiology, and other areas. Commonality will be stressed, to allow sharing of equipment for both human and animal research.

- o A large-diameter centrifuge to apply 1g to groups of animals and plants for up to 90 days. These specimens will serve as 1g ("normal") controls for similar specimens maintained at 0g. The centrifuge will also be capable of providing fractional g, and more than 1g, to study the g-thresholds at which physiologycal changes occur or can be prevented.

Total IOC Space Station resources which will be available for life sciences studies (SAAX 0307), divided approximately equally between human and non-human areas:

Power	: 20 - 25 kW for the SLM
Volume	: 20 - 30 m^3 for life sciences
Crew time	: 800 hours/year. One life scientist working half-time per day. Remaining 5 crewmembers available 1/2 day/week.

Space Station growth is scheduled to add a second laboratory module two years after IOC. At that time the first SLM will be converted to a Human Research Facility (SAAX 0303), and the new SLM is to be an animal/plant vivarium/laboratory (SAAX 0302). The latter module (SAAX 0302) will include a more extensive CELSS experimental system (SAAX 0304), which will then evolve to a pallet system (SAAX 0306) in 1995.

3.2.1 Reconfiguration Scenarios

Because each 90-day mission will begin with the supply of new specimens and some equipment items, all missions may be considered as reconfigurations. Several reconfiguration scenarios have been prepared, as examples of logical groupings of expeirments.

The guidelines used for reconfiguration mission scenarios are as follows:

- o Limit the number of species
- o Maximize the use of each specimen in terms of data collected
- o Group experiments with similar for specialized equipment or procedures
- o Include plant experiments in each mission

The rationale for these guidelines is addressed in Sec. 3-1 Science Requirements. Examples of four mission scenarios are given in the following subsections. A detailed breakdown of procedures and equipment is provided for the first scenario and is representative of the level of detail under development for the remaining three scenarios.

3.2.2 Rodent Emphasis Mission with BMVP (Bone, Muscle, Vestibular, Plant)

This scenario was designed to study three of the most important physiological changes in weightlessness: bone loss, muscle loss, and vestibular problems. These three studies can be carried out on one group of rats, half of which are maintained at 0g, and half on the centrifuge at 1g. Small numbers of animals are sacrificed at intervals and tissues removed to follow the time-course of the changes. Treatment of the tissues is described in the procedures below. The remaining tissues of the animals are not discarded, but are preserved in an appropriate way for many other experiments, most of which will be done after return to ground. An example is Spacelab 3, where one group of flown rats was used in approximately 30 experiments.

Plants studies are included to gain information on growth habit and yield, important to both basic studies and CELSS.

Experiments:		
	BL1A	Bone loss in rats
	BL4	Bone loss in rats using ^{40}Ca
	ML1A	Muscle Loss in rats
	VP1	Structural changes in labyrinth of rats
	PC 1	Plant growth
	PC 3	Plant growth/CELSS application

Specimen Requirements:

Animal specimens: 90 mature male white rats, 400-600 grams each (45 at station gravity) (45 at 1-g on centrifuge). Maintained in standard rodent holding facility. Sacrifice schedule: 6 from each group (0-g and 1-g), at 2, 10, 20, 30, 50, and 85 days. Remaining 9 animals from each group returned to ground at 90 days to follow readaptation to 1-g.

Plant Specimens:

Approximately 25 seeds each of Arabidopsis, carrot, pine, and bean in a plant growth unit. Approximately 20 seeds each of radish and lettuce in a second plant growth unit.

Procedures:

Animals. All live animals weighed every seven days. All live animals x-rayed approximately every 14 days; x-rays developed, digitized, and data downlinked. Incisor teeth measured approximately every seven days to determine eruption rate. Total urine and feces collected for each rat in seven day portion, for stable calcium isotope analysis after return. At sacrifice, bones dissected out, weighed, and preserved for histology and mechanical strength test; jaw for osteoblast differentiation; joints and kidneys for calcium deposits. Muscles dissected, weighed, and preserved for strength test, chemical and enzymatic analysis, and histology. Vestibular organs of the head removed and preserved. All the other tissues will be available for many additional studies.

Plants. Wet an aliquot of each type of seed with nutrient solution at five day intervals. Maintain growth conditions. Photograph at intervals. Return all plants live to ground for study.

Equipment Requirements:

- Rodent Holding Facility
- Rodent Holding Facility on 1-g Centrifuge
- Cage Washer
- Surgical Workbench
- Mass Measurement Device
- Sacrifice Kit
- Blood Collection Kit
- Small Animal X-Ray
- Dissecting Microscope
- Muscle Tensiometer
- Plant growth units
- Nutrient solutions
- Video camera, downlinked
- Photo camera
- Lab Centrifuge
- Freezer
- Chemicals
- Vials
- X-Ray Developer
- X-Ray Digitizer
- Waste Storage

3.2.3 Small Primate Mission MF (Metabolism, Fluids)

It would be assumed that the metabolic rate of an animal at 0g would be lower than at 1g, because no work is required to overcome gravity. There have been only limited measurements during spaceflight, but the data suggest that the metabolic rate is higher rather than lower. It is necessary to determine the true value in order to interpret other changes, such as muscle deterioration and loss of bone protein matrix. The metabolic rate will also influence the caloric intake required for the crew. These experiments, using squirrel monkeys, will measure the balance (intake vs. output) for nitrogen, fluids, elecrtrolytes, and respiratory gases. They will also study the metabolism of a key metabolite, glucose.

The experimental animals will be housed in closed metabolic cages, with complete collection of wastes. One half of the animals will be maintained at 0g, and the other half at 1g on the centrifuge.

Accurate measurements of food intake, water intake, animal mass, oxygen consumption, carbon dioxide production, and temperature are required. Animals may be returned to ground alive, or they may be retained on the

Station to be used in a different set of experiments on the following 90-day mission.

Experiments:	ML1B	Nitrogen balance and muscle loss in small primates
	FE1B	Fluid and electrolyte balance in small primates
	MB1B	Metabolic balance in the small primate
	MB5	Respiratory gas exchange in small primates
	MB7	Glucose tolerance and metabolites in small primates

3.2.4 Large Primate Mission CFVP (Cardiovascular Fluids, Vestibular, and Plants)

One of the rapid changes observed on reaching orbit is a shift of fluids toward the head. This places an increased load on the heart for the duration of the mission. If the mission is long enough to result in muscle degradation, there is concern that the cardiac muscle may be damaged during flight, or during the stress of reentry. This mission uses instrumented Rhesus monkeys to study the problem. The animals will be implanted with sensors to measure several parameters of cardiac function, as well as external measurements by EKG, echocardiograph, respiratory analysis, and blood sampling. Because animals implanted with instruments must be restrained, the mission will be limited to 30 days. Half the animals will be maintained at 1g on the centrifuge. All the animals will be returned live to ground after 30 days.

The plant study specified will measure the growth of chlorella, an alga which is a potential food source. It will be grown in submerged culture, with a light source. The yield and the experience with managing gases and liquids in 0g are the desired data. A 30-day culture period is ample. the organisms will be thoroughly examined for abnormalities in structure and biochemical constituents.

Experiments:	CV1	Cardiovascular function in restrained Rhesus monkeys
	FE2	Fluid and electrolyte balance in restrained Rhesus Monkeys

VP2C	Vestibular function in restrained Rhesus monkeys
PC5	Study of Chlorella

3.2.5 Rat Mission MFRP (Metabolism, Fluids, Reproduction, and Plants)

Equal numbers of rats will be maintained at 0g and on the centrifuge at 1g. At intervals, five or six specimens from each group will be sacrificed and dissected. The animals will be maintained in metabolic cages, to collect all waste, measure gas exchange, and measure food and water consumption. Mass will be determined weekly. At sacrifice, muscles will be removed for strength testing, mass, histology, etc. Other tissues will be available for additional studies.

Reproduction: Pregnant mice will be maintained on the Station. Newborn pups will be examined, tested for behavioral patterns, and samples sacrificed. Tissues will be fixed for histology after return, to determine whether abnormalities are produced by lack of gravity during pregnancy.

Plants will be grown in containers which permit recirculation of liquid nutrients. Plant growth will be monitored and photographed, using different nutrient solutions. Plants will be analyzed after return.

Experiments:	ML1A	Nitrogen balance and muscle loss in rats
	FE1A	Fluid and electrolyte balance in rats
	MB1A	Metabolic balance in the rat
	MB4	Respiratory gas exchange in the rat The above experiments require the use of metabolic cages for rats
	RD2C	Embryonic development in terrestrially impregnated mice
	PC4A	Plant growth and nutrient recycling

3.3 ENGINEERING REQUIREMENTS

3.3.1 LSRF Functional Requirements

The major functional requirements for the LSRF are:

- o Bioisolation of primates and rodents from crew
- o Flexible facilities for holding rodents, small primates and plants
- o Exchangeable metabolic and holding cages
- o Sufficient rack volume for basic rack-mounted equipment complement
- o Laminar flow workbench
- o Sufficient frozen storage capacity
- o Multi-g centrifuge capable of supporting rodent, primate, and human experimental subjects

3.3.2 Tradeoff Analysis & Update

The main trades investigated in this study were:

- o Bioisolation
  - Isolation level (cage vs rack vs module)
  - Specimen type

- o Animal ECLSS
  - Architecture (centralized vs. distributed)
  - Subsystems (open vs. closed vs. cabin air)

These are not isolated issues. The results of each trade effect the outcome of most of others. Bioisolation, for example, becomes a key driver and <u>the</u> dominant issue in the LSRF design. Other tradeoffs have been reported in earlier documents. Important issues which have been taken into account in the conceptual design (section 4) include the following:

- o Equipment Sharing & Commonality
- o Vivarium location (in lab vs. logistics module vs. special module)
- o Centrifuge

  - Location
  - Architecture
- o Waste storage
- o Logistics (animal re-supply)

3.3.2.1 Bioisolation. Because of its importance, the bioisolation issues was the main focus of a contract extension study, change order #5. The results of this study were published in a separate report (LMSC/D962181, August 85) and are summarized briefly here.

The study investigated three different levels of bioisolation: isolating an entire vivarium or module (the initial Space Station reference configuration); isolating each rack (the Spacelab approach); or housing each animal in its own isolator cage and performing all maintenance and experimental work inside a laminar flow bench. In addition, three different types of laboratory animals - differing in how microbially clean they are - were investigated. The first type, and the most common in earth-based labs, is classed as general, and undergoes little or no microbial screening. The next class of animals is Specific Pathogen Free (SPF) and has been screened carefully to be free of a list of certain specific pathogenic organisms. The cleanest class of animals is gnotobiotic, and is born and bred in a sterile environment. If kept in this condition, they are called axenic; however lacking the normal intestinal flora they are poor subjects for most research work and usually are innoculated with a few non-pathogenic species of bacteria to enable the gut to operate more normally. These animals are termed defined flora and must be raised and handled with the same strict aseptic technique as axemic specimens.

The study concluded that using SPF animals is the prefered approach; unscreened animals (primates specifically) present too much of a health risk to the crew, while the very strict aseptic technique required of gnotobiotes reduces the productivity of the on-board life scientist. In addition, gnotobiotic primates are very expensive and virtually impossible to obtain.

As for the proper placement of isolation, the study concluded that cage level isolation is both much more effective a measure than the use of module partitions, and is much less disruptive of routive activity. The use of module barriers requires a crewman to enter and exit the isolated section via a special biolock - an involved procedure that requires changing into a special laboratory gown and possibly taking a shower as well. Not only dies this waste valuable crew time (anywhere from 10-30 minutes each way) but considerable volume as well (1-4 m^3 for the biolock, depending on whether or not it has a shower) and places increased demands on the wash water recovery system (laundering of surgical gowns and the showers). In short, a very expensive way of doing a rather mediocre job of isolation.

Barriers are recommended only as a back up measure, and should be incorporated into the module design in a transparent fashion: i.e., either as part of the existing architecture or capable of being folded out of the way when not in use. Figure 3-5 illustrates an example of a folding partition.

Designing an isolator cage that will work in both micro g and normal gravity is difficult. Two basic appraoches were considered. The first is shown in Fig. 3-6. The animal, its feeder, and waste tray are housed between top and bottom microbial filters. Airflow is from the top of the cage to the bottom to move waste into the tray.

There are two problems with the flow-through microisolator design. Getting an appreciable airflow through the microbial filters requires considerable fan power; consequently the air velocity inside the cage is likely to be limited to 0.1 - 0.15 mps. As was discovered during Spacelab 3, this air velocity is insufficient to give the animal a preferred orientation (i.e., belly away from the draft). Therefore, the animal was seldom pointed toward the waste tray. Given this airflow velocity the upper microbial filter must be protected by a "splash guard" to prevent the animal from urinating on it.

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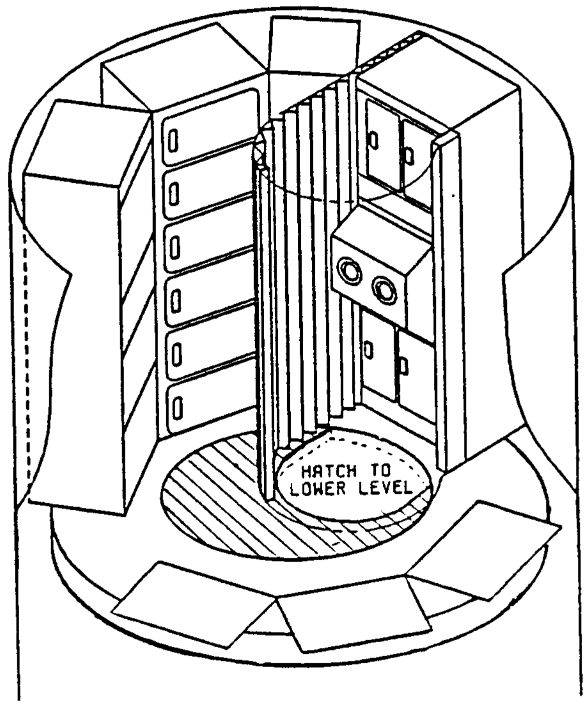

Figure 3-5 Folding Bioisolation Partition

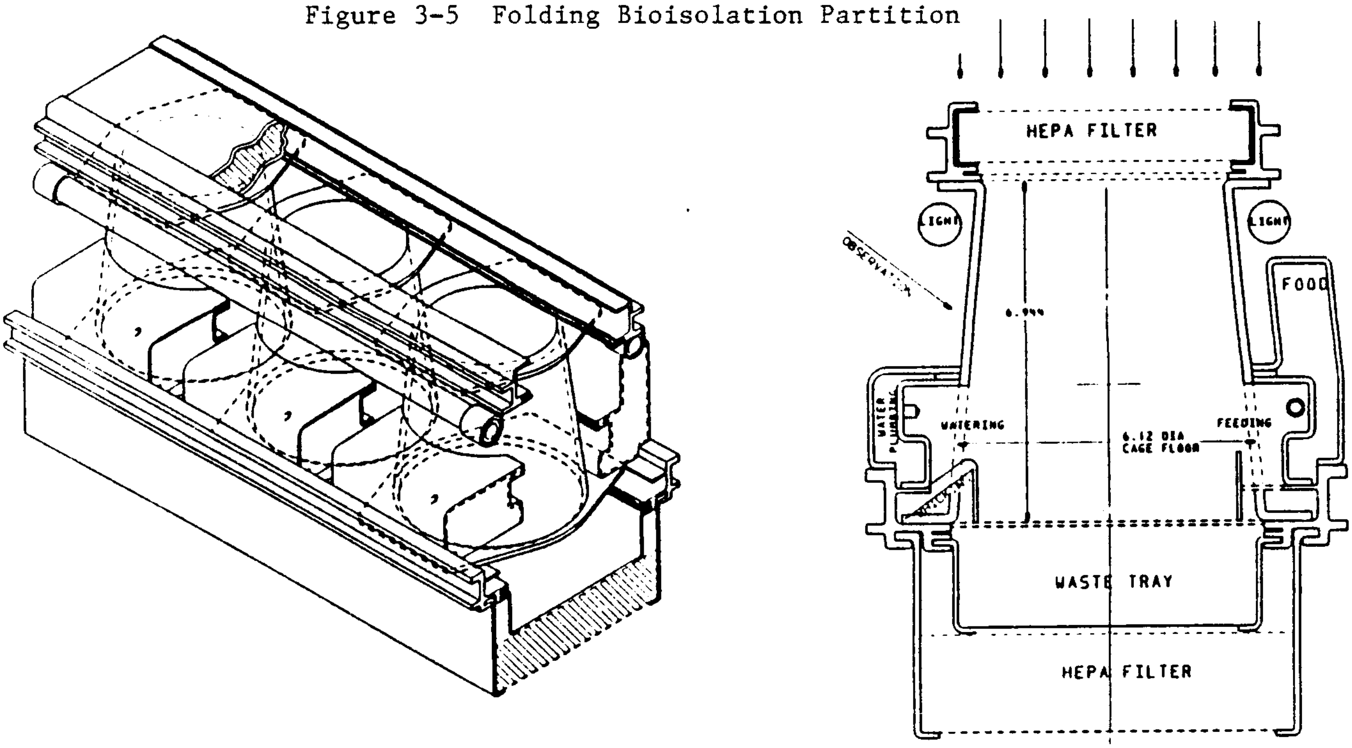

Figure 3-6 Flow-through Microisolator Cage

In order to minimize these problems, the dual cage concept (Fig. 3-7) was developed. The inner cage contains the animal, feeder, and waste tray and is designed to be washable in a cage washer. The cages are designed to fold or nest in the cage washer. The outer cage provides the isolation; air is circulated by a small internal fan. Only the amount of air necessary to remove the metabolic load from the animal goes through the microbial filters and roughly equals 20-25% of the total cage airflow (about 0.0014 m^3/sec for the rodent cage). Thus fan power is reduced considerably.

Lower fan power and greater operational versatility of the dual cage concept are sufficient to recommend it for further development as the baseline approach.

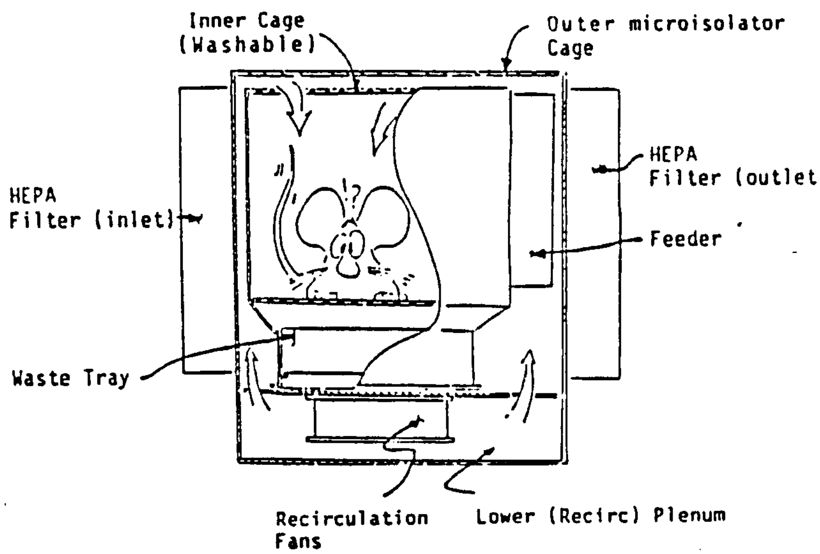

Figure 3-7 Dual Microisolator Cage Concept

3.3.2.2 Animal ECLSS. The animal ECLSS system for the LSRF provides temperature- humidity control, air circulation, and life support (O_2 production and - CO_2 removal) functions for experimental subjects. Three ECLSS options were studied. The first option utilizes a variation of the Spacelab approach in which air circulation is controlled at the cage, temperature - humidity functions are controlled at the rack(s) holding the cages, and crew and experimental animals utilize cabin air for the life support functions. A schematic of this option, generated for LMSC by Hamilton Standard under a separate effort, is presented in Fig. 3-8.

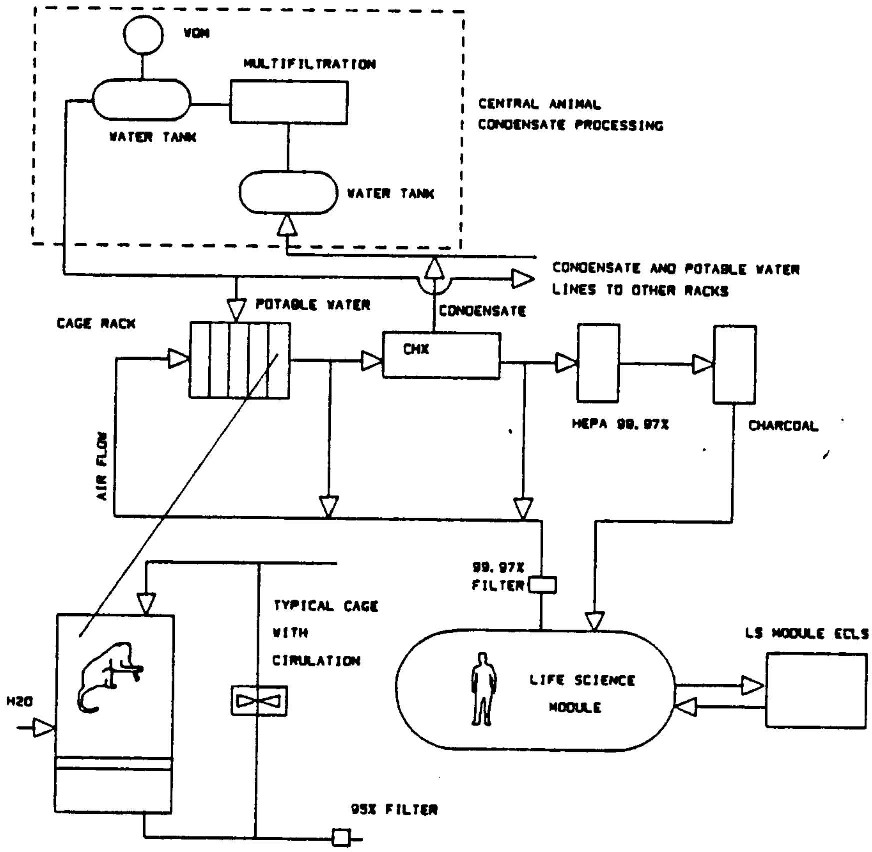

Figure 3-8 Animal ECLSS - Option 1
Distributed Temperature and Humidity Control

The second option utilizes a common central temperature and humidity control system for all the holing facility racks. This option trades decreased outfitting versatility for savings in hardware weight and cost due to an economy of scale. This option is shown in Fig. 3-9. As with option 1, cabin air is used for life support.

The third option studied, shown in Fig. 3-10, uses a centralized ECLSS providing both air revitalization and temperature and humidity control.

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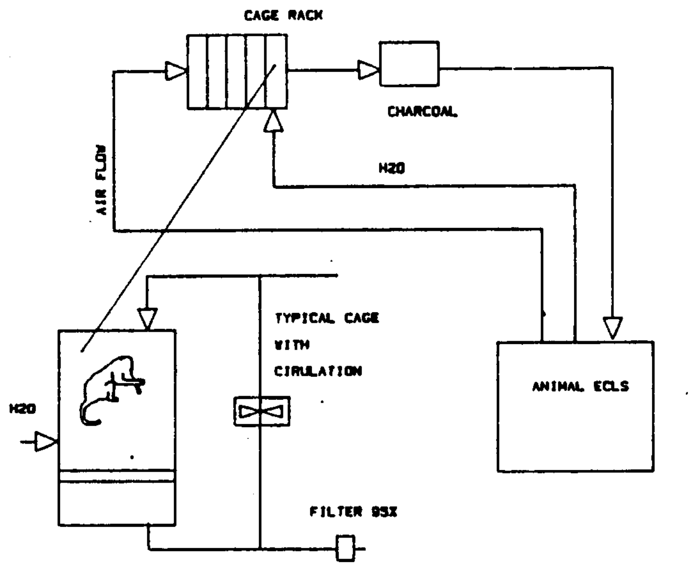

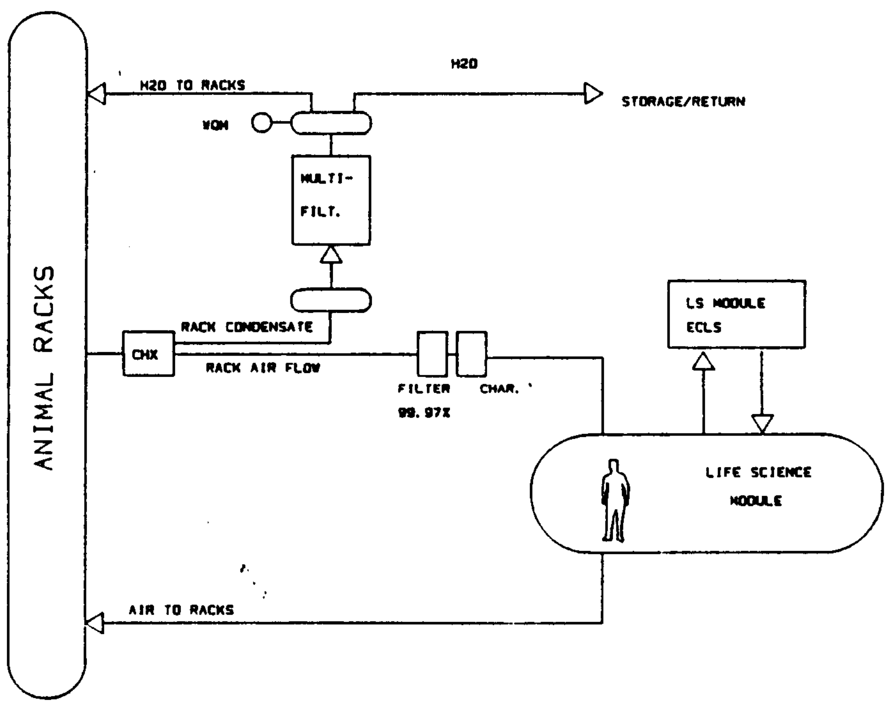

Figure 3-9 Centralized Holding Facility Temperature and Humidity Control

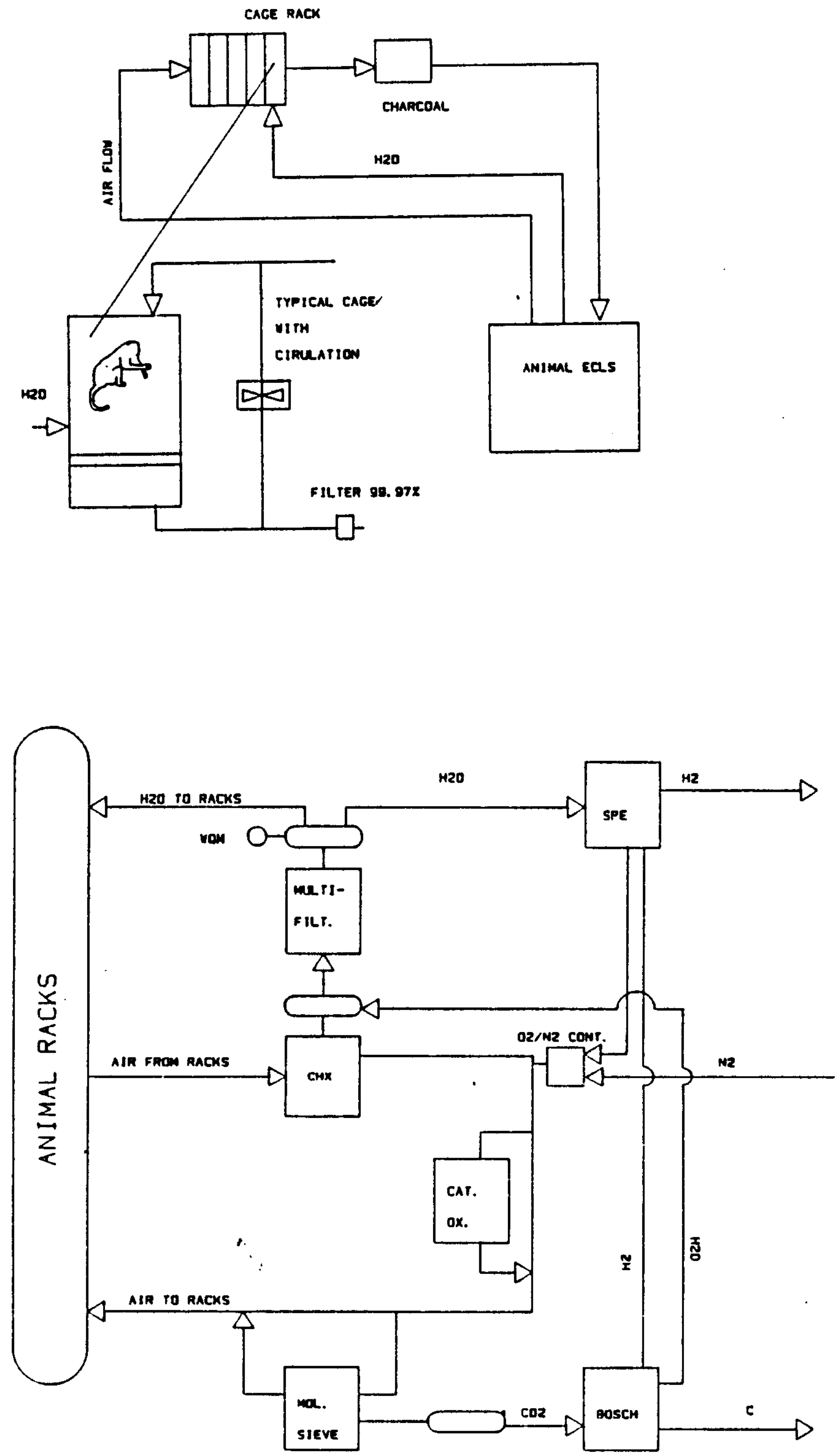

Figure 3-10 Centralized Animal ECLSS

Because of the use of isolator cages, the animal air is rather extensively HEPA filtered, and there is little difference in isolation between the three options. The real discriminator among the candidates is the ECLSS penalties associated with each. If the cabin ECLSS has excess capacity, then either option 1 or 2 is strongly preferred over option 3. Option 3, with its duplicate dedicated ECLSS is only a viable candidate if the cabin system is unable to handle the increased load. Of the two remaining options, there is a slight preference for option 1 (distributed temp/humidity control) based on the ease of integration with the gravity research centrifuge.

3.3.3 Engineering Requirements

Requirements documentation is to consist of a specification and associated ICDs, an item for future project work. The form and content of this documentation have been analyzed and are reported here.

The Engineering Requirements come from many sources; the C-2, C-3, and C-4 sections of the Space Station RFP and their updates, the Mission Requirements Database, the products of the other Work Packages, and the decisions made at Space Station Requirements update reviews 1 and 2. Analysis of suggested experiments and the questions raised in the course of SLM design studies are also important sources.

The LSRF is a multi-mission facility in an enclosure outfitted with a set of essentially independent general purpose subsystems and equipment items analogous to the spacelab LSLE. The lab is at the disposal of various users, each with a particular mission. The LSRF also has identifiable subsystems (ECLSS, power distribution, etc.) that are in support of the primary equipment complement and the users.

A convenient framework for the engineering requirements is the MIL-STD-490 Type A System Specification. Although some paragraphs of the MIL-STD-490 model do not apply, this approach has two advantages: (1) the outline provides a thoroughly tested checklist which ensures complete consideration of all relevant aspects of the requirement, and (2) the outline is familiar within the industry and can be followed easily by experienced people. Some of the more pertinent paragraphs are described briefly in the following material. The paragraph numbers in parentheses in the following text are those of the MIL-STD-490 format.

Scope. (Para.1.1) The specification establishes performance, design, development, and test requirements for the LSRF system.

General Description. (Para. 3.1.1) The LSRF system resides in a common module assigned to the SLM, and includes the associated ground segment and STS equipment and facilities, software, and documentation.

System Functions (Para. 3.1.4) The LSRF serves as a facility at the disposal of a community of users and LSRF system functions support a general purpose life sciences laboratory for plant and animal research.

Interface Definition (Para. 3.1.5) The LSRF system has external interfaces with the rest of the Space Station, the STS, ground facilities, and customers. These will be defined in appropriate top-level Space Station ICDs. The LSRF system also has internal interfaces among and within the equipment groupings. These will be defined in appropriate lower-level interfaces (at the level of the individual design items).

Operational and Organizational Concepts (Para. 3.1.7) The following are included: procedures, organization, support equipment, resources, and facilities for design, production, assembly/deployment, verification and test, operation (flight, launch-return, and ground), growth, and disposal.

Performance Characteristics (Para. 3.2.1) System functions and performance attributes are identified from scientific objectives, the needs of each PI throughout the life cycle of an experiment, and the functions necessary to support these. They are being quantified in areas such as environment, resources, equipment precision, and availability by the Space Station Program.

Physical Characteristics Para 3.2.2) The equipment groupings and the items they contain, with which the lab is outfitted, are defined by allocations for weight, space, access, etc. from the parameter Analysis Data Package (See sect. 1.1 background). Floors and partitions, windows and ports, airlocks, and retention means for equipment and personnel are being defined by Space Station.

Reliability (Para. 3.2.3) The Preliminary Design (PD) phase will allocate reliability requirements to individual items and specify the method of computation. Included will be redundancy, fault-tolerance, and various work-around or degraded modes as a means to reliability.

Maintainability (Para. 3.2.4) The PD phase also will specify maintainability features and criteria to be applied at each level of design, from overall LSRF outfitting to the lowest level of equipment covered. The requirements will be determined in conjunction with Customer Servicing, and will in general consist of a range of options to be utilized as appropriate in each specific case.

System Effectiveness Models (Para. 3.2.6) System effectiveness models will be the result of studies and trades in areas such as customer accommodations, crew productivity, autonomy, and automation and robotics. As such measures of system effectiveness are developed, they will be included in the specification.

Environmental Conditions (Para. 3.2.7) This section covers the external natural and man-made environments impinging on the LSRF during all stages of its life cycle. The main consideration is the space environment: radiation, micrometeorites, contamination from other portions of the Space Station, etc. EMI/RFI/EMC are explicitly included in Para. 3.3.2. below.

Materials, Processes, and Parts (Para. 3.3.1) Standards that apply to the Space Station, STS, or ground segment as a whole are included for the LSRF by reference. Standards applicable specifically to the LSRF would include compatibility with specimens, cleaning and sterilizability, handling and compatibility of reagents, pharmaceuticals, solvents, and cleaning agents, and similar issues.

Electromagnetic Radiation (Para. 3.3.2) The Space Station Program will define requirements governing inadvertant EMI/RFI/EMC, both external and internal to the LSRF system.

Commonality, Standadization, and Interchangeability (Para 3.3.5) Implementation of these attributes, both internal and external to the LSRF system will be required to the maximum practical extent.

Safety (Para. 3.3.6) Manned systems safety criteria apply to LSRF. These include limits on unsafe equipment or practices, and acceptable means of controlling or mitigating hazards.

Man Systems (Para. 3.3.7) The JSC man-systems division is developing requirements on the man-machine interface, and on the general sensory environment within the LSRF, so as to enhance the productivity and well-being of the crew.

Logistics (Para. 3.5) The requirements on logistics flow from the general operational concept and performance requirements as defined above.

Quality Assurance (Para 4.1, 4.2) The NASA Quality program documents define responsibility and the means whereby the conformance of the LSRF system to its requirements will be verified. This section forms the basis for the Test and Verification Plan.

3.4 OPERATIONS REQUIREMENTS

LSRF mission scenarios and internal layouts are the primary drivers influencing lab operations and support facilities. Elements in the operational sequence include pre-mission, on-orbit, post-mission support, and ground-based facility support activities. These activities must be fully integrated to handle all experiments in various phases of the operational sequence at anytime. Figure 3.11 provides an overview of the operational sequence for a typical LSRF mission.

3.4.1 Premission Sequence

Seven functional elements comprise the premission sequence. Experiment selection by NASA and the scientific community drives definition of mission scenarios, equipment and operational timelines. Premission functions are concerned principally with assembling Experiment Unique Equipment (EUE), or Principal Investigator Equipment for investigation into the LSRF portion of the SLM; providing appropriate training for equipment use; testing and verification and system checkout of LSRF equipment with the ground control facility prior to integration into STS orbiter; testing and verification of LSRF equipment-STS interfaces prior to launch, and loading specimens into the orbiter as late in the NSTS processing flow as feasible.

The primary design issues associated with the pre-launch operational phase are outfitting constraints imposed on the LSRF by STS performance and module pattern.

<u>STS Performance.</u> Given current STS lift performance capability, LSRF outfitting is weight limited. Assuming that a 13.7m long common module, and current STS standard launch capability (including the docking module) is 15,500 kg, only about 50% of LSRF outfitting can be launched initially. Thus, LSRF equipment must be designed for on-orbit outfitting from the outset. The benefit of this is that reconfiguration and transitioning to other modules will be accommodated in the original design.

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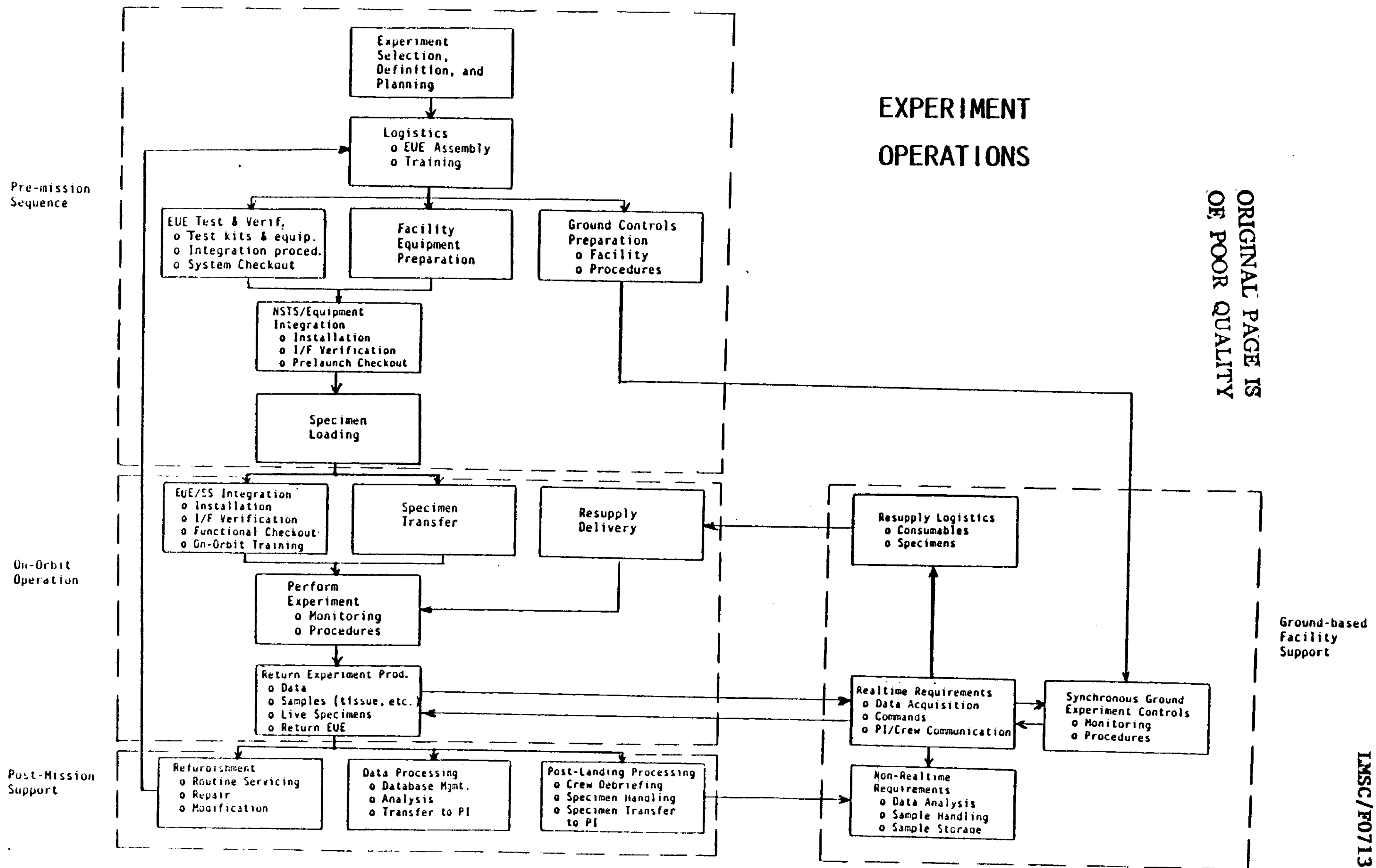

Figure 3-11 Engineering & Operational Relationships, Interactions, & Interfaces

Module Pattern. The primary driver for LSRF outfitting considering module pattern is the provision of useful volume. Useful volume is defined as that module volume not preempted by hatch area. The number of axial ports and the presence or absence of radial ports and their location when they are present affect useful volume. In addition, design and accommodation of the centrifuge are affected by whether a center-hub pass through is required.

3.4.2 On-Orbit Sequence

On-orbit LSRF equipment integration involves interface verification and functional checkout of LSRF equipment with other SLM subsystems and SS elements. Specimen transfer from the STS orbiter to the SLM will maintain bioisolation to the maximum extent practicable. Experiment related consummables delivered to the SS will be transferred from the logistics module in the Shuttle bay to the SLM in support of LSRF experiments. Experimental products (e.g., data) and LSRF equipment requiring changeout (e.g., ORUs) will be returned to ground via downlink or via the Shuttle, respectively. Experimental tissue samples or whole specimens may be returned via the Shuttle or a rapid specimen return capsule.

3.4.3 Post-Mission Support

Post-mission support includes repair and refurbishment of ORUs and routine ground maintenance of equipment that could not be maintained on-orbit. Post-landing database management, data analysis and specimen handling will be performed in ground based facilities at KSC and the contractor's site. There are no LSRF design issues that directly or indirectly impact post-mission operations.

3.4.4 Ground-Based Facility Support

Ground-based facilities supporting pre-mission, on-orbit, and post-mission activities include: (1) the Payload Operations Control Center (POCC) responsible for managing and performing normal payload (P/L) operations, coordinating related experiments and serving as the center for P/L performance analysis; (2) the Space Station Support Center (SSSC) which has responsibility for strategic aspects of Space Station operation (e.g. launch, rendezvous, assembly and construction, orbital adjustment) and POCC coordination and monitoring; (3) an integrated logistics support facility (ILS) capable of resupplying consumables to the LSRF; acquiring equipment returned for repair or maintenance; acquiring, provisioning and maintaining spares; and training personnel in maintenance of Space Station hardware on-orbit or on the ground; (4) a ground facility in which 1g experiments mimicking on-orbit experiments can be conducted concurrently with orbital experiments.

Definition of Orbital Replaceable Units (ORUs) for LSRF equipment and designing a high-fidelity 1g mock-up for the LSRF are the principal design issues for ground-based facility support. ORU definition is necessary to establish sparing approach, maintainability and reliability requirements, and training protocols for the ILS facility. The high-fidelity LSRF mock-up could serve as a 1g experiment control facility mimicking on-orbit experiments to the maximum extent practicable.

SECTION 4

SUBTASK 3.2 CONCEPTUAL DEFINITION AND DESIGNS

Eight module arrangement layouts are presented (see Table 4-1) with nonhuman equipment outfitting volumes equal to either half of a module or a full module. Prioritized equipment lists were developed by NASA Ames Research Center that were used in equipping the halflab and full lab options. These lists are shown in Tables 4-2 and 4-3.

Module length is constant at 13.7 meters. The options are based on the use of a 2.75m diameter centrifuge combined with a horizontal or vertical layout or a 3.75m diameter double rotor centrifuge combined with a horizontal or vertical layout. Both racetracks and modified racetracks were considered.

The Space Station Common Module is the carrier for the LSRF layouts. It provides basic services such as environmental control, thermal control, power distribution, and a link to the communications and data systems.

TABLE 4-1 LAYOUT OPTIONS CONSIDERED

Half Module (SAAX0307)	Horizontal	Small Centrifuge	Figs. 4-1 and 4-2	#1
		Large Centrifuge	Figs. 4-3 and 4-4	#2
	Vertical	Small Centrifuge	Figs. 4-5 and 4-6	#3
		Large Centrifuge	Figs. 4-7 and 4-8	#4
Full Module (SAAX0302)	Horizontal	Small Centrifuge	Figs. 4-9 and 4-10	#5
		Large Centrifuge	Figs. 4-11 and 4-12	#6
	Vertical	Small Centrifuge	Figs. 4-13 and 4-14	#7
		Minilab Option	Figs. 4-15 and 4-16	#7A
		Large Centrifuge	Figs. 4-17 and 4-18	#8

4.1 LAYOUT OPTIONS - SAAX 0307 (HALF MODULE)

The half laboratory layouts were developed in both horizontal and vertical internal arrangements. These designs meet the requirements for science mission SAAX0307 a nonhuman life sciences lab occupying one half of a common module and intended for the Space Station Initial Operating Capability (IOC).

4.1.1 Horizontal Layouts

Option #1 the reference half module horizontal layout with small (2.75m diameter) ceiling mounted centrifuge, is shown in Fig. 4-1. Its $23m^3$ of equipment, stowage, and rack volume accommodates 20 m^3 of animal and plant research equipment and $3m^3$ of shared human and plant and animal research equipment. The concept features behind the racks moving storage container system to use otherwise wasted space. The equipment list by rack location is shown in Fig 4-2.

The option #2 (Fig. 4-3) half module layout modifies the racetrack module pattern by locating radial docking ports toward the module length mid-point. It contains the large (3.75m) double centrifuge. It is more volumetrically efficient, providing $37.2m^3$ of volume is apportioned as follows: the centrifuge utilizes $18m^3$ and is mounted in the end cone, rack volume $15.4m^3$, liquid stowage $2.0m^3$, dry stowage $1.8m^3$.

Figure 4-4 shows a total of $13.9m^3$ of dedicated animal-plant research equipment and $22.4m^3$ of shared human and animal/plant research equipment can be accommodated. The shared human/nonhuman volume is large because the full-diameter centrifuge has the potential to accommodate limited (short duration) human experiments such as in neurophysiology and cardiovascular work.

TABLE 4-2 RESEARCH EQUIPMENT FOR NONHUMAN LIFE SCIENCES:
FIRST HALF-MODULE

Item	Quantity	Unit characteristics Weight, kg	Volume, liters	Power, W
0-g standard habitat, ECLS[a] (24 rat equiv.)	1	450	1800	500
0-g breeding habitat, ECLS (12 rat equiv.)		250	1000	250
0-g metabolic habitat, ECLS (4 rat equiv.)		200	500	200
1-g centrifuge, controls, ECLS (18 rat)		1000	4000	500
Plant growth facility (100 liter capacity)	1	250	1000	1500
Multipurpose workbench	1	350	2000	500
Animal restraint/transport device	1	20	100	
Refrigerator (-20°C) 30-liter capacity	2	100	300	200
Freezer (-70°C), 20-liter capacity	1	100	300	300
Cryogenic freezer (-195°C)		100	400	500
Computer/data display/data storage	1	100	500	400
Video camera, recorder, monitor, tape	1	50	200	200
Animal physiological monitoring system	1	20	100	50
Biomedical recorder/plotter	1	30	100	150
Autoclave/drying oven		100	200	500
Incubator/culture growth system	1	100	200	100
Laboratory refrigerator centrifuge	1	30	100	450
Small mass measuring device	1	20	50	20
Dissecting or binocular microscope	1	10	20	200
Gas chromatograph	1	25	150	100
Mass spectrometer	1	40	100	200
Echocardiograph		100	200	450
Spectrophotometer	1	40	100	300
Ultrasound		100	200	600
pH/ion analyzer	1	10	5	10
Radiation dosimeter	1	5	5	15
Hematology, fluid handling kit	1	10	20	100
Surgery/dissection kit, guillotine	1	15	10	
Plant tool kit or veterinary kit (ea)	2	20	10	100
Hand wash facility	1	100	500	375
Gown change room, partitions	1	1000	3000	
Waste handling system, freeze dryer	1	100	300	300
Cage cleaning system	1	100	250	250
Secondary structure, grips, restraints	1	200	50	
Dynamic environment/accelerometer system	1	40	100	20
Environmental monitoring and control	1	200	500	3000
Lighting system and controls	1	50	50	300
Storage allowance	1	25	1000	
TOTALS (unit characteristics × quantity)		3730	13230	9940

[a]ECLS = environmental control and life support

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TABLE 4-3 RESEARCH EQUIPMENT FOR NONHUMAN LIFE SCIENCES:
SECOND HALF-MODULE

Item	Quantity	Unit characteristics Weight, kg	Volume, liters	Power, W
0-g standard habitat, ECLS[a] (24 rat equiv.)	1	450	1800	500
0-g breeding habitat, ECLS (12 rat equiv.)	1	250	1000	250
0-g metabolic habitat, ECLS (4 rat equiv.)	1	200	500	200
1-g centrifuge, controls, ECLS (18 rat)	1	1000	4000	500
Plant growth facility (100 liter capacity)	1	250	1000	1500
Multipurpose workbench		350	2000	500
Animal restraint/transport device	1	20	100	
Refrigerator (-20°C) 30-liter capacity	2	100	300	200
Freezer (-70°C), 20-liter capacity	1	100	300	300
Cryogenic freezer (-195°C)	1	100	400	500
Computer/data display/data storage		100	500	400
Video camera, recorder, monitor, tape	1	50	200	200
Animal physiological monitoring system	1	20	100	50
Biomedical recorder/plotter	1	30	100	150
Autoclave/drying oven	1	100	200	500
Incubator/culture growth system		100	200	100
Laboratory refrigerator centrifuge	1	30	100	450
Small mass measuring device	1	20	50	20
Dissecting or binocular microscope	1	10	20	200
Gas chromatograph		25	150	100
Mass spectrometer		40	100	200
Echocardiograph	1	100	200	450
Spectrophotometer		40	100	300
Ultrasound	1	100	200	600
pH/ion analyzer		10	5	10
Radiation dosimeter		5	5	15
Hematology, fluid handling kit	1	10	20	100
Surgery/dissection kit, guillotine	1	15	10	
Plant tool kit or veterinary kit (ea)	2	20	10	100
Hand wash facility		100	500	375
Gown change room, partitions		1000	3000	
Waste handling system, freeze dryer		100	300	300
Cage cleaning system		100	250	250
Secondary structure, grips, restraints	1	200	50	
Dynamic environment/accelerometer system		40	100	20
Environmental monitoring and control	1	200	500	3000
Lighting system and controls	1	50	50	300
Storage allowance	1	25	1000	
TOTALS (unit characteristics × quantity)		3570	12520	10370

[a]ECLS = environmental control and life support

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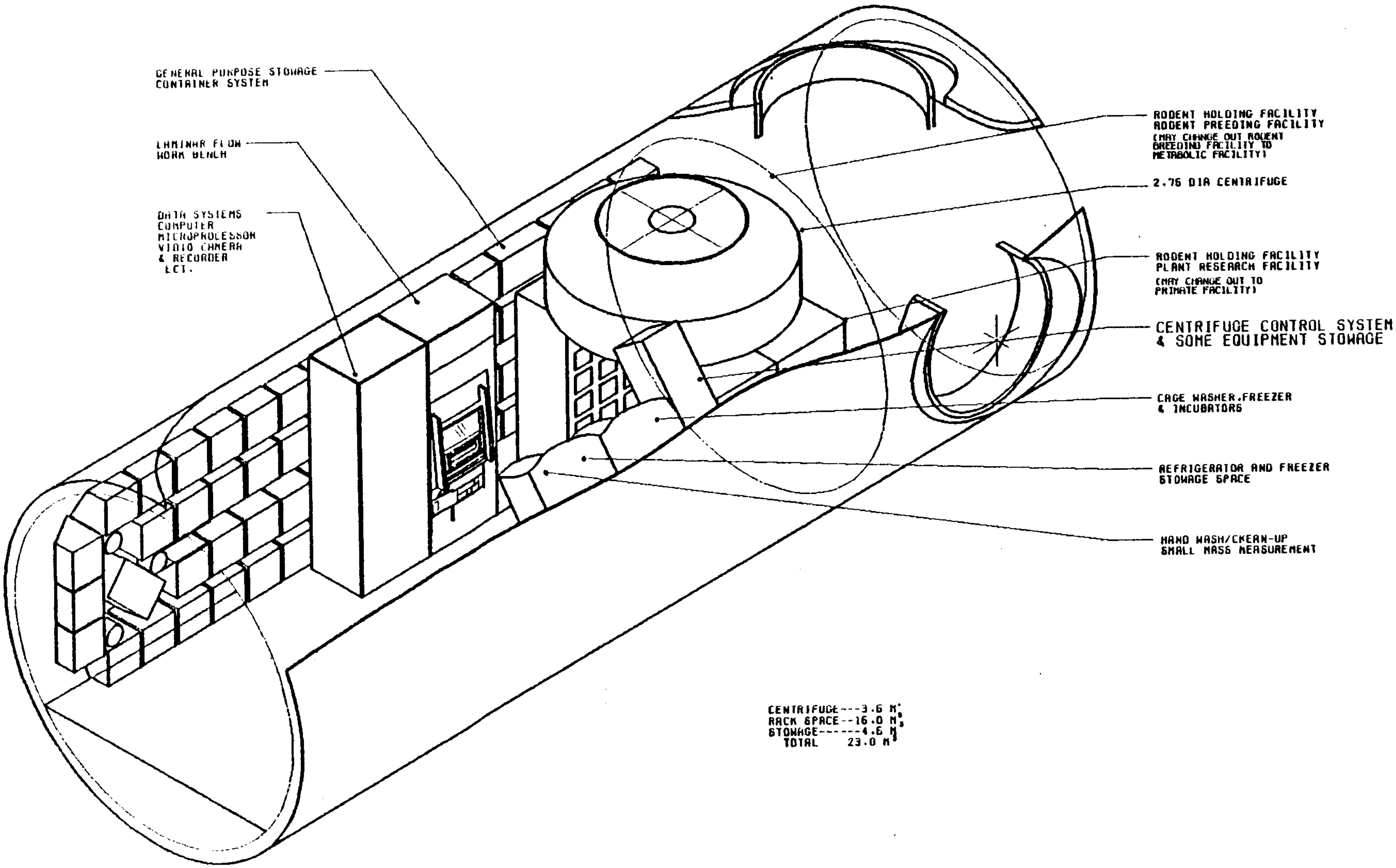

Figure 4-1 Option # 1. Half Lab, Horizontal, Small Centrifuge

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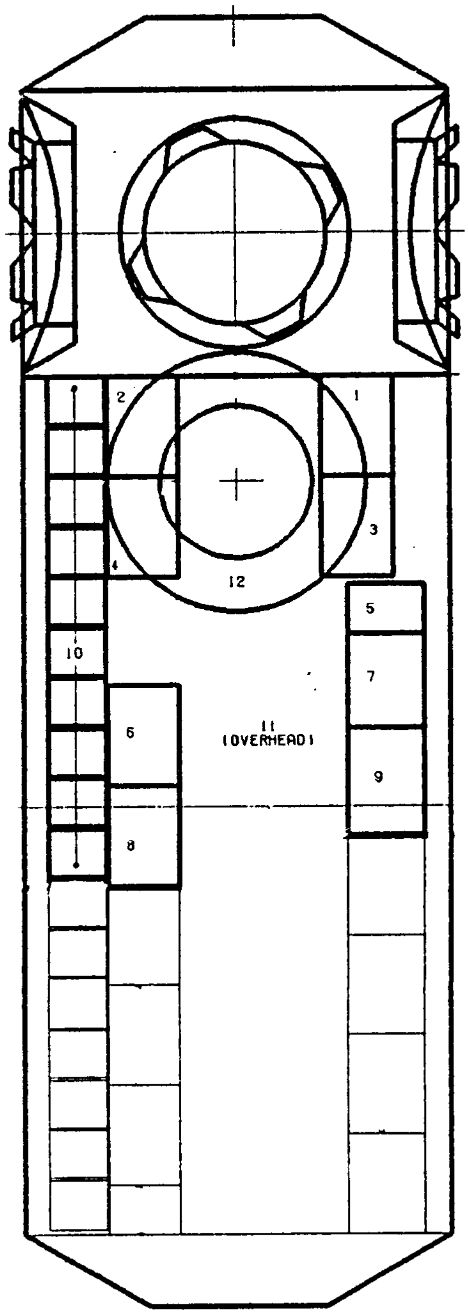
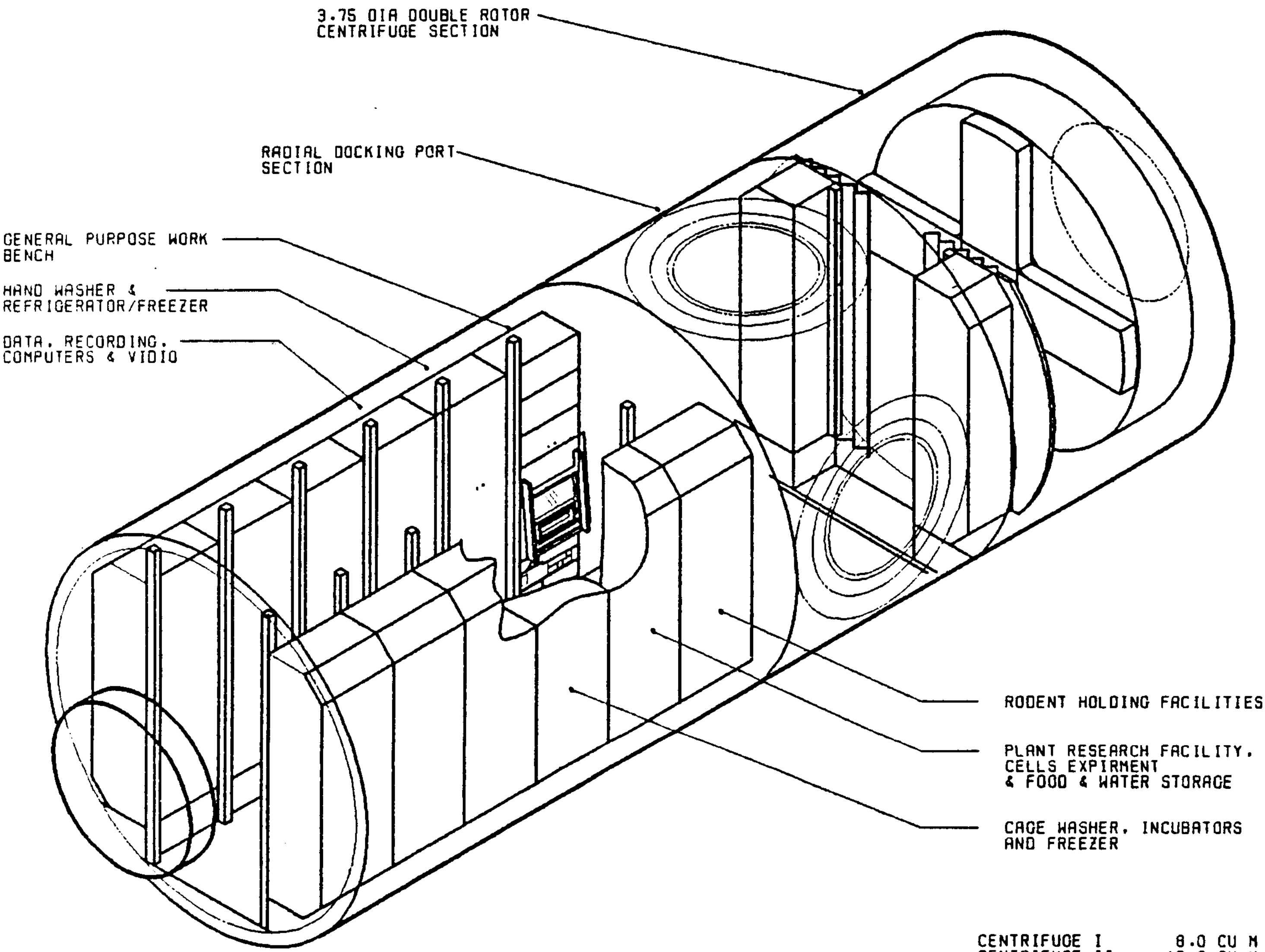


NON-HUMAN LAB EQUIPMENT			
RACK NUMBER	RACK VOLUME (CUBIC M)	USER DESIGNATION	EQUIPMENT
1	1.5	NON-HUMAN	RODENT STANDARD HOLDING FACILITY (#52), SPECIMEN FOOD AND WATER (#96,97), STORAGE.
2	1.5	NON-HUMAN	RODENT BREEDING HOLDING FACILITY (#53).
3	1.5	NON-HUMAN	PLANT RESEARCH FACILITY (#81).
4	1.5	NON-HUMAN	RODENT STANDARD HOLDING FACILITY (#52).
5	1	NON-HUMAN	CENTRIFUGE CONTROLS, PH.ION ANALYZER (#208), OSCILLOSCOPE (#207), MICROSCOPES (#).
6	2	NON-HUMAN	GENERAL PURPOSE WORK STATION (#11), DISSECTION KIT(#124), SPECTROPHOTOMETER (#206), MASS SPEC/GAS ANALYZER (#163), ANIMAL MONITORING (#203).
7	2	NON-HUMAN	CAGE WASHER (#98). INCUBATOR CO2(#202), EGG INCUBATOR (#76), CELSS (#90), FREEZER (#46).
8	2	1 H, 1 N-H	DATA SYSTEM (#33-36), COMPUTER (#61), STRIP CHART RECORDER (#162), MICROPROCESSOR (#209), VIDEO CAMERA AND RECORDER (#141).
9	2	.5 H, 1.5N-H	HAND WASHER (#100). REFRIGERATOR/FREEZERS (#44,46), ENVIRONMENTAL MONITOR (#142), PHYSIOLOGICAL AMPLIFIER (#143), DOSIMETER (#126), SMALL MASS MEASUREMENT (#112).
10	2.6	NON-HUMAN	SOLIDS WASTE STORAGE (#93), STORAGE.
11	2	NON-HUMAN	LIQUID WASTE STORAGE (#92).
12	3.5	NON-HUMAN	2.75 M DIA ARTIFICIAL GRAVITY CENTRIFUGE (#63).
	21.5 1.6	NON-HUMAN HUMAN	TOTAL VOLUME

Figure 4-2 Equipment Option #1



CENTRIFUGE I	8.0 CU M
CENTRIFUGE II	10.0 CU M
RACK (2 @ 1.1)	2.2 CU M
RACK (6 @ 2.2)	13.2 CU M
LIQUID STOWAGE	2.0 CU M
STOWAGE (12 @.15)	1.8 CU M
TOTAL	37.2 CU M

Figure 4-3 Half Lab Horizontal Layout in Modified Racetrack Pattern with Large Centrifuge

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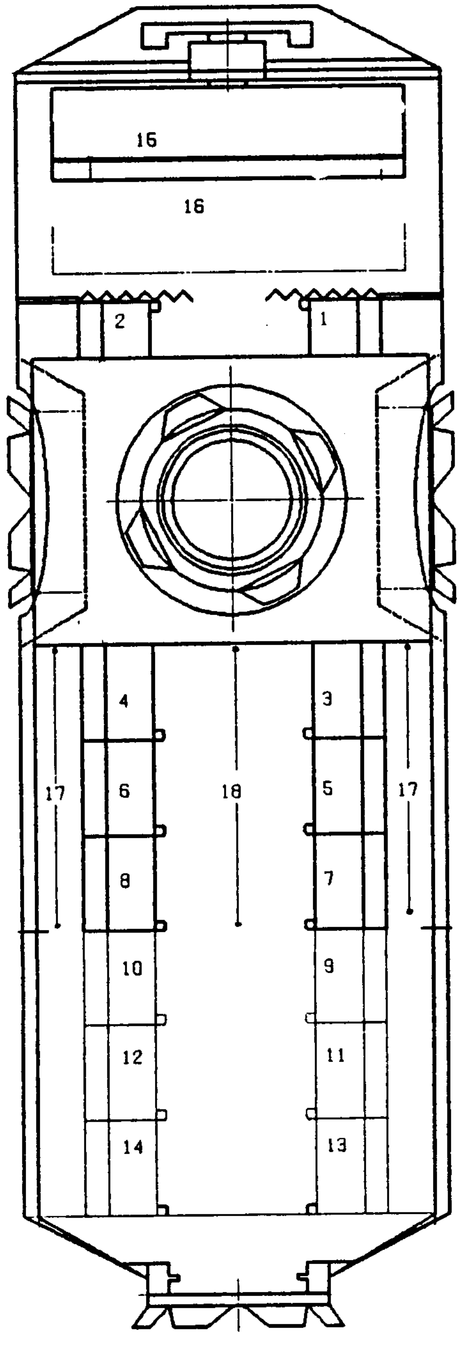

NON-HUMAN LAB EQUIPMENT

RACK NUMBER	VOLUME (CUBIC M)	USER DESIGNATION	EQUIPMENT
1	1.1	.6 H, .5 N-H	CENTRIFUOE ANCELLARARY EQUIP STORAOE (#63)
2	1.1	.5 H, .6 N-H	CENTRIFUOE CONTROL SYSTEM (#63)
3	2.2	NON-HUMAN	RODENT STANDARD HOLDING FACILITY 2 UNITS (#62).
4	2.2	NON-HUMAN	GENERAL PURPOSE WORK STATION (#11), DISSECTION KIT(#124), SPECTROPHOTOMETER (#206), MASS SPEC/OAS ANALYZER (#163), ANIMAL MONITORINO (#203).
5	2.2	NON-HUMAN	PLANT RESEARCH FACILITY (#81), CELLS (# 90) PH.ION ANALYZER (#208), OSCILLOSCOPE (#207), MICROSCOPES (#) FOOD AND WATER (#96,97), STORAOE.
6	2.2	NON-HUMAN	HAND WASHER (#100). REFRIOERATOR/FREEZERS (#44,46), ENVIRONMENTAL MONITOR (#142), PHYSIOLOOICAL AMPLIFIER (#143), DOSIMETER (#125), SMALL MASS MEASUREMENT (#112).
7	2.2	NON-HUMAN	CAGE WASHER (#98). INCUBATOR CO2(#202), EOO INCUBATOR (#76), FREEZER (#45).
8	2.2	1 H, 1 N-H	DATA SYSTEM (#33-36), COMPUTER (#61), STRIP CHART RECORDER (#162), MICROPROCESSOR (#209), VIDEO CAMERA AND RECORDER (#141).
15	8	NON-HUMAN	3.76 M DIA ARTIFICIAL GRAVITY CENTRIFUGE I (#63).
16	10	9 H, 1 N-H	3.76 M DIA RESEARCH CENTRIFUOE II (#63).
17	1.8	NON-HUMAN	SOLIDS WASTE STORAOE (#93), STORAOE.
18	2	NON-HUMAN	LIQUID WASTE STORAOE (#92).
	24.5 11.7	NON-HUMAN HUMAN	TOTAL VOLUME

Figure 4-4 Equipment for Option #2

4.1.2 Vertical layouts

Option #3 is a half laboratory module in the vertical layout with small (2.75m) centrifuge. This configuration, shown in Figs. 4-5 and 4-6, provides $2m^3$ of internal volume on two levels, apportioned as follows: $3.m^3$ for centrifuge, $15m^3$ rack volume, and $4.5m^3$ stowage. The centrifuge is mounted in the side wall and additional equipment can be accommodated on the centrifuge level. Openings to windows on each level are provided by omitting a double rack, yet the equipment volume available is equal to the horizontal option due to the efficiency created by aligning the long dimension of the rack with the long dimension of the common module. Nonhuman research equipment utilizes $20m^3$ and shared plant/animal and human research $3m^3$ of the total volume, respectively.

The half laboratory module vertical arrangement with a large (3.75m) centrifuge (option #4 , Figs. 4-7 and 4-8) affords $30m^3$ for equipment on two levels. Of this, $12m^3$ is animal-plant research equipment and $18m^3$ is shared plant-animal and human research equipment.

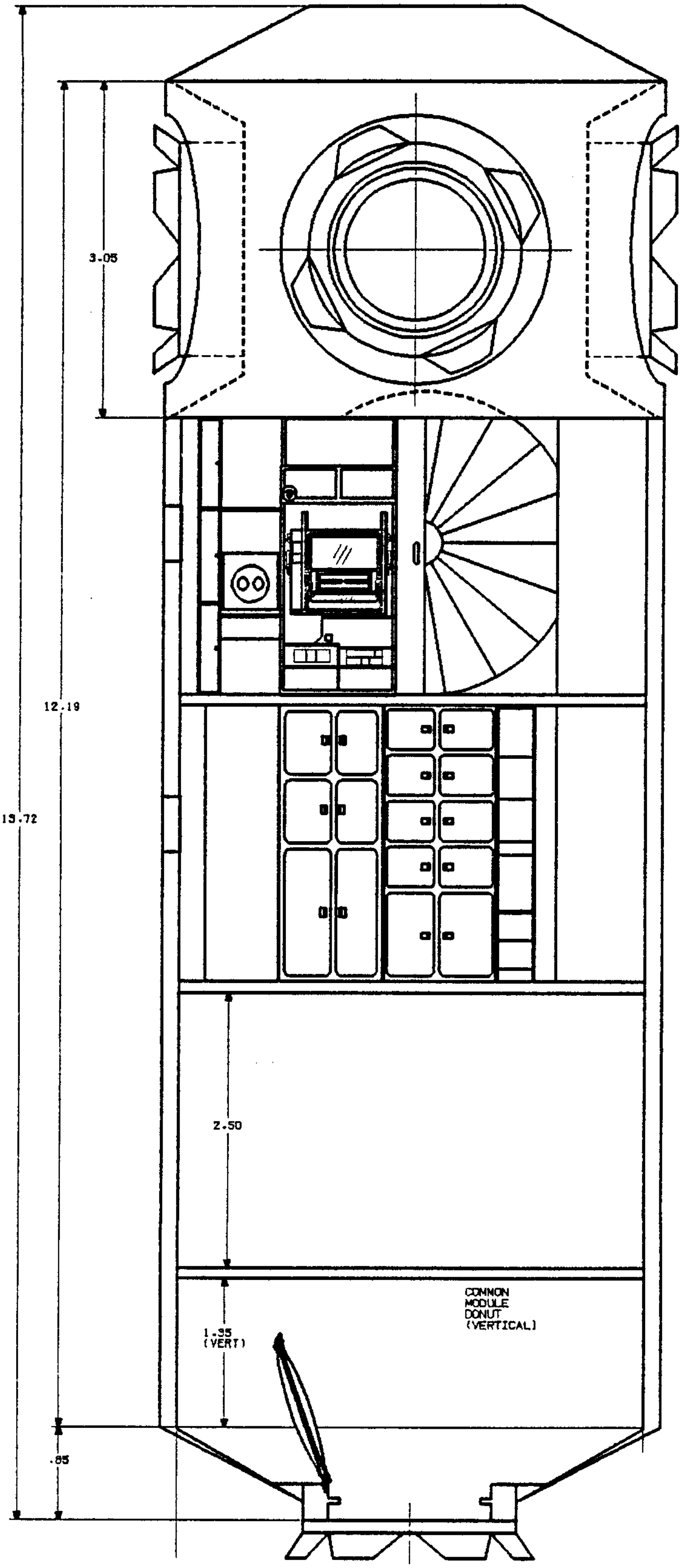

Figure 4-5 Option #3. Half Lab Vertical Layout with Small Centrifuge

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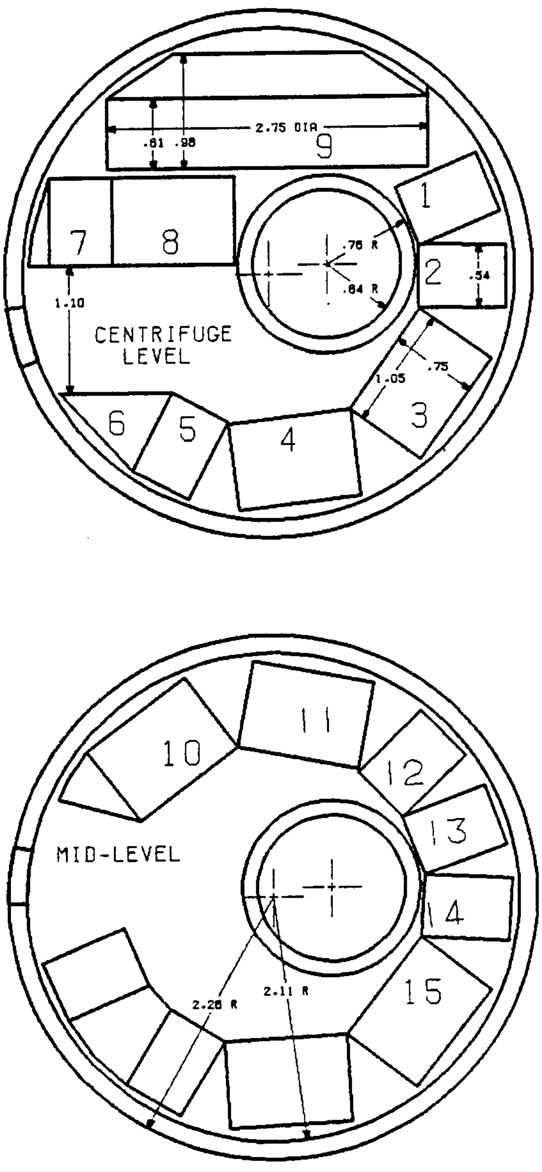

NON-HUMAN LAB EQUIPMENT			
RACK NUMBER	RACK VOLUME (CUBIC M)	USER DESIGNATION	EQUIPMENT
1	1	NON-HUMAN	CENTRIFUGE CONTROLS (#63). STORAGE.
2	1	NON-HUMAN	RODENT STANDARD HOLDING FACILITY (#52).
3	2	NON-HUMAN	CAGE WASHER (#98). SPECIMEN FOOD AND WATER (#96,97). STORAGE.
4	2	NON-HUMAN	RODENT BREEDING HOLDING FACILITY (#53).
5	1	NON-HUMAN	RODENT STANDARD HOLDING FACILITY (#52A).
6	0.5	NON-HUMAN	STORAGE. PH/ION ANALYZER (#205). OSCILLOSCOPE (#207). MICROSCOPES (#).
7	1	NON-HUMAN	HAND WASHER (#100).
8	2	NON-HUMAN	GENERAL PURPOSE WORK STATION (#11). DISSECTION KIT(#124). SPECTROPHOTOMETER (#206). MASS SPEC/GAS ANALYZER (#163). ANIMAL MONITORING (#203).
9	3.5	NON-HUMAN	2.75 M DIA ARTIFICIAL GRAVITY CENTRIFUGE (#63).
10	2	NON-HUMAN	LIQUID WASTE STORAGE (#92).
11	2	NON-HUMAN	SOLIDS WASTE STORAGE (#93).
12	1	NON-HUMAN	INCUBATOR CO2(#202). EGG INCUBATOR (#76). CELSS (#90). FREEZER(#45A).LABORATORY CENTRIFUGE (#28).
13	1	NON-HUMAN	PLANT RESEARCH FACILITY (#81).
14	1	.5 H. .5N-H	REFRIGERATOR/FREEZERS (#44.45). ENVIRONMENTAL MONITOR (#142). PHYSIOLOGICAL AMPLIFIER (#143). DOSIMETER (#125). SMALL MASS MEASUREMENT (#112).
15	2	1 H. 1 N-H	DATA SYSTEM (#33-38). COMPUTER (#51). STRIP CHART RECORDER (#162). MICROPROCESSOR (#209). VIDEO CAMERA AND RECORDER (#141).
	21.5 1.5	NON-HUMAN HUMAN	TOTAL VOLUME

Figure 4-6 Equipment for Option #3

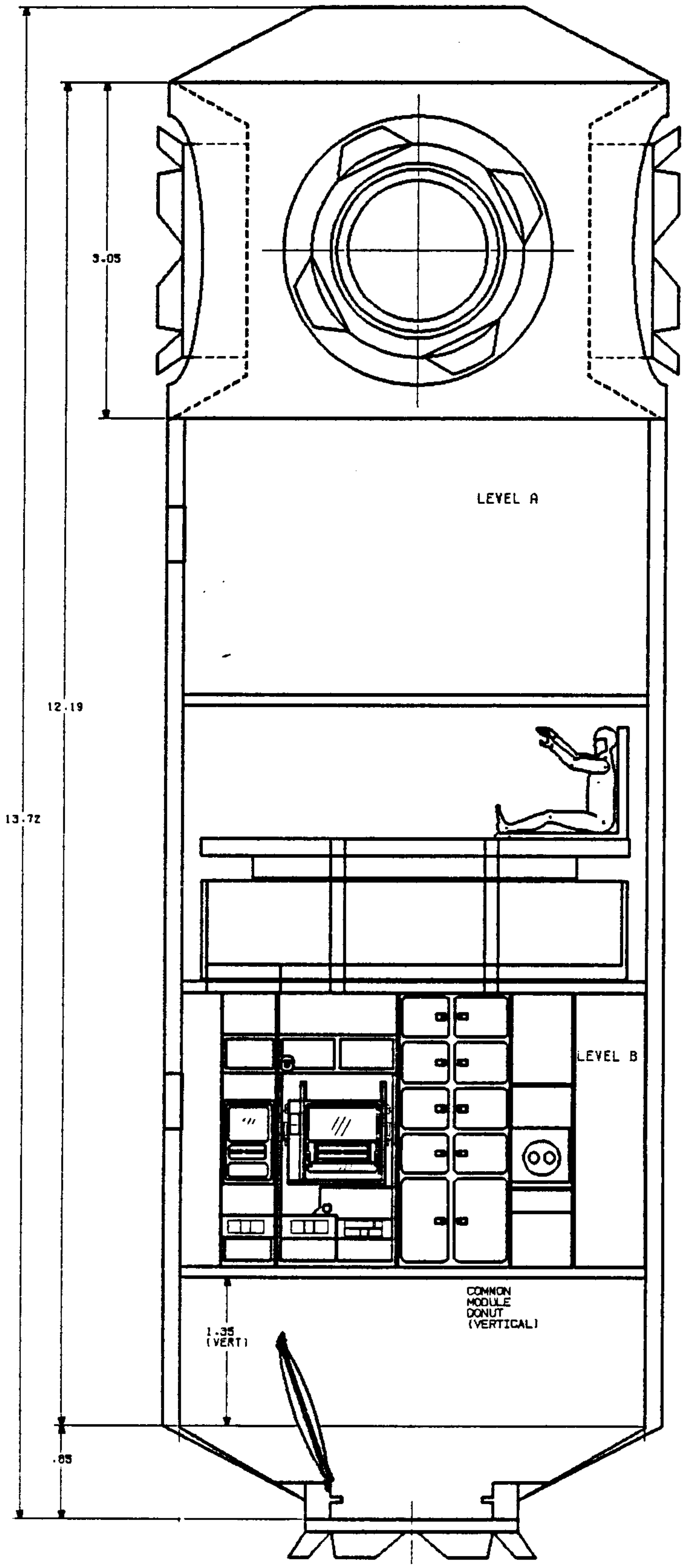

Figure 4-7 Option #4 Half Lab Vertical With Large Centrifuge

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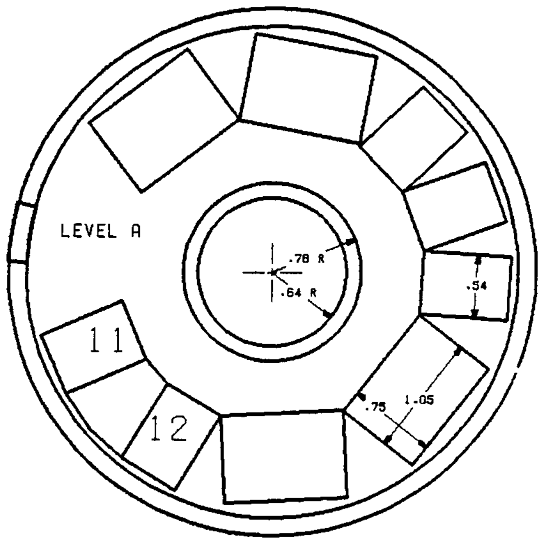

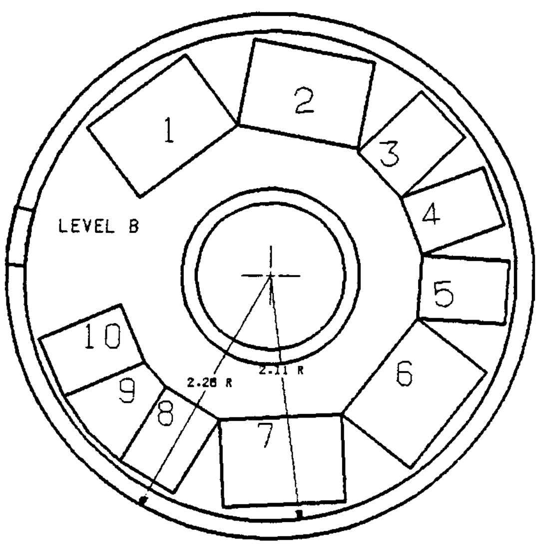

NON-HUMAN LAB EQUIPMENT

RACK NUMBER	RACK VOLUME (CUBIC M)	USER DESIGNATION	EQUIPMENT
1	2	NON-HUMAN	GENERAL PURPOSE WORK STATION (#11), DISSECTION KIT(#124). SPECTROPHOTOMETER (#206). MASS SPEC/GAS ANALYZER (#163). ANIMAL MONITORING (#203).
2	2	NON-HUMAN	STORAGE.
3	1	NON-HUMAN	HAND WASHER (#100).
4	1	NON-HUMAN	INCUBATOR CO2(#202). EGG INCUBATOR (#76). CELSS (#90). FREEZER(#45A).LABORATORY CENTRIFUGE (#28).
5	1	NON-HUMAN	PLANT RESEARCH FACILITY (#81).
6	2	1 H. 1 N-H	DATA SYSTEM (#33-38). COMPUTER (#51). STRIP CHART RECORDER (#182). MICROPROCESSOR (#209). VIDEO CAMERA AND RECORDER (#141).
7	2	NON-HUMAN	CAGE WASHER (#98). SPECIMEN FOOD AND WATER (#96.97). STORAGE.
8	1	NON-HUMAN	RODENT STANDARD HOLDING FACILITY (#52A).
9	1	NON-HUMAN	STORAGE. PH/ION ANALYZER (#208). OSCILLOSCOPE (#207). MICROSCOPES (#).
10	1	NON-HUMAN	RODENT STANDARD HOLDING FACILITY (#52).
XX	14	7 H. 7 N-H	3.75 METER DIAMETER SPECIMEN RESEARCH CENTRIFUGE
11	1	.5 H. .5 NH	CENTRIFUGE CONTROLS (#63). STORAGE.
12	1	.5 H. .5N-H	REFRIGERATOR/FREEZERS (#44.45). ENVIRONMENTAL MONITOR (#142). PHYSIOLOGICAL AMPLIFIER (#143). DOSIMETER (#125). SMALL MASS MEASUREMENT (#112).
	14 2	NON-HUMAN HUMAN	TOTAL VOLUME

Figure 4-8 Equipment for Option #4

4.2 SAAX 0302 FULL LABORATORY OPTIONS

Full laboratory options also were developed in horizontal and vertical internal arrangements.

4.2.1 Horizontal Layouts

Option #5 is a full module horizontal layout (Fig. 4-9) dedicated to animal-plant research. It contains two small (2.75m diameter) centrifuges and provides $44.2m^3$ of equipment volume apportioned as follows: 2 centrifuges $7m^3$, rack space $27.7m^3$, and stowage space $9.5m^3$. Figure 4-10 shows how the volume is dedicated to animal-plant experimental equipment.

The full lab modified racetrack horizontal layout containing the large 3.75m centrifuge (option #6) is shown in Fig. 4-11. It provides $54.2m_3$ of volume apportioned as follows: centrifuge $18m^3$, rack volume $28.6m_3$, liquid stowage $4m_3$, and dry stowage $3.6m^3$. Equipment for option #6 is shown in Fig. 4-12.

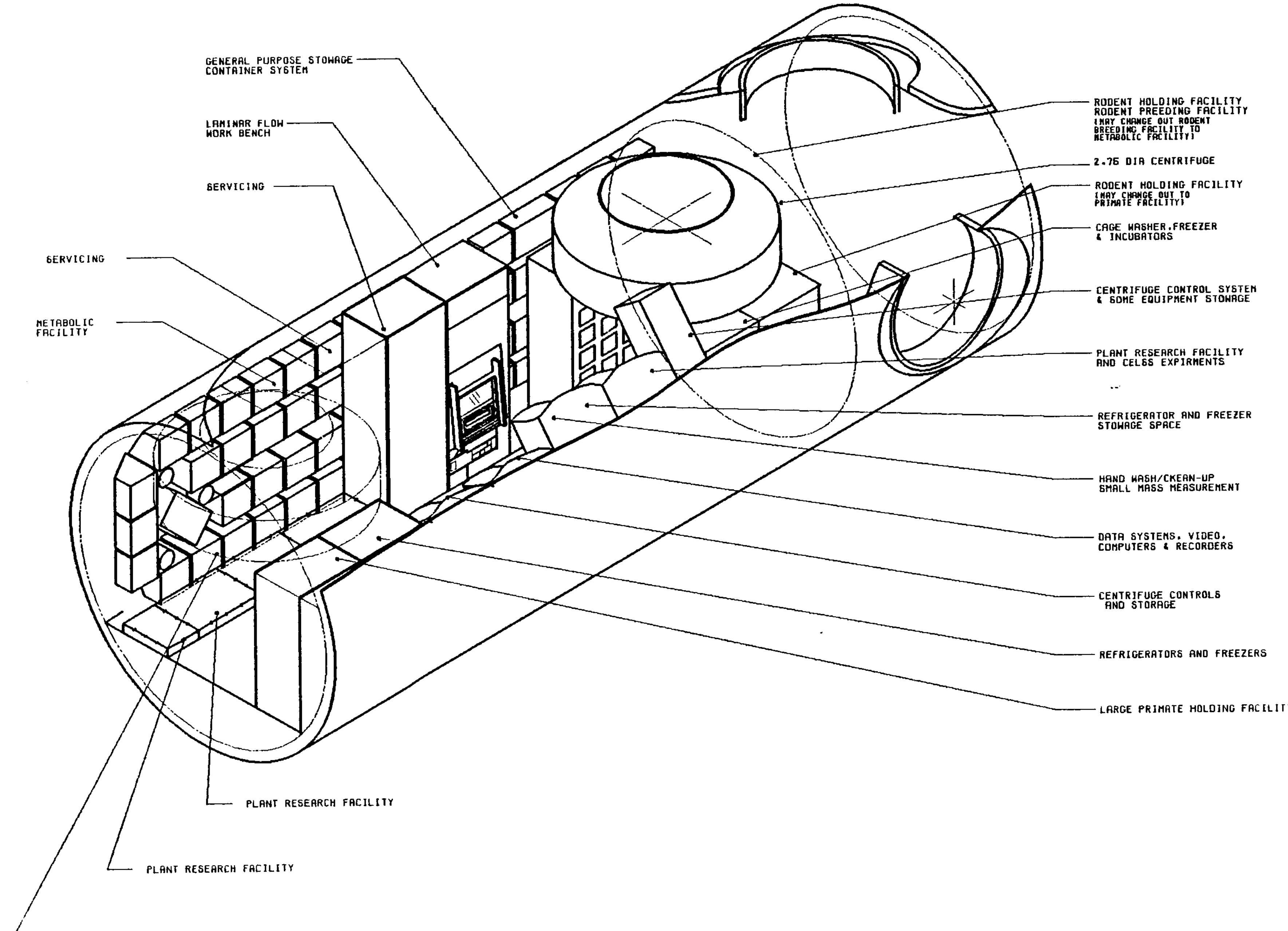

Figure 4-9 Option #5. Full Lab Horizontal Layout with Small Centrifuge

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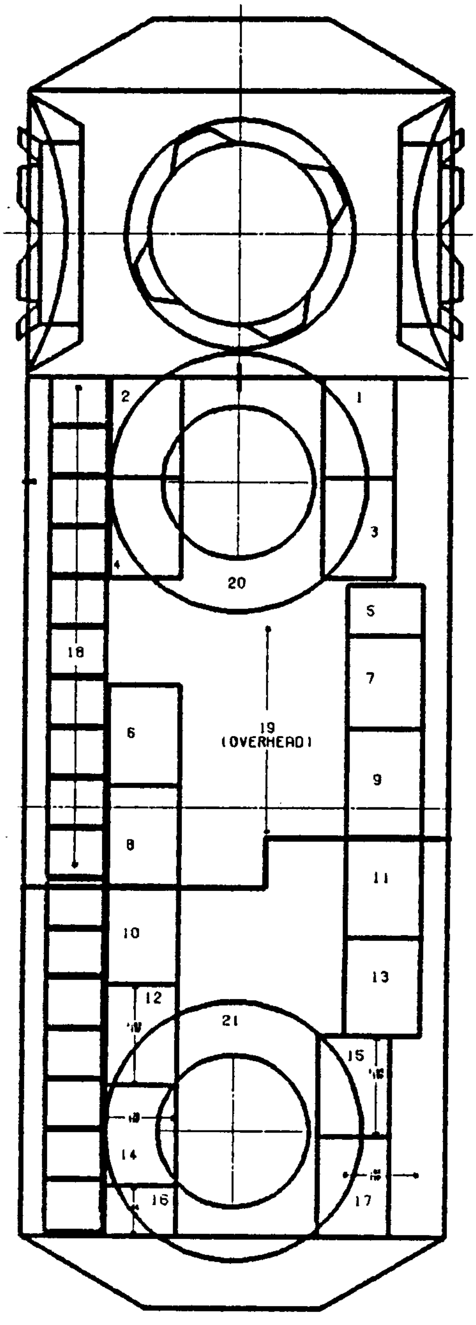
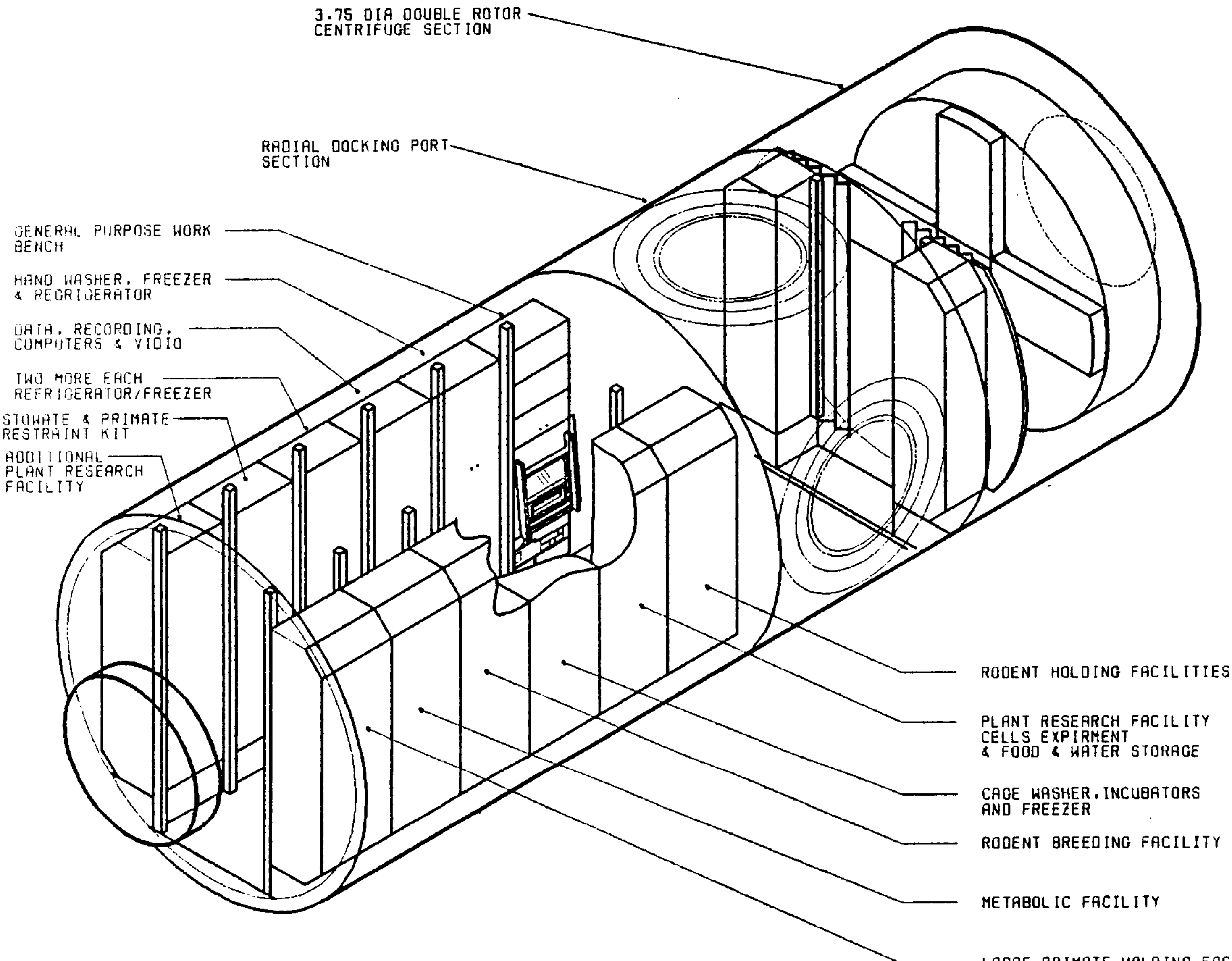


NON-HUMAN LAB EQUIPMENT			
RACK NUMBER	RACK VOLUME (CUBIC M	USER DESIGNATION	EQUIPMENT
1	1.5	NON-HUMAN	RODENT STANDARD HOLDING FACILITY (#52), SPECIMEN FOOD AND WATER (#96,97), STORAOE.
2	1.5	NON-HUMAN	RODENT BREEDING HOLDING FACILITY (#53).
3	1.5	NON-HUMAN	PLANT RESEARCH FACILITY (#81).
4	1.5	NON-HUMAN	RODENT STANDARD HOLDING FACILITY (#52).
5	1	NON-HUMAN	CENTRIFUGE CONTROLS, PH.ION ANALYZER (#208). OSCILLOSCOPE (#207), MICROSCOPES (#).
6	2	NON-HUMAN	GENERAL PURPOSE WORK STATION (#11), DISSECTION KIT(#124), SPECTROPHOTOMETER (#206), MASS SPEC/ OAS ANALYZER (#163), ANIMAL MONITORINO (#203).
7	2	NON-HUMAN	CAGE WASHER (#98). INCUBATOR CO2(#202), EOO INCUBATOR (#76), CELSS (#90), FREEZER (#45), LABORATORY CENTRIFUOE(#28)
8	2	1 H, 1 N-H	DATA SYSTEM (#33-36), COMPUTER (#61), STRIP CHART RECORDER (#162), MICROPROCESSOR (#209). VIDEO CAMERA AND RECORDER (#141).
9	2	.5 H,1.5N-H	HAND WASHER (#100). REFRIOERATOR/FREEZERS (#44,45). ENVIRONMENTAL MONITOR (#142), PHYSIOLOOICAL AMPLIFIER (#143), DOSIMETER (#125). SMALL MASS MEASUREMENT (#112).
10	2	.5 H,1.5N-H	STORAGE, PRIMATE RESTRAINT KIT (#205).
11	2	.5 H,1.5N-H	2 REFRIGERATOR/FREEZERS (#44), FREEZER (#45).
12	1.5	.5 H,1.5N-H	METABOLIC FACILITY (#).
13	2	.5 H,1.5N-H	STORAGE
14	1.5	.5 H,1.5N-H	ADDITIONAL PLANT RESEARCH FACILITY (#81)
15	1.5	.5 H,1.5N-H	ADDITIONAL RODENT HOLDING FACILITY (#52).
16	.7	.5 H,1.5N-H	ADDITIONAL PLANT RESEARCH FACILITY (#81)
17	1.5	.5 H,1.5N-H	LARGE PRIMATE HOLDING FACILITY (#58), SPECIMEN FOOD AND WATER (#96,97).
18	5.5	NON-HUMAN	SOLIDS WASTE STORAOE (#93). STORAOE.
19	4	NON-HUMAN	LIQUID WASTE STORAOE (#92).
20	3.5	NON-HUMAN	2.75 M DIA ARTIFICIAL GRAVITY CENTRIFUGE (#63).
21	3.5	NON-HUMAN	2.75 M DIA ARTIFICIAL GRAVITY CENTRIFUGE (#63).
	44.2	NON-HUMAN	TOTAL VOLUME

Figure 4-10 Equipment for Option #5



CENTRIFUGE I	8.0 CU M
CENTRIFUGE II	10.0 CU M
RACK (2 @ 1.1)	2.2 CU M
RACK (12 @ 2.2)	26.4 CU M
LIQUID STOWAGE	4.0 CU M
STOWAGE (24 @ .15)	3.6 CU M
TOTAL	54.2 CU M

Figure 4-11 Option #6 Full Lab Modified Racetrack Horizontal Layout with Large Centrifuge

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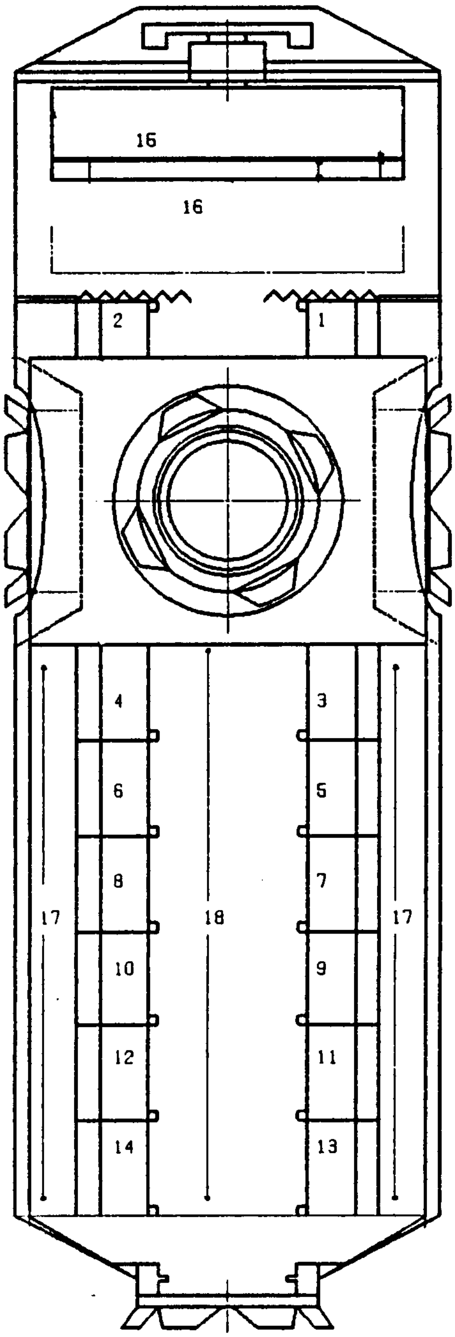


RACK NUMBER	RACK VOLUME (CUBIC M)	USER DESIGNATION	EQUIPMENT
1	1.1	NON-HUMAN	CENTRIFUGE ANCELLARARY EQUIP STORAGE (#63)
2	1.1	NON-HUMAN	CENTRIFUGE CONTROL SYSTEM (#63)
3	2.2	NON-HUMAN	RODENT STANDARD HOLDING FACILITY 2 UNITS (#62)
4	2.2	NON-HUMAN	GENERAL PURPOSE WORK STATION (#11), DISSECTION KIT(#124), SPECTROPHOTOMETER (#206), MASS SPEC/GAS ANALYZER (#163), ANIMAL MONITORING (#203).
5	2.2	NON-HUMAN	PLANT RESEARCH FACILITY (#81), CELLS (# 90) PH.ION ANALYZER (#208), OSCILLOSCOPE (#207), MICROSCOPES (#) FOOD AND WATER (#96,97). STORAGE.
6	2.2	NON-HUMAN	HAND WASHER (#100). REFRIGERATOR/FREEZERS (#44,45), ENVIRONMENTAL MONITOR (#142), PHYSIOLOGICAL AMPLIFIER (#143), DOSIMETER (#126), SMALL MASS MEASUREMENT (#112)
7	2.2	NON-HUMAN	CAGE WASHER (#98). INCUBATOR CO2(#202), EGG INCUBATOR (#76), FREEZER (#46).
8	2.2	NON- HUMAN	DATA SYSTEM (#33-36), COMPUTER (#61), STRIP CHART RECORDER (#162), MICROPROCESSOR (#209), VIDEO CAMERA AND RECORDER (#141).
9	2.2	NON-HUMANH	RODENT BREEDING HOLDING FACILITY (#53).
10	2.2	NON-HUMAN	2 REFRIGERATOR/FREEZERS (#44), FREEZER (#45).
11	2.2	NON-HUMAN	METABOLIC FACILITY (#).ADDITIONAL RODENT HOLDING FACILITY (#62).
12	2.2	NON-HUMAN	STORAGE, PRIMATE RESTRAINT KIT (#205).
13	2.2	NON-HUMAN	LARGE PRIMATE HOLDING FACILITY (#58), SPECIMEN FOOD AND WATER (#96,97).
14	2.2	NON-HUMAN	ADDITIONAL PLANT RESEARCH FACILITY (#81)
15	8	NON-HUMAN	3.75 M DIA ARTIFICIAL GRAVITY CENTRIFUGE I (#67).
16	10	NON-HUMAN	3.75 M DIA RESEARCH CENTRIFUGE II (#63).
17	3.6	NON-HUMAN	SOLIDS WASTE STORAGE (#93), STORAGE.
18	4	NON-HUMAN	LIQUID WASTE STORAGE (#92).
	53.2	NON-HUMAN	TOTAL VOLUME

Figure 4-12 Equipment for Option #6

4.2.2 Vertical Layouts

The full module vertical layout with small 2.75m centrifuge (option #7) is shown in Fig. 4-13. It dedicates $43m_3$ to animal-plant experiments of which $3.5m^3$ is centrifuge volume, $22.5m^3$ is rack volume, $15m^3$ is dry stowage, and $2m^3$ is liquid storage volume. Figure 4-14 shows the equipment and its rack location.

In an alternate layout to the above, designated #7A (Fig. 4-15), a full lab is provided with small 2.75m centrifuge and a minilab. It has $6m^3$ of racks that may be used for experiment specific lab equipment or a second centrifuge with control specimens. In this arrangement $43m^3$ of equipment can be accommodated with dry stowage volume reduced from $15m^3$ to $10.5m^3$ and an additional $1m^3$ of rack volume available (Fig. 4-16).

The last option, #8, is a vertical layout with the large 3.75m centrifuge (see Fig. 4-17). It provides $42m^3$ for experiment equipment. The dual-rotor centrifuge occupies $14m^3$, rack volume equals $20m^3$, and dry stowage volume equals $8m^3$ (Fig. 4-18).

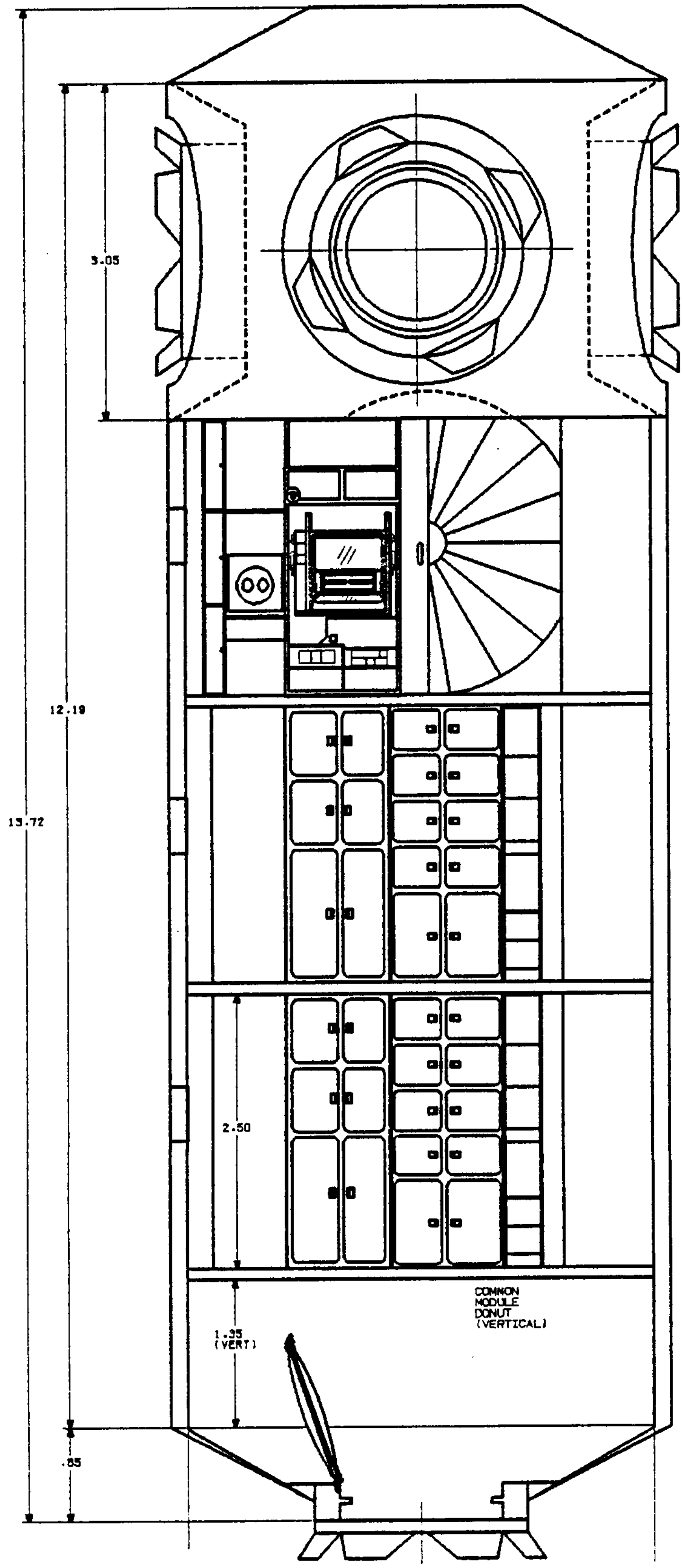
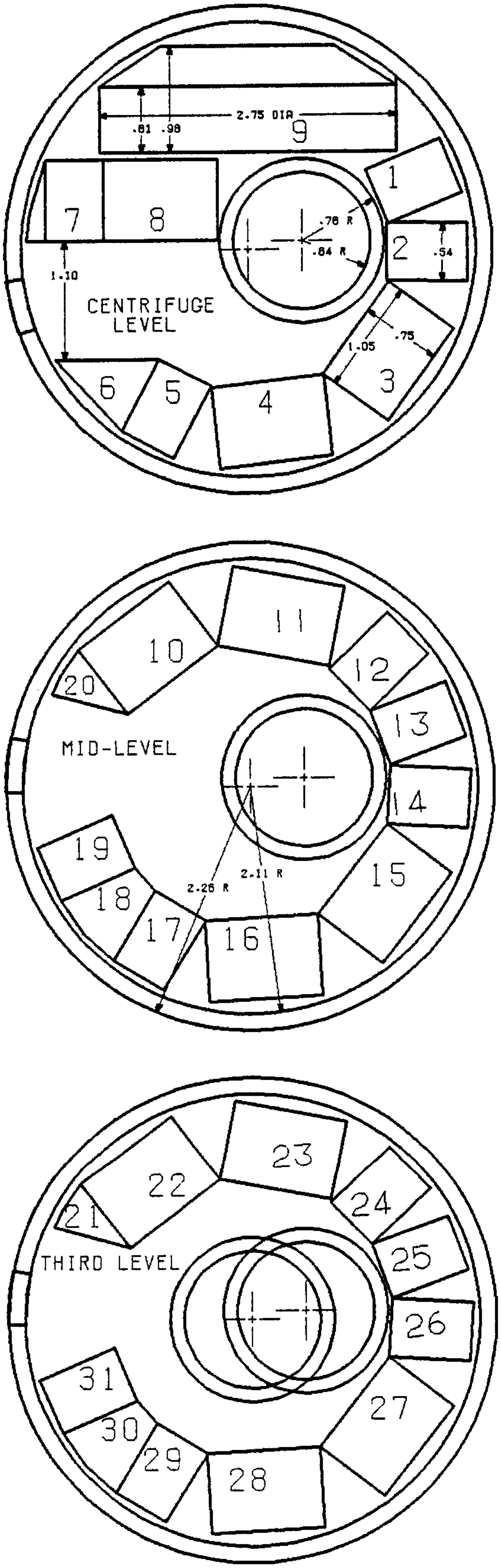


Figure 4-13 Option #7 Full Lab Vertical Arrangement with Small Centrifuge



NON-HUMAN LAB EQUIPMENT		
RACK NUMBER	RACK VOLUME (CUBIC M)	EQUIPMENT
1	1	CENTRIFUGE CONTROLS (#63). STORAGE.
2	1	RODENT STANDARD HOLDING FACILITY (#52).
3	2	CAGE WASHER (#98). SPECIMEN FOOD AND WATER (#96,97). STORAGE.
4	2	RODENT BREEDING HOLDING FACILITY (#53).
5	1	RODENT STANDARD HOLDING FACILITY (#52A).
6	0.5	STORAGE. PH/ION ANALYZER (#208). OSCILLOSCOPE (#207). MICROSCOPES (#). PRIMATE KIT (#205).
7	1	HAND WASHER (#100).
8	2	GENERAL PURPOSE WORK STATION (#11). DISSECTION KIT(#124). SPECTROPHOTOMETER (#206). MASS SPEC/ GAS ANALYZER (#163). ANIMAL MONITORING (#203).
9	3.5	2.75 M DIA ARTIFICIAL GRAVITY CENTRIFUGE (#63).
10	2	LIQUID WASTE STORAGE (#92).
11	2	SOLIDS WASTE STORAGE (#93).
12	1	INCUBATOR CO2(#202). EGG INCUBATOR (#76). CELSS (#90). FREEZER (#45A).LABORATORY CENTRIFUGE(#28).
13	1	PLANT RESEARCH FACILITY (#81).
14	1	REFRIGERATOR/FREEZERS (#44. 45). ENVIRONMENTAL MONITOR (#142). PHYSIOLOGICAL AMPLIFIER (#149). DOSIMETER (#125). SMALL MASS MEASUREMENT (#112).
15	2	DATA SYSTEM (#33-36). COMPUTER (#51). STRIP CHART RECORDER (#162). MICROPROCESSOR (#209). VIDEO CAMERA AND RECORDER (#141).
	23	TOTAL VOLUME

RACK NUMBER	RACK VOLUME (CUBIC M)	EQUIPMENT
16	2	LARGE PRIMATE HOLDING FACILITY (#58). SPECIMEN FOOD AND WATER (#96A. 97A).
17	1	ADDITIONAL RODENT HOLDING FACILITY (#52B).
18	1	STORAGE.
19	1	METABOLIC FACILITY (#).
20	0.5	STORAGE.
21	0.5	STORAGE.
22	2	STORAGE.
23	2	STORAGE.
24	1	STORAGE.
25	1	STORAGE.
26	1	2 REFRIGERATOR/FREEZERS (#44A.B). FREEZER (#45B).
27	2	ADDITIONAL PLANT RESEARCH FACILITY (#81A).
28	2	STORAGE.
29	1	STORAGE.
30	1	STORAGE.
31	1	STORAGE.
	20	TOTAL VOLUME

Figure 4-14 Equipment for Option #7

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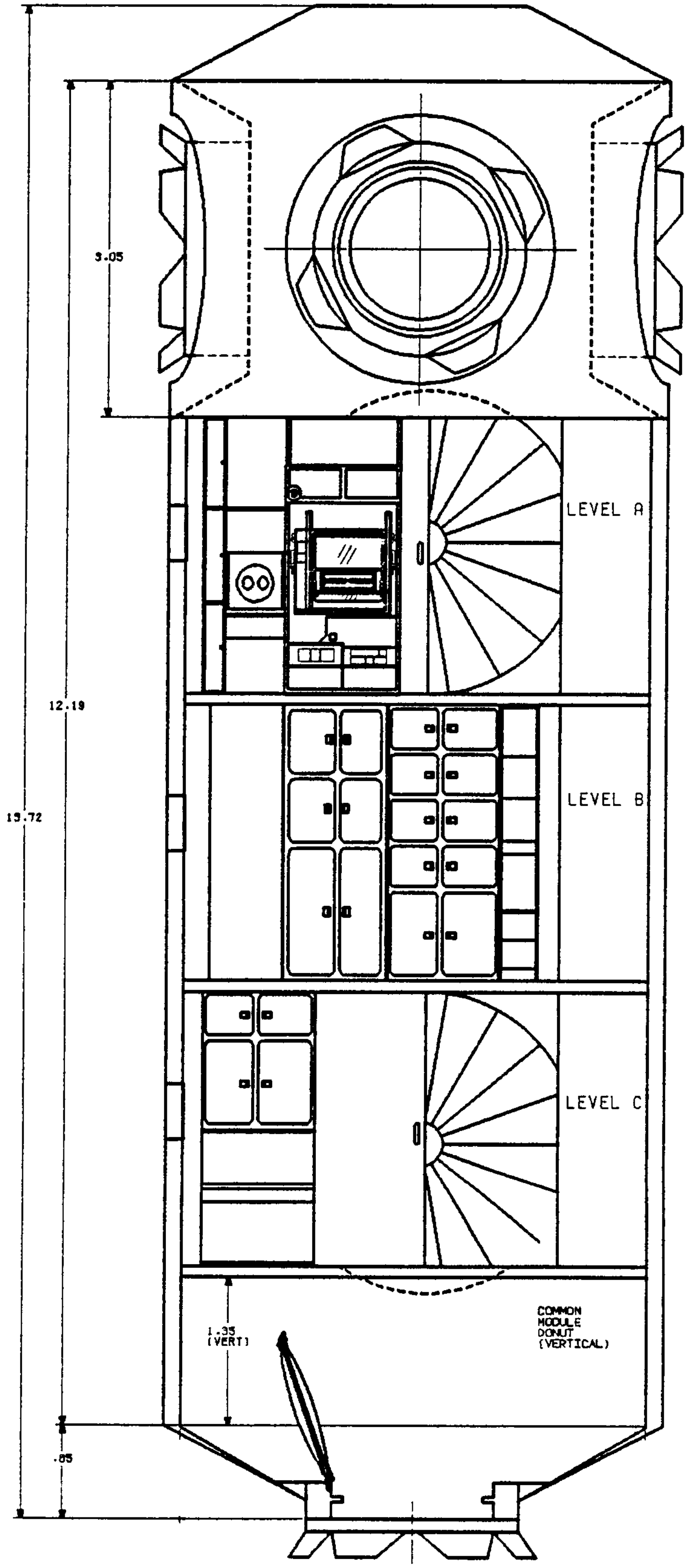
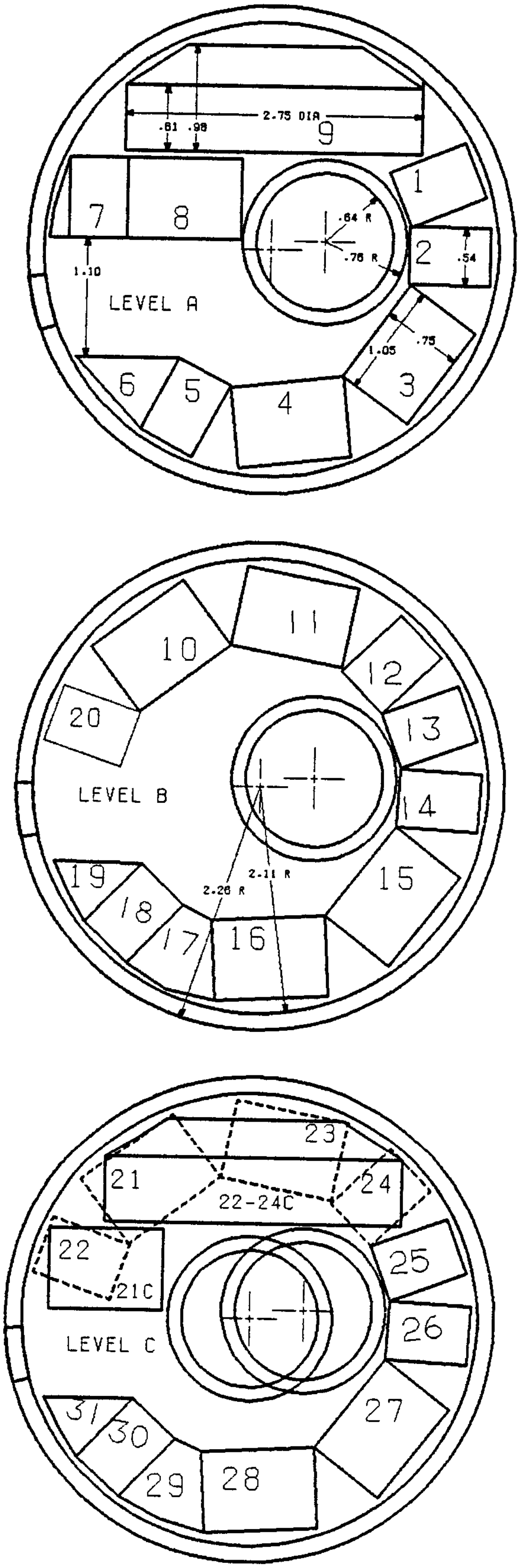


Figure 4-15 Option #7A.
Full Lab with second Centrifuge or Minilab Options



PACK NUMBER	RACK VOLUME (CUBIC M)	EQUIPMENT
1	1	CENTRIFUGE CONTROLS(#63). STORAGE.
2	1	RODENT STANDARD HOLDING FACILITY (#52).
3	2	CAGE WASHER (*98). SPECIMEN FOOD AND WATER (*96,97). STORAGE.
4	2	RODENT BREEDING HOLDING FACILITY (#53).
5	1	RODENT STANDARD HOLDING FACILITY (#52A).
6	0.5	STORAGE. PH/ION ANALYZER (#208). OSCILLOSCOPE (*207). MICROSCOPES (*). PRIMATE KIT (*205).
7	1	HAND WASHER (#100).
8	2	GENERAL PURPOSE WORK STATION (#11). DISSECTION KIT(*124). SPECTROPHOTOMETER (*206). MASS SPEC/GAS ANALYZER (*163). ANIMAL MONITORING (*203).
9	3.5	2.75 M DIA ARTIFICIAL GRAVITY CENTRIFUGE (#63).
10	2	LIQUID WASTE STORAGE (*92).
11	2	SOLIDS WASTE STORAGE (*93).
12	1	INCUBATOR CO2(*202). EGG INCUBATOR (*76). CELSS (*90). FREEZER (*45A).LABORATORY CENTRIFUGE(*28).
13	1	PLANT RESEARCH FACILITY (*81).
14	1	REFRIGERATOR/FREEZERS (*44.45). ENVIRONMENTAL MONITOR (*142). PHYSIOLOGICAL AMPLIFIER (*143). DOSIMETER (*125). SMALL MASS MEASUREMENT (*112).
15	2	DATA SYSTEM (*33-36). COMPUTER (*51). STRIP CHART RECORDER (*162). MICROPROCESSOR (*209). VIDEO CAMERA AND RECORDER (*141).
16	2	LARGE PRIMATE HOLDING FACILITY (*58). SPECIMEN FOOD AND WATER (*96A.97A).
17	1	STORAGE.
18	1	ADDITIONAL RODENT HOLDING FACILITY (*52B).
19	0.5	STORAGE.
20	1	METABOLIC FACILITY (*).
21	2	21C CENTRIFUGE CONTROLS. STORAGE. / 21R
22	1	22C / 22R MINILAB OR EXPERIMENT SPECIFIC EQUIPMENT
23	2	23C OPTIONAL SECOND 2.75 M DIAMETER ARTIFICIAL GRAVITY CENTRIFUGE(*63A) / 23R
24	1	24C / 24R
25	1	STORAGE.
26	1	2 REFRIGERATOR/FREEZERS (*44A.B). FREEZER (*45B).
27	2	ADDITIONAL PLANT RESEARCH FACILITY (*81A).
28	2	STORAGE.
29	1	STORAGE.
30	1	STORAGE.
31	0.5	STORAGE.

Figure 4-16 Equipment for Option #7A

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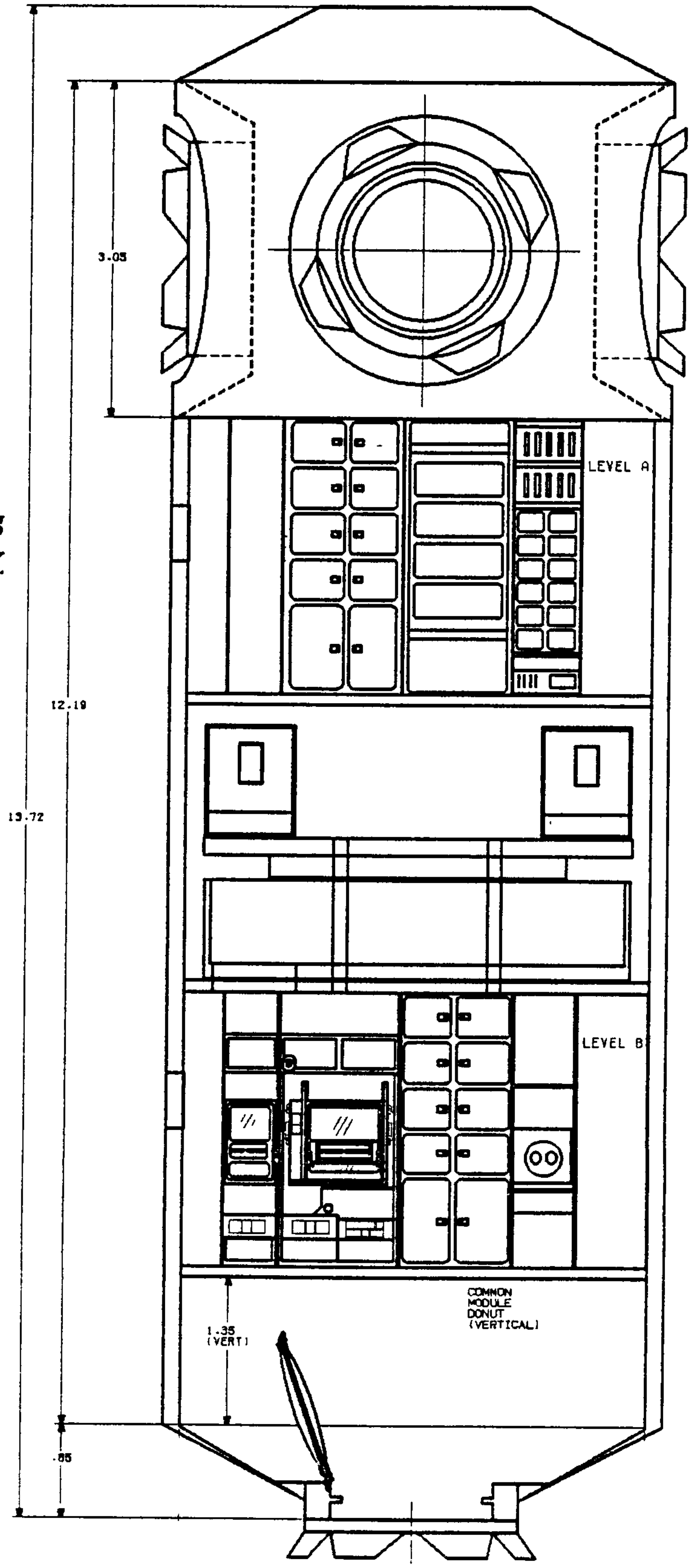

Figure 4-17 Option #8 Full Lab with Large Centrifuge

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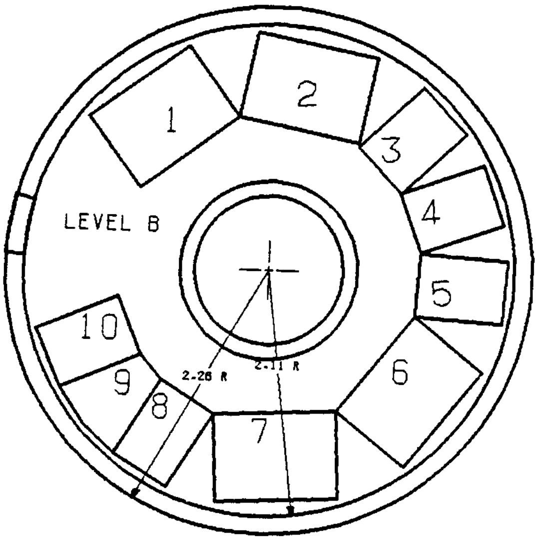

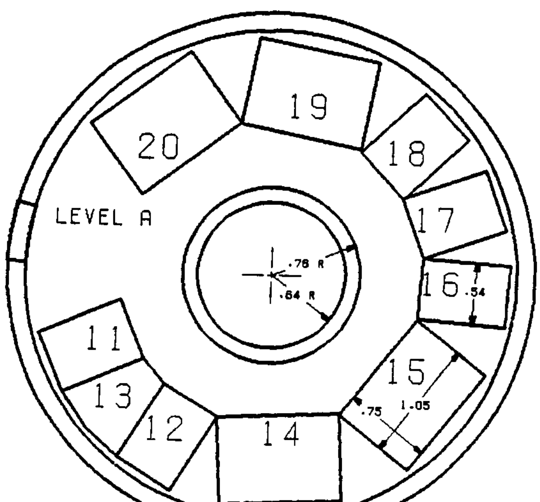

RACK NUMBER	RACK VOLUME (CUBIC M)	EQUIPMENT
1	2	GENERAL PURPOSE WORK STATION (#11). DISSECTION KIT(*124). SPECTROPHOTOMETER (*206). MASS SPEC/GAS ANALYZER (*163). ANIMAL MONITORING (*203).
2	2	STORAGE.
3	1	HAND WASHER (#100).
4	1	INCUBATOR CO2(*202). EGG INCUBATOR (*76). CELSS (*90). FREEZER(*45A).LABORATORY CENTRIFUGE (*28).
5	1	PLANT RESEARCH FACILITY (*81).
6	2	DATA SYSTEM (*33-36). COMPUTER (*51). STRIP CHART RECORDER (*162). MICROPROCESSOR (*209). VIDEO CAMERA AND RECORDER (*141).
7	2	CAGE WASHER (*98). SPECIMEN FOOD AND WATER (*96.97). STORAGE.
8	1	RODENT STANDARD HOLDING FACILITY (#52A).
9	1	STORAGE. PH/ION ANALYZER (#208). OSCILLOSCOPE (*207). MICROSCOPES (*). PRIMATE KIT (*205).
10	1	RODENT STANDARD HOLDING FACILITY (#52B).
XX	14	3.75 METER DIAMETER SPECIMEN RESEARCH CENTRIFUGE.
11	1	CENTRIFUGE CONTROLS (*63). STORAGE.
12	1	PLANT RESEARCH FACILITY (*81A).
13	1	REFRIGERATOR/FREEZER (*44A). ENVIRONMENTAL MONITOR (*142). PHYSIOLOGICAL AMPLIFIER (*134). DOSIMETER (*125). SMALL MASS MEASUREMENT (*112).
14	2	STORAGE.
15	2	RODENT BREEDING HOLDING FACILITY (*153).
16	1	REFRIGERATOR/FREEZERS(*44B.45B). SPECIMEN FOOD AND WATER(*96A.97A).
17	1	METABOLIC HOLDING FACILITY.
18	1	RODENT STANDARD HOLDING FACILITY (*52C).
19	2	LARGE PRIMATE HOLDING FACILITY (*58). STORAGE.
20	2	STORAGE.
	42	TOTAL VOLUME

Figure 4-18 Equipment for Option #8

4.3 INTERNAL LAYOUT OPTIONS - VERTICAL VS HORIZONTAL

Internal layout options directly influence the number and type of experiments to be done and the ability of the crew to complete the experiments that are flown. Table 4-2 presents the results of a trade study comparing vertical-octagon, vertical-square, horizontal-square, and horizontal-back-storage layouts. Vertical arrangements are the preferred internal layout because with similar equipment volumes vertical arrangements are simpler and more uniform with a greater degree of commonality possible.

Vertical module packaging also appears to be more simply arranged allowing more working space as well as higher packaging efficiency resulting in more desirable equipment accommodation than horizontal arrangements. The vertical octagon is the most desirable layout because it maximizes versatility, useable volume, and safety features.

TABLE 4-2 DECISION ANALYSIS FOR HORIZONTAL VS VERTICAL INTERNAL ARRANGEMENTS

Decision Analysis Worksheet

Decision Statement: SELECT INTERNAL ARRANGEMENT WHICH OPTIMIZES SLM OUTFITTING

WANT OBJECTIVES	WT	A VERTICAL-OCTAGON INFO	SC	WT SC	B VERT.-SQUARE INFO	SC	WT SC	C HORIZONTAL-SQUARE INFO	SC	WT SC	D HORIZ.-BACK STORAGE INFO	SC	WT SC
VERSATILITY	10	AISLE WIDTH 2.5M	10	100	2.1M	8	80	2.1M	8	80	1.7M	6	60
USEABLE VOLUME	10	93M³/44 M³ Pr.	10	100	90/41	9	90	89/25	5	50	98/41	9	90
SAFETY	10		10	100		10	100		8	80		8	80
MAINTAINABILITY	7		6	42		8	56		8	56		10	70
CREW PRODUCTIVITY	7	AISLE 2.5	10	70	2.1	8	56	2.1	8	56	1.7	6	42
SCARRING FOR GROWTH	5	8 UTILITY RUNS	10	50	4 UTIL	5	25	4	5	25	4	5	25
WEIGHT	4		8	32		8	32		10	40		9	36
ISOLATION	3		10	30		10	30		4	12		4	12
PERFORMANCE	2		10	20		5	10		5	10		5	10
EXTERNAL INTERFACE	1		5	5		10	10		10	10		10	10
FUNCTIONAL PARTIONING	1		10	10		10	10		5	5		5	5
TOTAL WT SC				559			499			424			440

TOTAL ADVERSE CONSEQUENCES RISK FACTOR

COMPARE AND CHOOSE BEST BALANCED ALTERNATIVE

4.4 SUBSYSTEMS

4.4.1 Electrical Power and Standard Interfaces

Electrical power and data services for a typical equipment arrangement are shown in Figure 4-19. Detail diagrams of this type were used to assist in defining common requirements for equipment groups and development of candidate common elements for the LSRF including standard interface candidates required to support laboratory equipment shown in Fig. 4-20. The rack standard interfaces are added to individual racks as required to support the contents or activities at that rack.

4.4.2 Secondary Structure - Equipment Mounting Options

The SLM containing the LSRF consists of a common module shell with internal and external structural elements, hard points, and attachment interfaces. In addition to standard racks for attaching lab equipment and stowage, the common module contains secondary structure and network distribution system for life support, data management, electrical power distribution and final conditioning, thermal management and communications.

Internal LSRF outfitting must be compatible with external structural features to facilitate: equipment/specimens/supplies transfer from STS orbiter into the SLM, earth viewing, power, ECLSS, thermal and data management interfaces with the logistics module, and safety egress requirements for crew in emergency situations.

LSRF internal arrangements must be compatible with common module interior characteristics shown below to ensure proper interface during ground and on-orbit assembly activities. Early identification and input of LSRF requirements on common module design will assure smooth integration.

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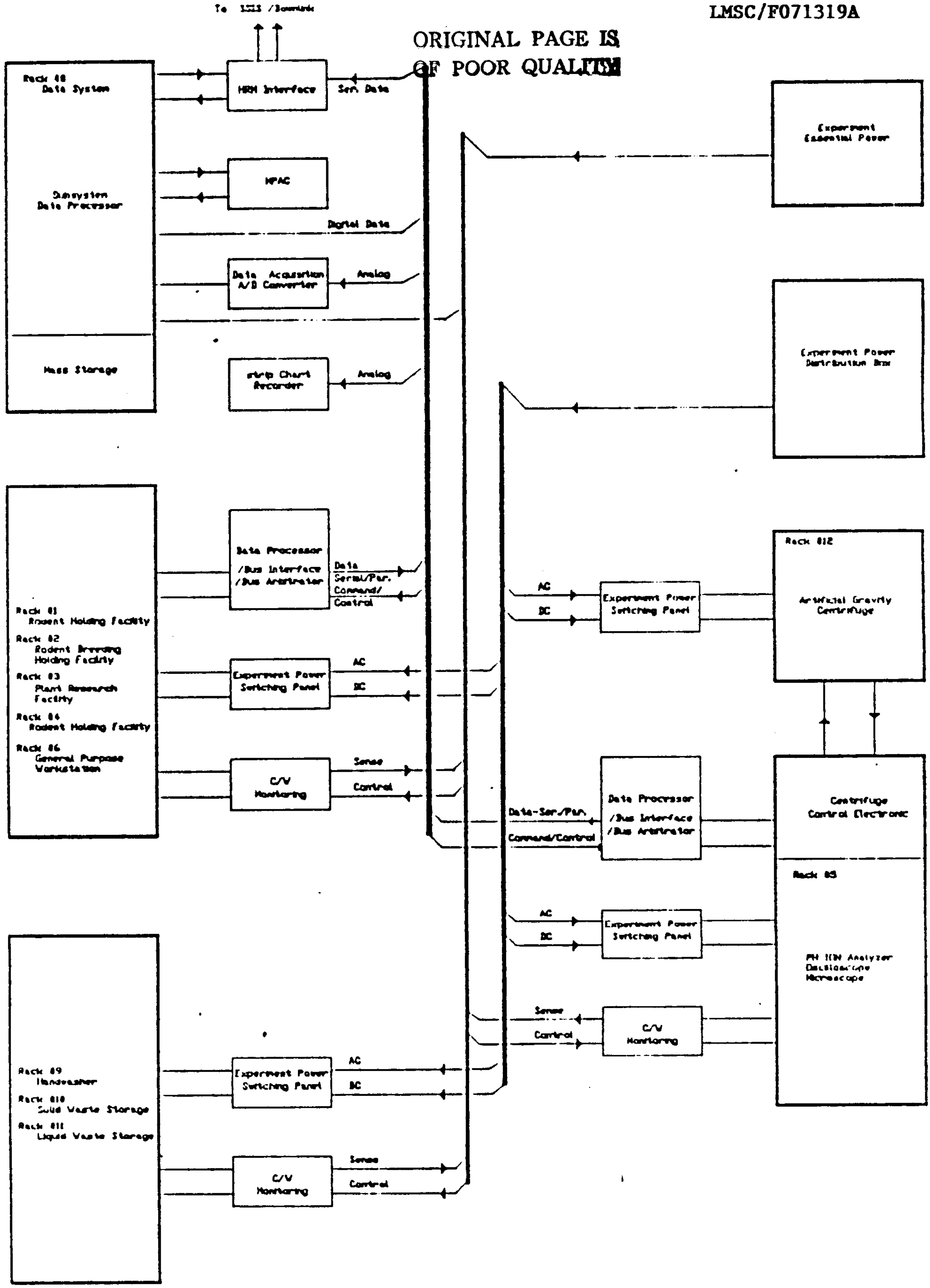
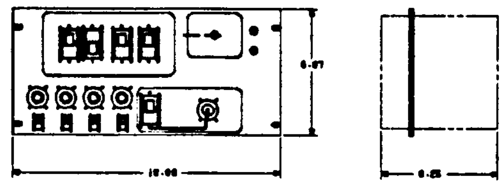
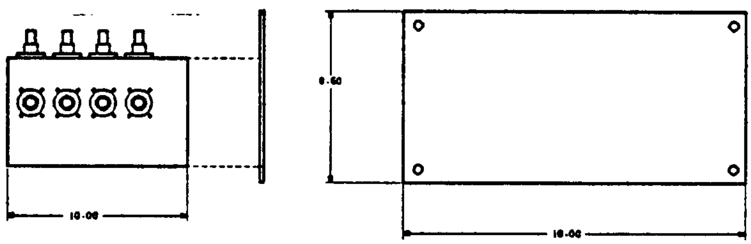


Figure 4-19 Typical Electrical Interfaces - Half Lab

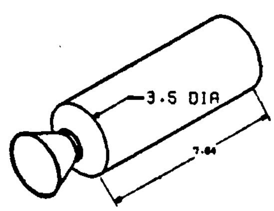
POWER EPSP



DATA PROCESSOR/BUS INTERFACE/BUS ARBITRATOR
MICROPROCESSOR & INTERFACES



FIRE SUPRESSION - LIKELY A FREON BOTTLE TYPE



VIDEO CONNECTOR - CONNECTOR INTERFACE THAT MAY BE INTEGRATED WITH EPSP

INTERCOM - PANEL WITH SPEAKER, MICROPHONE, TO/FROM SWITCHES, JACKS TO PLUG IN HEADSET/VOICE ACTIVATED MICROPHONE.

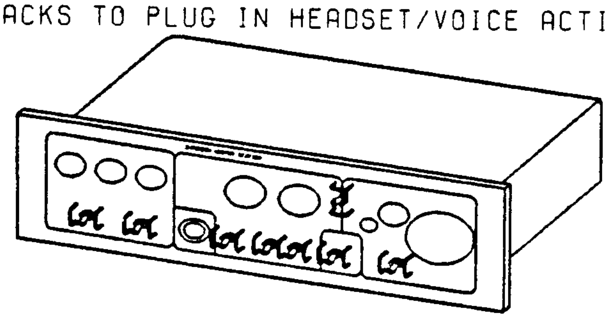


Figure 4-20 Rack Standard Interface Candidates

Key internal structural considerations that LSRF internal arrangements must consider are:

- o Optical fiber, electrical, ECLSS and thermal routing
- o Attachment point for standard racks and containers
- o Attachment point for centrifuge
- o Individual racks and containers
- o Individual equipment items

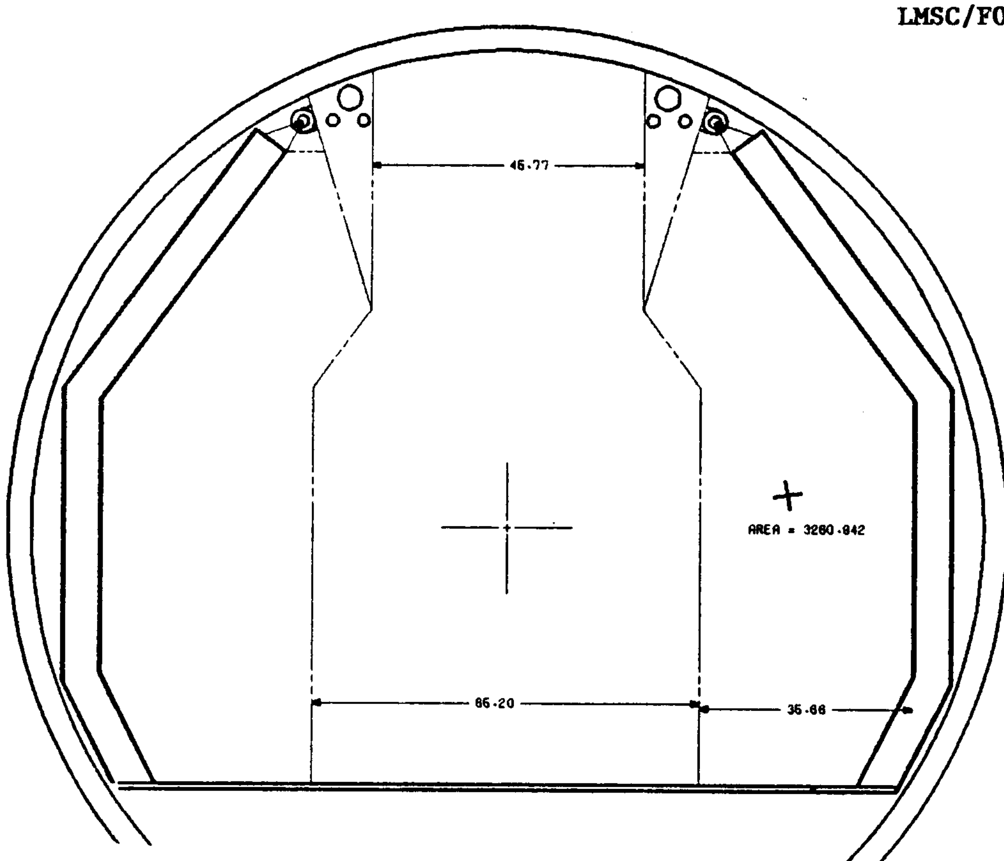
Internal LSRF arrangements must be sufficiently flexible to accommodate an internal/external airlock. In addition, built-in flexibility for optical fiber, electrical and thermal pass-thrus must be included to allow for payload and/or configuration changes during the transition from the Space Station IOC through growth phases.

The equipment mounting system is the means for integrating the laboratory elements into laboratory arrangements. To complete this integration, the mounting system must provide the following:

- o Interfaces for laboratory equipment; common elements which support operation of laboratory equipment and user equipment.
- o Structural integrity for applicable loads and environments.
- o Easy reconfiguration and change-out of ORUs.
- o Accessibility for maintenance, service, and repair of laboratory equipment and of module elements.
- o Commonality with other Space Station elements.

Figures 4-21 and 4-22 show a number of mounting options. Standardization and commonality tend to favor Spacelab-type racks.

Ease of integration and flexible efficient volume utilization might best be served by mounting arrangements shown in Fig. 4-23. Mounting options were not developed in sufficient detail to support final trade-offs.



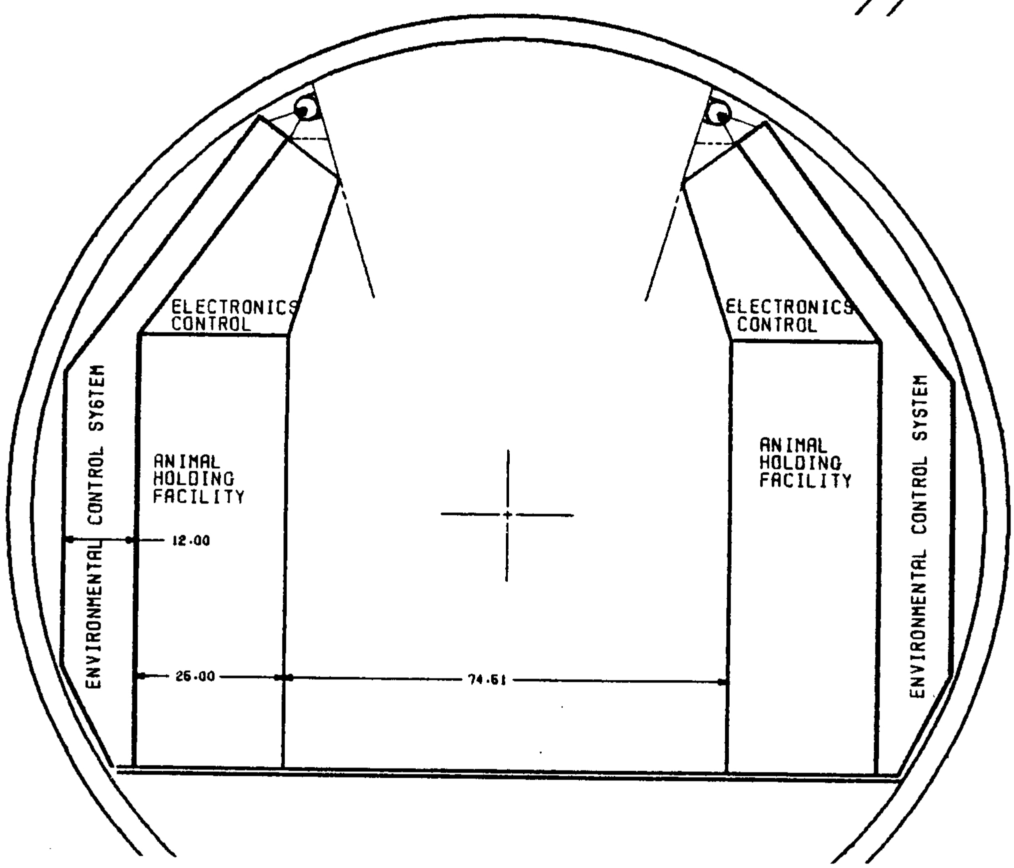


Figure 4-21 Secondary Structure in Module

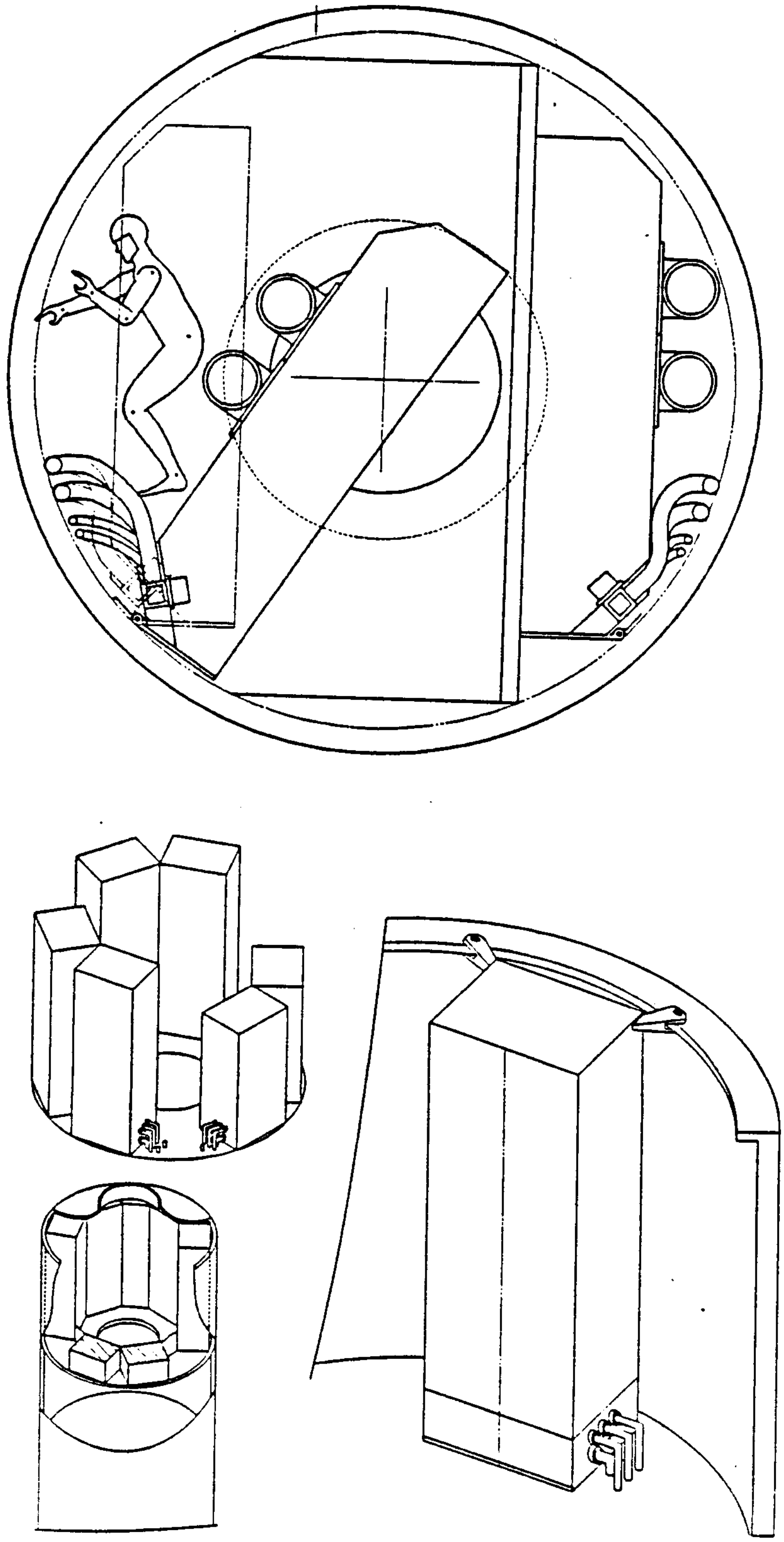


Figure 4-22 Secondary Structure and Wall Access Considerations

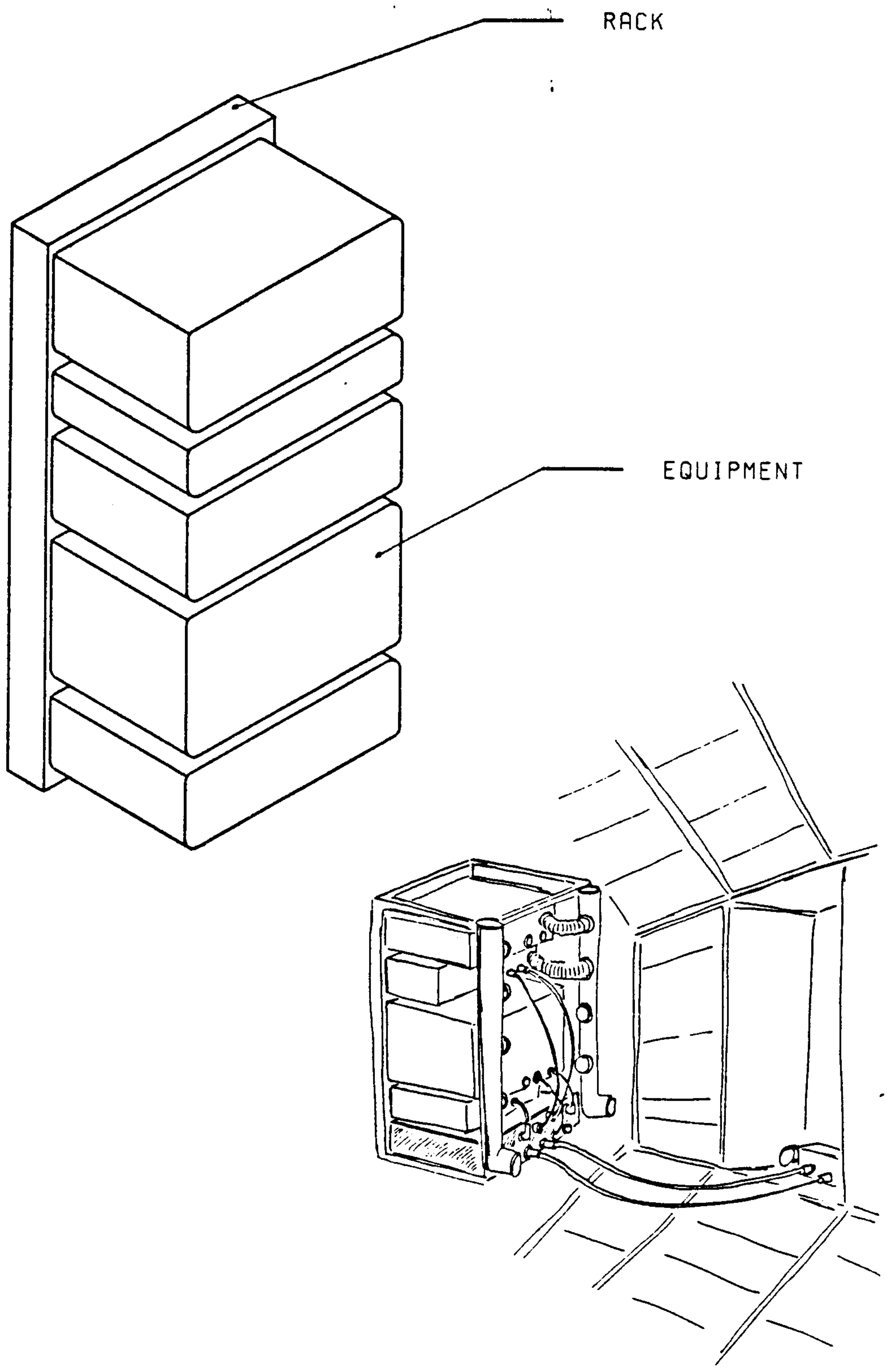


Figure 4-23 Rack Approaches for Transition and Reconfiguration

4.5 CONCEPT EFFECTIVENESS

4.5.1 Internal Layouts For Mission SAAX0307

As shown many internal arrangement layouts are under consideration. The primary objectives and considerations in these options are as follows:

- Volume available for 0-g experiments
- Centrifuge diameter
- Centrifuge volume available
- Centrifuge adaptation to human subjects

The results of a comparison between horizontal and vertical layouts using these considerations is shown in Table 4-5.

TABLE 4-5 EVALUATION OF LAYOUT OPTIONS (HALF LAB)

LAYOUT OPTION (#)	VOL. AVAIL. 0-G EXPTS.	CENTRIFUGE DIAMETER (M)	CENTRIFUGE VOL. AVAIL.	ADAPTABLE TO HUMAN	OPTION OVERALL RANKING
HORIZ (1)	CLOSE TO MINIMUM	2.75	MINIMUM	NO	4-LOWEST
HORIZ (2)	MINIMUM	3.75	MAXIMUM	YES	2
VERT (3)	MAXIMUM	2.75	MINIMUM	NO	3
VERT (4)	CLOSE TO MAXIMUM	3.75	MAXIMUM	YES	1-HIGHEST

Evaluation of layout options for the combined laboratory (Mission SAAX 0307) suggests that option 4, the vertical layout utilizing the 3.75m centrifuge, is the preferred option principally because the vertical arrangement provides maximum volume for 0-g experiments and for centrifuge integration and because the large centrifuge can accommodate human subjects.

4.5.2 Internal Layouts For Mission SAAX 0302

An approach similar to that used for comparing layout options for Mission SAAX 0307 was used to compare Mission SAAX 0302 layouts. Results of the comparison are shown in Table 4-6.

TABLE 4-6 EVALUATION OF LAYOUT OPTIONS (FULL LAB)

LAYOUT OPTION (#)	VOL. AVAIL. 0-G EXPTS. RANKING	CENTRIFUGE DIAMETER (M)	CENTRIFUGE VOL. AVAIL. RANKING	ADAPTABLE TO HUMAN	OPTION OVERALL RANKING
HORIZ (5)	2	2.75	4-LEAST	NO	6
HORIZ (6)	6-LEAST	3.75 (DUAL)	1-MOST	YES	2
HORIZ (6)	4	4.0 (SINGLE)	2	YES	3
VERT (7A)	3	2.75 + 2.75	3	NO	4
VERT (7)	1-MOST	2.75	4-LEAST	NO	5
VERT (8)	5	4.0 (DUAL)	1-MOST	YES	1

Evaluation of layout options for the dedicated animal plant laboratory (Mission SAAX 0302) suggests that the vertical layout option #8 is favored because it provides the greatest volume for the large dual-rotor centrifuge despite the low volume available for 0-g experiments.

4.5.3 Transitioning From Mission SAAX 0307 To Missoin SAAX 0302

Operationally, transitioning from the combined laboratory (SAAX 0307) to the dedicated plant-animal lab (SAAX0302) should minimize equipment changeout as much as possible. Given this operational constraint, it is recommended that the combined lab grow to become the dedicated animal-plant lab leaving the centrifuge in place. The newly-launched module then would be the dedicated human research facility (SAAX 0303).

The reason for this recommendation is as follows. Assume that Mission SAAX 0307 contains a specimen centrifuge and that at transition a new module is placed in orbit. If the new module is to become a dedicated animal and plant facility, the centrifuge would have to be dismantled and moved from the SAAX 0307 module to the new module or left in what will become the dedicated human research facility. Neither option is desirable. Moving the centrifuge seems cumbersome and inefficient given its size and configuration. Leaving the centrifuge in the human research facility utilizes space that should be dedicated to human research equipment and requires specimen transitioning to the centrifuge from animal holding facilities located in another module. This transitioning process is inefficient and potentially impacts operational timelines for animal-plant experiments.

SECTION 5
SUBTASK 3.3 PROGRAMMATICS

5.1 WORK BREAKDOWN STRUCTURE AND DICTIONARY

The Work Breakdown Structure (WBS) for the LSRF is detailed in Figs. 5-1. and 5-2. This WBS represents an updated version of the WBS presented in the December 1984 report and corresponds to WBS elements presented in the Space Station RFP. Figure 5-1 shows WBS levels 1 through 4. WBS elements 1.0 through 7.0 address common module end items from Work Package 01 that must be enhanced to achieve an operational LSRF by IOC. Items 8.0 through 21.0 address LSRF operational activities and associated hardware required for IOC. WBS level 5 items are shown in Fig. 5-2. Definition for each WBS level 4 and 5 element follows.

5.1.1 WBS DICTIONARY

Structure. Consists of all structure that bridges between common module hardpoints and the structural interfaces of equipment in all other groupings. Includes primary and secondary structure, mechanisms, tanks (pressurized and unpressurized), and subsystem engineering.

Thermal Control. All thermal and thermoelectric equipment. Includes radiators, insulation, liquid cooling systems, gas cooling systems, sensors and controls, heat pipes, thermionics, cold plates, and subsystem engineering.

Power. All electrical power equipment including power storage, distribution, conditioning, regulation and control, and subsystem engineering.

Environmental Control and Life Support. Consists of any required modifications to the common module ECLSS and any additional ECLSS items required to support the life science hardware. Includes internal contamination control, temperature and humidity control, pressure and atmospheric composition monitoring and control, ventilation and cabin air distribution, food and potable water supply, waste management systems, trash collection and disposal, equipment and module cleaning and subsystem engineering.

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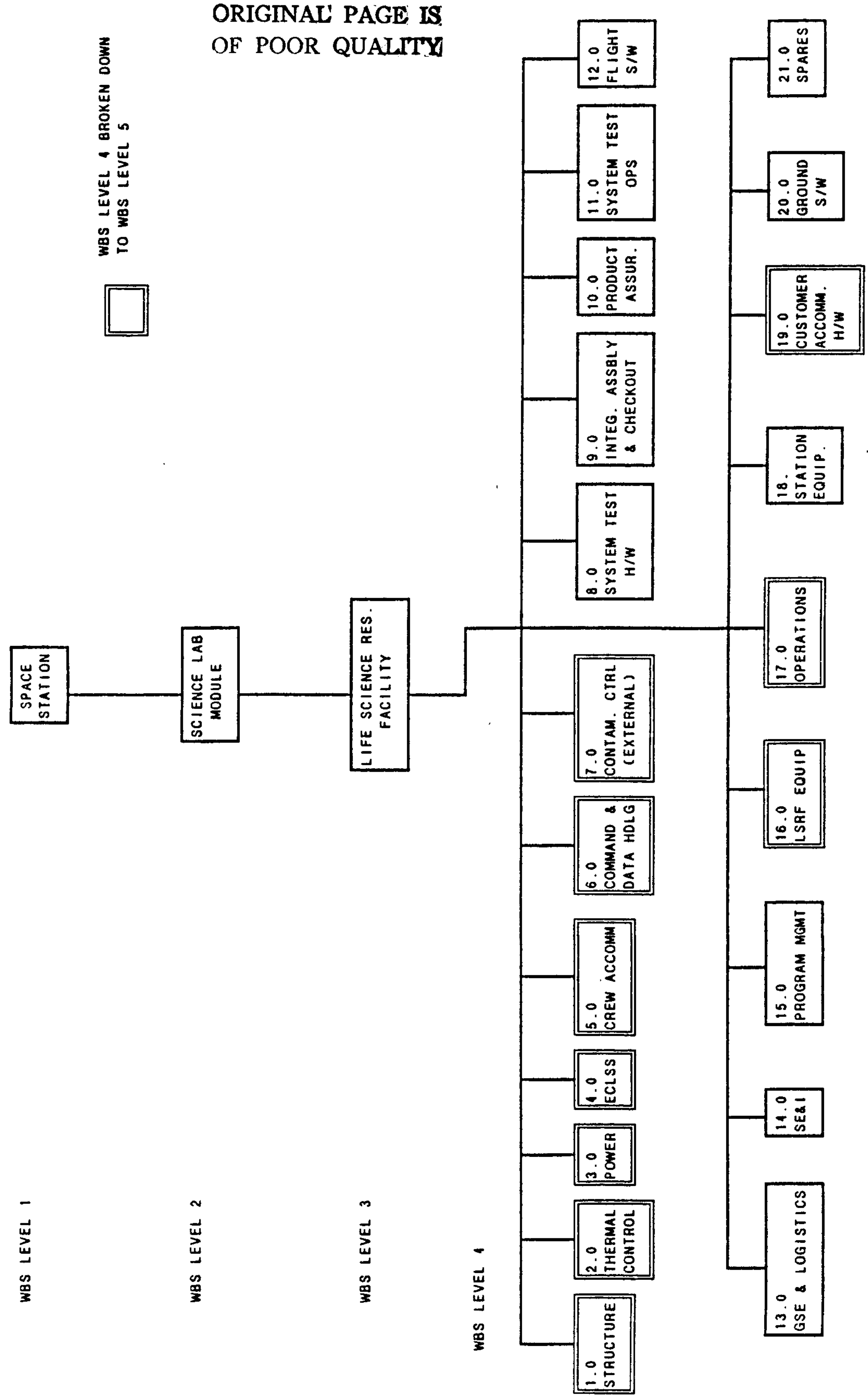


Figure 5-1 Work Breakdown Structure

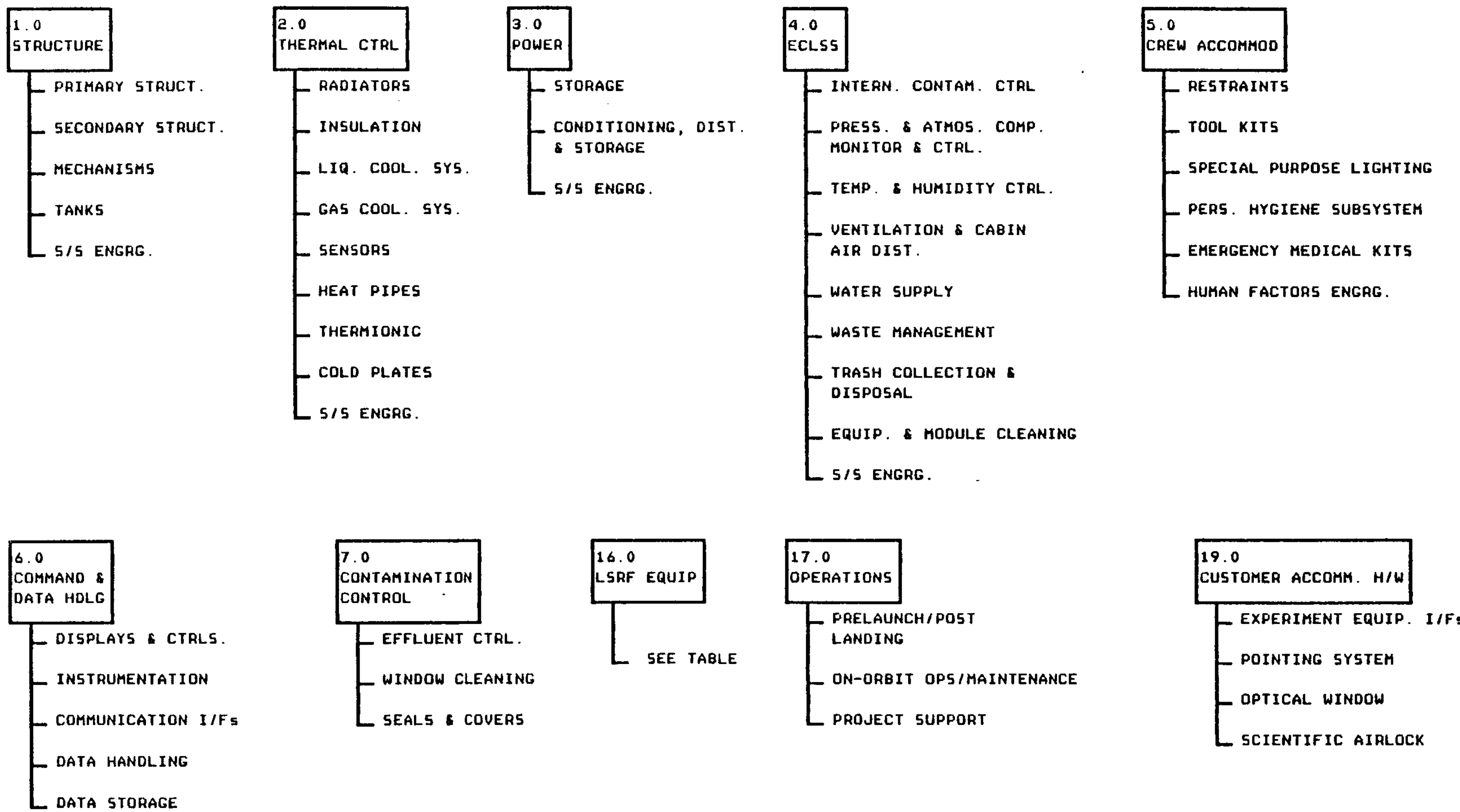


Figure 5-2 Work Breakdown Structure Level 5

and subsystem engineering.

Crew Accommodations. Consists of personnel restraints, tool kits, special purpose lighting, personal hygiene subsystem, emergency medical kits, and human factors engineering.

Command & Data Handling Subsystem. Consists of data processing, display, entry, memory, peripheral equipment, data bus, and interfaces with the instrumentation and SSIS. Includes displays and controls, instrumentation, communications interfaces, command and data handling, data storage, and subsystem engineering.

Contamination Control. Consists of external contamination control including effluent control, window cleaning apparatus, and shields and covers.

System Test Hardware. Consists of equipment items used for qualification, acceptance and other testing activities. Includes equipment used for mechanical, RF, electrical, thermal and vacuum/thermal test, alignment and mass properties measurement equipment, and equipment interface simulation equipment.

Integration, Assembly & Checkout. Consists of integration and assembly hardware, checkout consoles and supporting hardware, design maintenance and liaison, and tool planning, design, and fabrication.

Product Assurance. Consists of all efforts to support safety, reliability, quality assurance, and maintainability activities.

System Test Operations. Consists of the conduct of all systems testing of laboratory equipment. Includes electrical, vibration and acceleration, thermal, EMI, EMC, alignment, calibration, thermal vacuum and acoustic tests and simulation modeling.

Flight Software. Consists of the generation and testing of all software for inflght application. Includes software for data handling and processing, command, communication, applications interface, fault isolation, and BITE.

Ground Logistics Support Equipment. Consists of equipment required to checkout, handle and transport all material and specimens during inflight, postflight and inflight operations.

Systems Engineering & Integration. Consists of effort required to conduct all SE&I activities. Includes hardware development planning, configuration control, mission analysis, interface requirements, specifications, engineering data, and engineering analyses.

Program Management. Consists of effort required to conduct all program management activities. Includes project management and coordination, coordination planning and scheduling, controls, subcontractor/vendor liaison, management data, reviews, and design to cost.

General Purpose Facilities and Equipment. Consists of equipment required to conduct and support life science experiments. Includes module specific and other science equipment.

Operations. Consists of all operations and procedures associated with the general functions of the science laboratory except for specific experimental prototcols. Includes training, logistics, airborne support equipment, maintenance and servicing, mockups, ground operations (preflight, inflight and postflight), flight operations and recovery.

Station Equipment. Consists of secondary equipment required to be housed within the laboratory. Includes safe haven, secondary controls, lighting, caution and warning, fire detection and suppression equipment, and work stations.

Customer Accommodation Hardware. Consists of equipment to support generalized science experiment requirements in the laboratory. Includes electrical, data and thermal interfaces for experiment equipment. Does not include experiment unique equipment.

Ground Software. Consists of the generation and testing of all software required for ground operations. Includes software for system test, inflight verification and checkout, data handling and processing, telemetry and command, communications, applications interfaces, and real-time on-orbit interface.

Spares. Consists of initial and production spares for hardware items. Includes batteries, filters, and light bulbs.

5.2 TECHNOLOGY DEVELOPMENT REQUIREMENTS

Technology development activities play an integral part in the development of a fully operational LSRF that is compatible with other Space Station elements. The following section provides detailed discussions of a Variable Gravity Research Centrifuge (VGRC), Metabolic Measurement System (MMS), and a Cage Washer. These technology development areas were selected for study after an evaluation of experimental protocols and equipment lists presented in the following sources:

- Space Station Life Sciences Research Facility Technology Assessment and Technology Development Plan: Volume II Experiment Technology Requirements and Volume III Equipment Information Catalog--Prepared by McDonnell Douglas, MDC H0743, September 1983

- Ames Research Center report "Life Sciences Research and the Science and Applications Space Platform"

  "Experiments Derived from the 1982 Life Science Workshops"

Criteria for selecting these technology areas included: applicability to the widest range of LSRF experimental and operational activities, enhancement of human productivity, and impact on overall LSRF design. Detailed discussions presented below address the following:

- specific areas within each technology requiring additional study
- advances required to fully develop the technology

5.2.1 Variable Gravity Research Centrifuge (VGRC)

The overall goal of the VGRC program is to develop a preliminary design for a gravity research centrifuge to be incorporated into the LSRF at Space Station IOC. Design issues impacting the centrifuge design are: elimination of vibration and imbalance impacts, cancellation of centrifuge momentum, and elimination of accommodation difficulties due to the centrifuge blocking access to other modules.

Subsystem technology areas that must be developed to address these issues include power and signal transfer, hub and bearing design, specimen habitat interfacing and specimen life support, and experiment servicing.

Power and Signal Transfer Preliminary trades have narrowed potential power transfer techniques to roll rings, slip rings, or rotary transformers. Roll rings are advantageous because they have low drag torque and offer size, weight, friction and capacity advantages over slip rings. However, they may be inapplicable because the long path of travel around the stator decreases their life. In addition, the amount of radial displacement of the centrifuge may require excessive flexing of the roll rings.

Slip rings have been used extensively in the past in similar applications, although they have a higher frictional torque. The springs which hold the brushes in contact may have fatigue problems due to centrifuge radial displacements.

Rotary transformers provide a no-contact means to transfer AC power magnetically. This technique seems attractive since it is analogous to magnetic bearings. In-depth analysis will determine the preferred method for the centrifuge.

Data transfer candidates include roll rings, slip rings, capacitive couplers, and optical slip rings. If roll rings or slip rings are used for centrifuge power transfer, then data transfer using the same technique would be desireable. Capacitive couplers and optical slip rings both appear to be viable for use on the centrifuge. Data transfer analyses concurrent with the power transfer analyses will yield the best data transfer method.

Previous studies concluded that fluid transfer using rotary joints was not feasible. Further investigation concurred with this finding. A seven day supply of specimen drinking water will be carried on the centrifuge and the reservoirs will be changed weekly during specimen habitat cleaning. Air to air heat exchangers are being investigated for thermal control on the centrifuge.

Bearing and Hub Design. The major bearing types considered include roll bearings, oil bearings, air bearings, and magnetic bearings. For the 3.75 m centrifuge with a 1.5 m diameter center pass-through, roll and oil bearings created unacceptable vibration, required high torque, and did not have the needed accuracy. Air bearings were acceptable in the these areas; however, potential manufacturers felt that air bearings of this diameter would be imposssible to construct. Magnetic bearings remained the only feasible approach for centrifuge bearings. The advantages of magnetic bearings are:

- Feasibility
- Virtually unlimited life due to increased reliability and no mechanical contact between rotor and stator
- Operational in a wide variety of temperature ranges and environments
- Less torque than ball and oil bearings
- Electronics provide continuous monitoring and control of the active bearings allowing control of stiffness and damping characteristics as well as the position of the rotor
- Bearings eliminate vibrations using an automatic balancing system resulting in totally silent operation and reduction in the disturbance to the Space Station microgravity environment

Specimen Habitat Interfacing. Specimen environmental control and life support options to determine the degree of support that can be efficiently included on board the centrifuge. Requirements for interfacing centrifuge life support with the lab need to be determined. The interfaces between the specimen habitats and the centrifuge rotor structure will determine the feasibility of generic, multi-purpose interfaces for both plant and animal habitats. Trades determining power and signal transfer methods are needed. Additional trades should consider robotics applications and human research support options.

Experiment Servicing. Experiment servicing in the current context is defined as the capacity of the crew to access specimens attached to the main centrifuge rotor while it is operating. Preliminary investigations found that automated specimen access should be feasible using a second rotor as a service rotor. Figure 5-3 illustrates a concept of a two-arm service rotor that could be spun up to match the

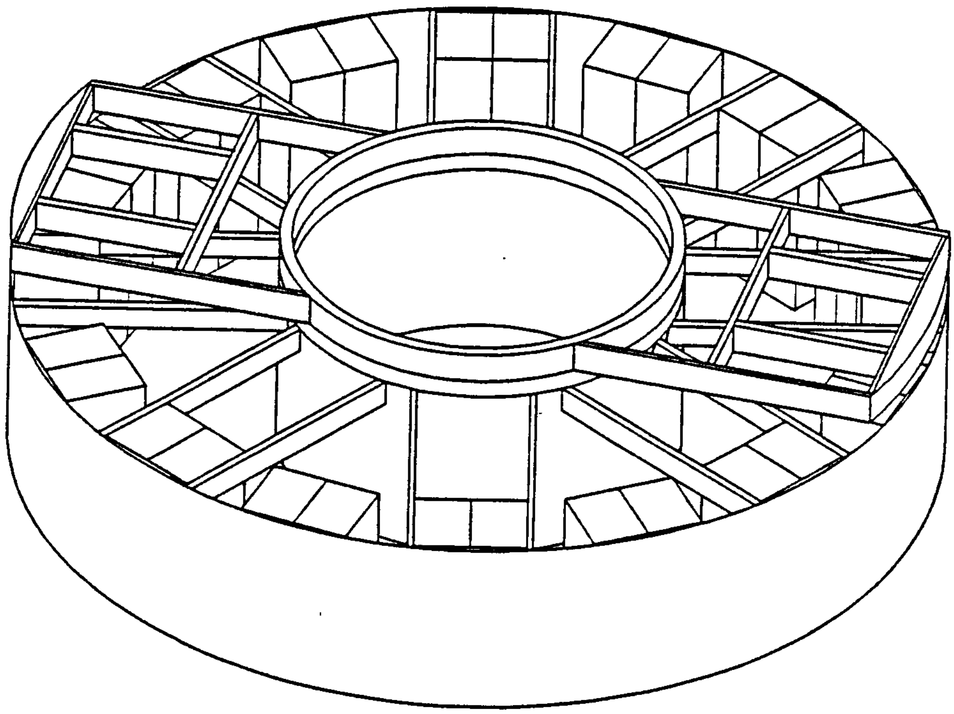


Figure 5-3 Dual Rotor Centrifuge showing Two-Arm Service Rotor

speed of the principal rotor and be aligned with the habitats to be removed. The habitats would be robotically transferred to the service rotor which would spin down. A crew member or a robotic device could then capture the habitat for cleaning or specimen manipulation. This rotor could also support short-term gravity research, acceleration and deceleration studies, and human research.

5.2.2 Metabolic Measurement System (MMS)

The purpose of developing the MMS is to provide a metabolic measurement instrument capable of precisely measuring food and water intake, urine and feces excretion, oxygen consumption and carbon dioxide production in laboratory specimens in a 0g environment. This objective can be met by developing: a feces and urine collection system capable of operating in the presence or absence of gravity, a metabolic gas measurement system capable of monitoring oxygen consumption and carbon dioxide production, food and water distribution systems capable of monitoring food and water consumption, and an environmental control system to regulate ambient temperature and humidity.

Urine and Feces Separator. The basic principles for separating feces from urine in zero-gravity experiments are to capture both feces and urine in a stream of air and carry them away from the animal to a collection device. Feces and urine are collected together without separation, are separated from each other mechanically by differential filtration, or are separated based on a physical property difference between feces and urine. The following collection devices have been investigated by LMSC:

RAHF Feces Collector. This system designed for the Research Animal Holding Facility absorbs urine into phosphoric acid impregnated glass wool layered between screen mesh. This system only collects urine and feces and does not attempt to separate the two.

CERMA Feces Collector. This device designed by CERMA (French medical branch of the Air Force) is similar to the RAHF design concept except the absorbing material is changed automatically.

Conveyer Belt Feces Collector. A wire-mesh screen revolving as a conveyor belt is sized such that feces are captured from the incoming air stream and urine passes through the wire mesh.

None of the above urine and feces collectors satisfy the Space Station requirements. Either urine and feces are not separated or urine is not collected into a vessel that prevented evaporation. Therefore, a new design is needed as follows. Urine and feces are carried by an air stream to the waste collection system. Both waste products hit a rotating disk and are projected radially against an angular rotating section. Urine clings to this material and flows into a collection groove which is connected to collection vials. The feces repel off the angular section and are carried to the feces collection vials. A diagram of the waste separator and collector system is shown schematically in Fig. 5-4 with a lab prototype shown in Fig. 5-5.

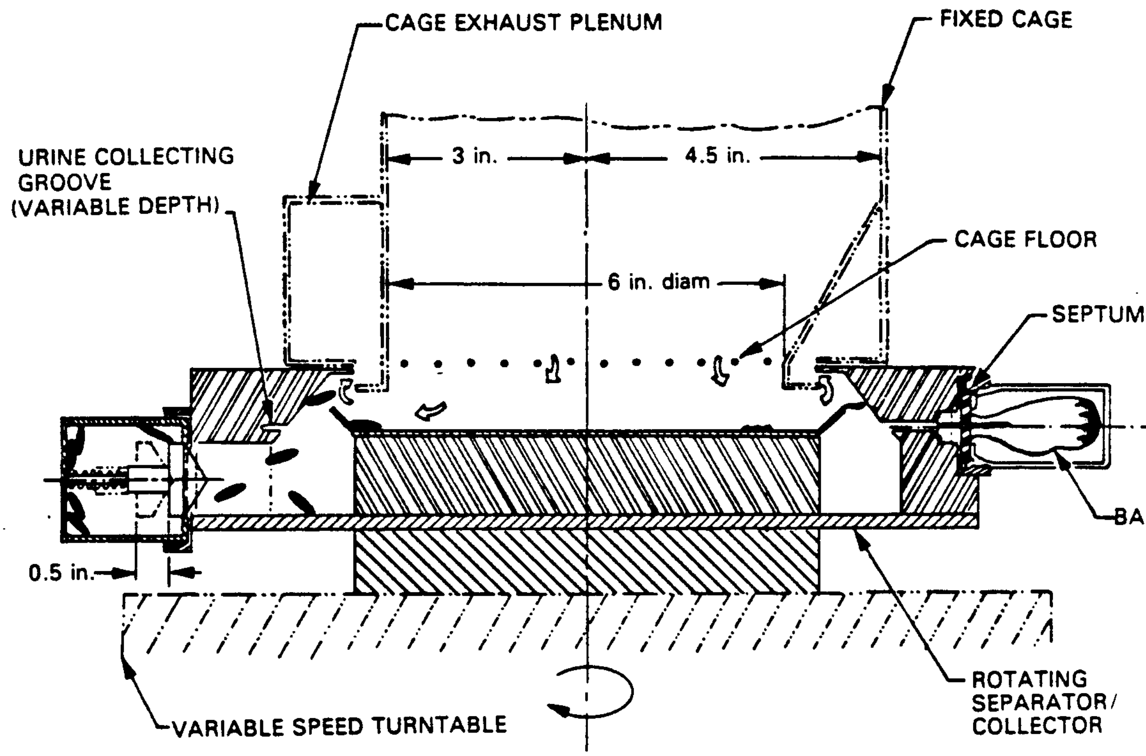


Figure 5-4 MMS Waste Separator and Collector

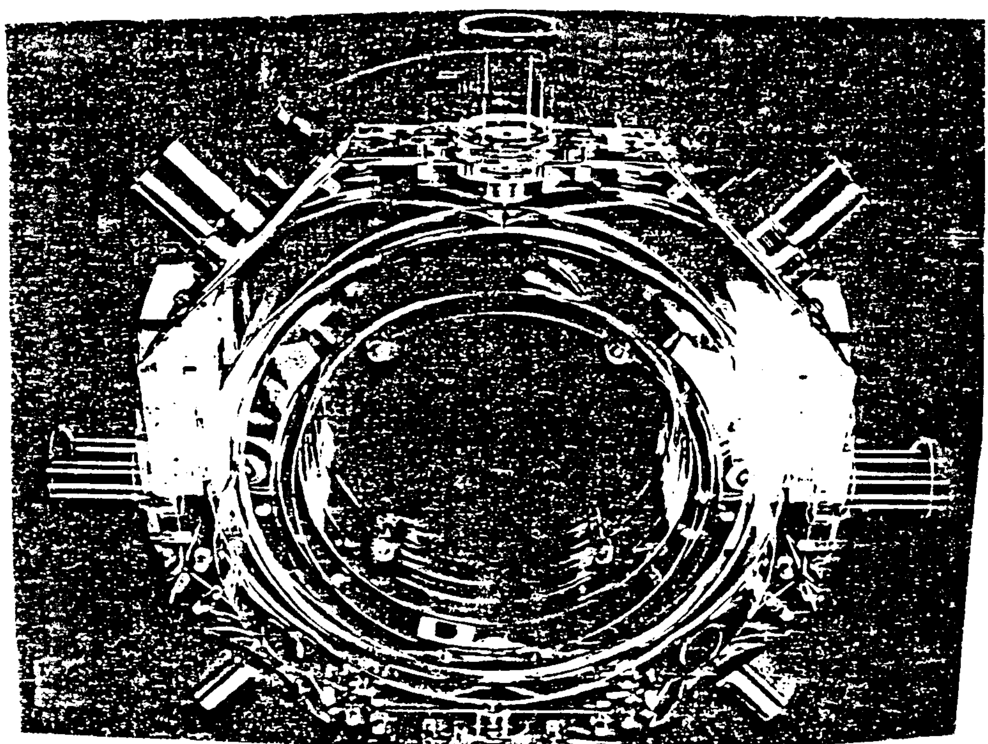


Figure 5-5 MMS Urine-Feces Collector Prototype

This device has been tested in the laboratory. An excellent separation of feces-like material from water was accomplished. However, some advancements to this design are required. Cage air flow should exit through the rotating collector to aid in trans porting waste. Also, experiments have shown that a hydrophobic surface on the rotating disk is preferred. Additional liquid collection grooves are suggested as back up to prevent some urine from entering the feces collection vial. The ramps leading into the solids collector were shown to be too shallow. Doubling the number of collector units should solve this problem.

Respiratory Gas Measurement Subsystem. Concepts for closed and open systems are shown in Figs. 5-6 and 5-7. The closed MMS requires oxygen supplies, a carbon dioxide scrubber, and internal pressure regulation whereas the open MMS does not. Therefore, complexity of the open MMS is reduced, increasing its reliability. Although internal MMS gas composition cannot be regulated, most metabolic experiments do not require atmospheric conditions that differ from ambient. Furthermore, at IOC no metabolic experiments require varying atmospheric composition.

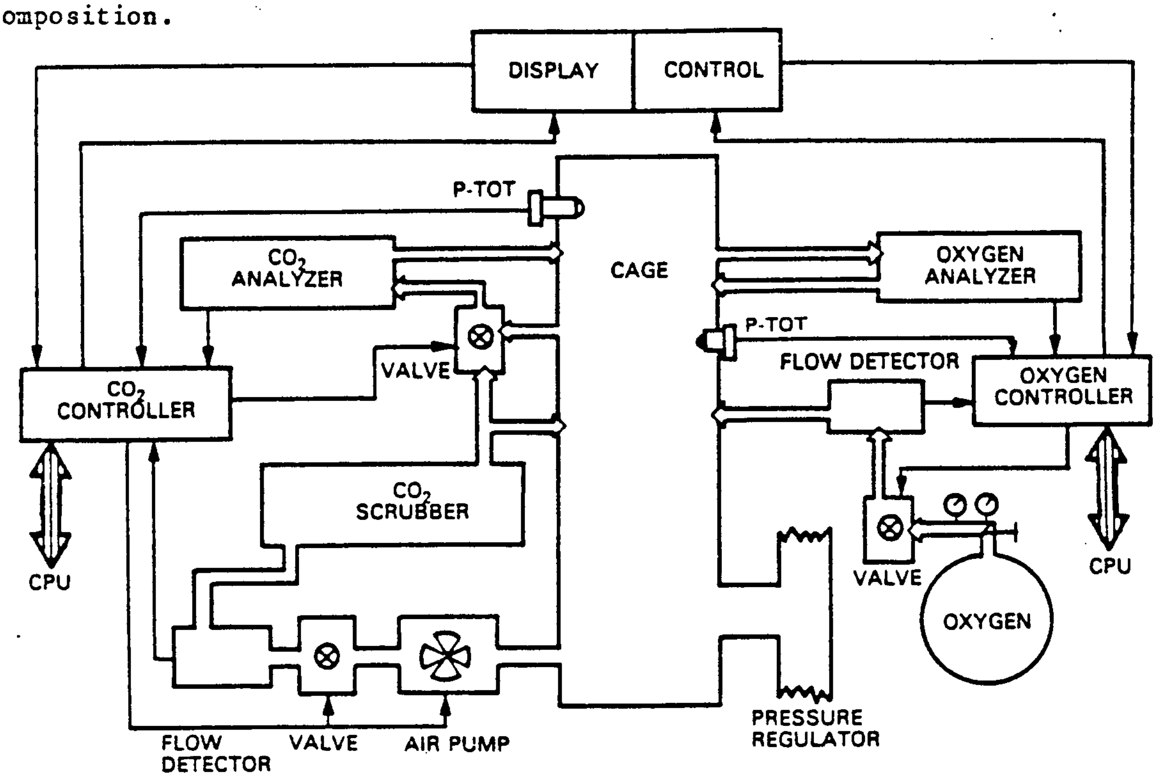
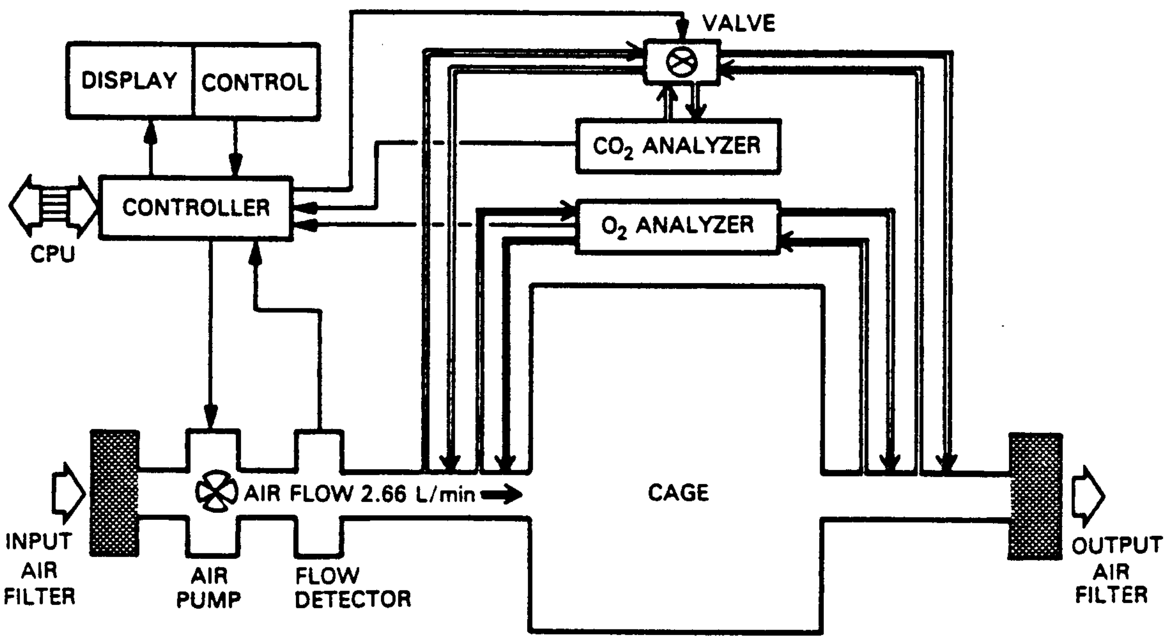


Figure 5-6 Closed Metabolic Measurement System Concept



5.7 Open Metabolic Measurement System Concept

In the open MMS, the ammonia level reaches a steady-state which is not detrimental to the animal, whereas in the closed concept, an ammonia alarm is required. Humidity regulation requires both water vapor injection and extraction for either the closed MMS or open MMS. Temperature regulation is not necessary for the open MMS.

An additional factor that has scientific impact is the minimum length of time a specimen must remain in the MMS. A specimen must remain in the closed MMS for at least 90 minutes to obtain a meaningful measurement. In the open MMS residence time is limited to 30 minutes for meaningful measurements. This residence time delta is significant when considering experimental designs and protocols. Shorter measurement times would allow more specimens to be sampled per day thereby increasing the amount of science conducted per day.

In conclusion, these tradeoffs indicate that the open MMS would be more advantageous than the closed. An experimental model of the open MMS has been designed and is being fabricated for testing at LMSC.

5.2.3 Cage Washer

The overall objective of the cage washer is to reduce crewtime associated with periodic housekeeping and sterilization of specimen cages. Trade studies conducted in 1985 on four candidate systems produced two competitive design approaches, steam cleaning and incineration, capable of achieving the following design parameters:

- Volume: 30" x 40" x 84"
- Power: 2 kW peak
- Cycle criteria: 96 rodent and 8 squirrel monkey cages cleaned per week; 12 rodent or 2 squirrel monkey cages/cycle for 12 cycles per week. Daily use must be limited to 14 hours due to peak solar power availability for a maximum of two cycles/day. All processing of reusables will be performed the day of use

Steam Cleaning. Steam cleaning (see Figs. 5-8 and 5-9) combines low water usage with high power efficiency to create a very attractive cleaning process. Steam cleaning and cage liner systems were the only systems meeting the tentative 2 kW power limit. This is achieved by using a quick-rise heat pipe steam generator. Longer heating times must be integrated into an energy management plan that will accommodate cycle times of only one hour in duration. The system is a proven method of sterilization. Holding times of 30 minutes have been found to be adequate for sterilization of lab equipment at 260^{o}F and will serve as a reference in cycle time allocations. Material safeguards must be taken into account due to the corrosive nature of a repetitive steam environment.

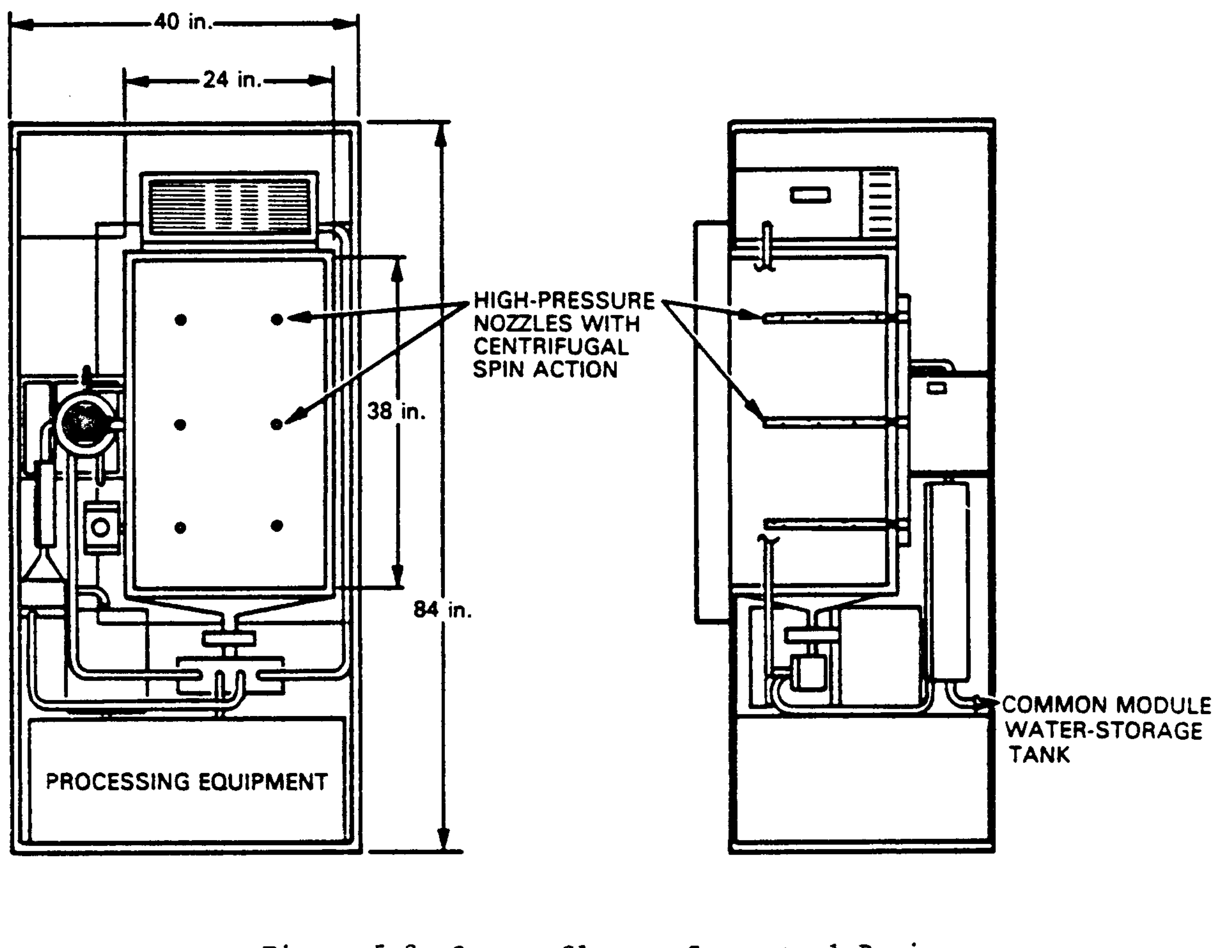


Figure 5-8 Stream Cleaner Conceptual Design

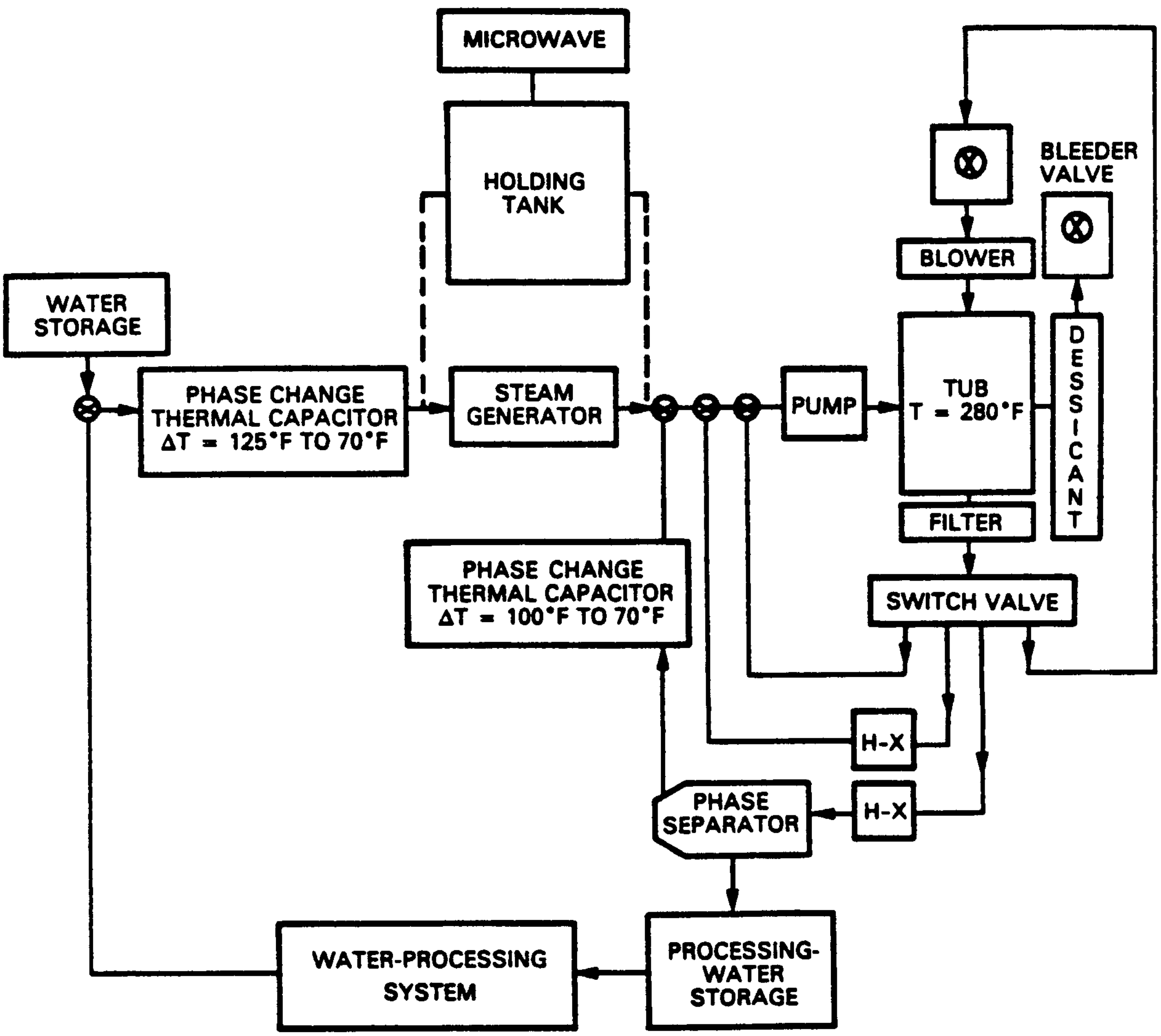


Figure 5-9 St eam Cleaner Schematic

Heat Cleaning. Incineration (see Figs. 5-10 and 5-11) represents the most volume and weight efficient system. Not only does it use comparatively little oxygen in burning the the waste, it also reduces the waste to a negligible mass and volume. A lithium hydroxide (LiOH) absorbent bed would be needed to supplement the ECLSS for processing of harmful oxides, but this would be small relative to a complete water processing system. The process is based on the self-cleaning properties of various porcelain enamels when heated to temperatures greater than 800oF. Material safeguards for heat cleaning would be very important in the hot corrosion environment. Instant sterilization at temperatures of $800^{o}F-1200^{o}F$ is a key factor in its attractiveness. The main drawback of incineration is its high power usage in attaining such temperatures. However, a power-optimized incinerator design would make it more attractive than steam cleaning. Such optimization would include using catalytic oxidizers to lower the oven operating temperature, thermal capacitors, and other heat recovery/reduction technology that is available.

Discarded Options. The spray/wash cleaning system was discarded primarily due to its high water usage and lack of inherent sterilization. The high water usage results in significant resupply needs in order to replace the water lost in processing. The lack of inherent sterilization introduces the need for an electric heater or germicides.

The cage liner option was discarded principally because of its long-term cost. Replaceable cage liners also are not practical because of bioisolation, intricate cage interiors, and automation difficulties.

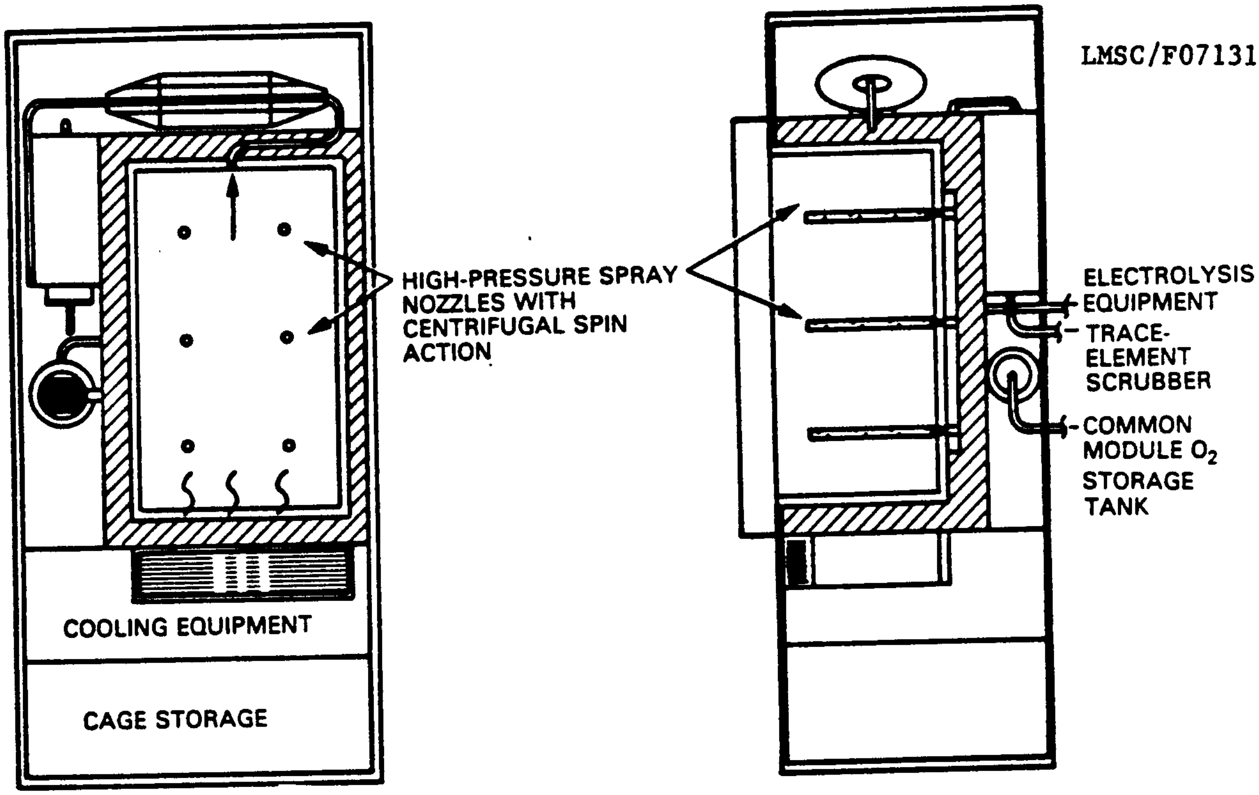


Figure 5-10 Conceptual Design of Heat Cleaner

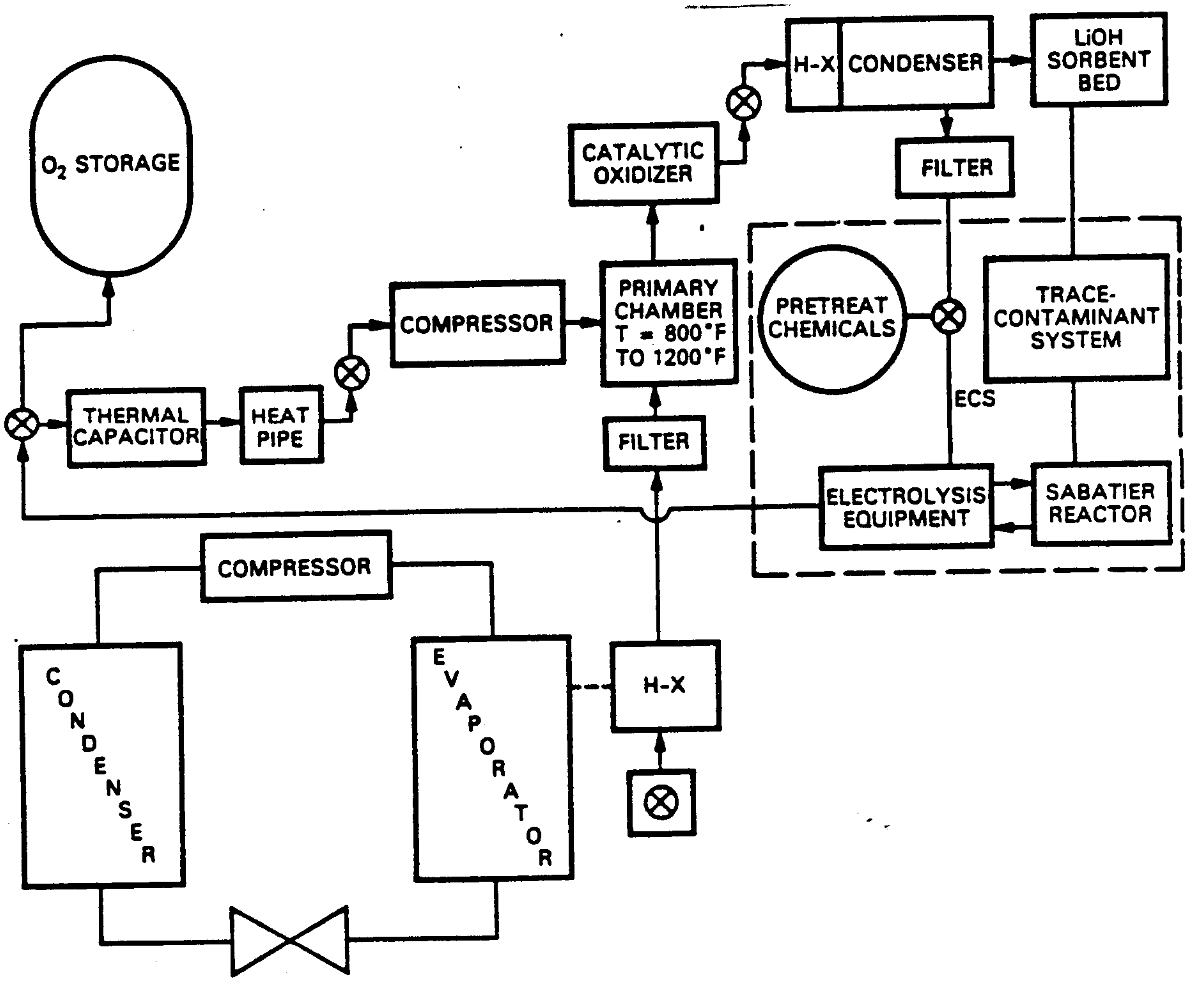


Figure 5-11 Schematic of Heat Cleaner

5.3 COST ESTIMATES

The cost estimates presented in this section address design, development, test and evaluation (DDT&E) and operations costs for IOC (SAAX0307) and FOC (SAAX0302) LSRF. The SAAX0307 represents the LSRF portion or one-half of a Science Laboratory Module (SLM) at IOC. The SAAX0302 estimate is for a dedicated animal-plant vivarium lab which becomes operational two years after IOC. Assumptions and groundrules used to generate cost estimates include the following:

- Costs are in constant year FY 1987 million dollars
- Estimates are for a 45 foot module in a racetrack configuration
- Phase C/D start date is 7/1/87 and IOC date is 1/1/93
- Development approach is protoflight program
- Costs for WBS functional elements and non-flight hardware are generated by applying factors arrived at by engineering judgement
- Weights for life science flight hardware are based on earlier LSRF work, adjusted in some cases to reflect current to reflect current thinking

Cost estimating relationships (CERs) for equipment items are computed on the basis of weight, a complexity factor, and state of development. Cost adjustments within each CER can be made by assigning a complexity factor (FC) for each equipment item. The normal factor is unity. An equipment item deemed to be lower or higher in complexity should be assigned a complexity factor lower or higher than unity.

Equipment costs also can be adjusted relative to development status of the item. For example, an item that has already been developed or exists as flight qualified hardware should not be charged for full development costs. Each equipment item, therefore, must be assigned a number that reflects its development status as it will exist at the start of Phase C/D. Development status definitions and number codes are as follows:

1 Concept
2 Breadboard
3 Prototype

4 Flight prototype
5 Flight qualified
6 Flight tested
7 Issue/Rethink

The estimating model uses five categories of CERs because it is impractical to define CER equations for each piece of hardware. These categories were derived from an RCA PRICE estimating model calibrated against available cost data. The CER categories and CERs for development (CD) and unit costs (CU) are described below.

Category 1. Simple Structures. Pure mechanical hardware with no complicated mechanisms and/or few moving parts. Example: Stowage lockers. Equations were derived using typical RCA PRICE book values:

$CD = .037 x W^{.734} x FC$ $\qquad$ $CU = .0035 x W^{.837} x FC$

Category 2. Simple Electromechanical Hardware. Hardware slightly more complicated than Category 1 but performing functions that are common in ground-based applications. Example: Refrigerator/Freezer. Equations were calibrated against LMSC Refrigerator/Freezer Proposal cost estimate:

$CD = .035 x W^{.760} x FC$ $\qquad$ $CU = .0056 x W^{.854} x FC$

Category 3. More Complicated Electromechanical Hardware: Hardware more complicated than Category 2. Similar type equipment has been developed for space flight. Example: Life support system gas supply. Equations were calibrated against LMSC RAHF life support system cost:

$CD = .087 x W^{.735} x FC$ $\qquad$ $CU = .009 x W^{.850} x FC$

Category 4. Still More Complicated Electromechanical Hardware. Hardware more complicated than Category 3. Development history is limited and applications are more unique than those of Category 3. Example: Research Animal Holding Facility. Equations were calibrated against LMSC RAHF cost:

$CD = .098 x W^{.745} x FC$ $CU = .0095 x W^{.870} x FC$

Category 5. Electronic Equipment. Hardware that is almost pure electronics. Whatever mechanical parts it contains provide only elementary and simple functions. Examples: Transponder, Signal Conditioners. Equations were derived using typical RCA PRICE book values.

$CD = .326 x W^{.730} x FC$ $CU = .0166 x W^{.880} x FC$

Cost estimates for SAAX0307 and SAAX0302 are provided in Table 5-1. The DDT&E cost estimate for SAAX0302 is less than double that for SAAX0307 because SAAX0307 contains expensive lab equipment (e.g. centrifuge and analytical equipment) that will be supplanted by less expensive vivarium equipment during transition to SAAX0302. Annual operating costs for SAAX0302 are estimated to be double those for SAAX0307. Details of the DDT&E and annual operating costs for SAAX0307 and SAAX0302 are provided in the following subsections.

TABLE 5-1 SAAX0307 AND SAAX0302 DDT&E AND OPERATIONS COSTS ($M)

OPTION	DDT&E	ANNUAL OPS
SAAX0307	233.6	31.5
SAAX0302	309.5	63.0

5.3.1 DDT&E COSTS

In the strict sense of the word, a protoflight program resulting in a single lab module should incur no Recurring Production costs, or at least none that can be identified at this time. However, for the purpose of this estimate, recurring and non-recurring costs were calculated for production of each protoflight hardware item. Recurring and non-recurring cost calculations are based upon the RCA PRICE model and are estimated at 19% and 81% of the total DDT&E costs, respectively.

DDT&E costs for SAAX0307 (Table 5-2) and SAAX 0302 (Table 5-3) are estimated from an outfitters point of view and therefore assume that the common module provides ECLSS and utility runs for LSRF equipment interfaces. Items listed in these tables are those necessary to convert the common module to a fully operational life sciences module at IOC.

TABLE 5-2 DDT&E COST ESTIMATE FOR SAAX0307

LEVEL	WBS ELEMENT TITLE	COST(M$) TOTAL	COST(M$) NON-RECURR	COST(M$) RECURR
5	Science Laboratory Module	233.59	189.21	44.38
6	1. Structure	3.16	2.56	0.60
7	1.1 Primary	(2)		
7	1.2 Secondary	2.85		
7	1.3 Mechanisms	0.00		
7	1.4 Tanks (Pressurized & Unpressurized)	0.31		
7	1.5 Subsystem Engineering	(1)		
6	2. Thermal Control	1.26	1.02	0.24
7	2.1 Radiators	(1)		
7	2.2 Insulation	(1)		
7	2.3 Liquid Cooling System	(1)		
7	2.4 Gas Cooling System	(1)		
7	2.5 Sensors & Controls	(1)		
7	2.6 Heat Pipes	(1)		
7	2.7 Thermionics	(1)		
7	2.8 Cold Plate	(1)		
7	2.9 Subsystem Engineering	(1)		
6	3. Power	0.67	0.54	0.13
7	3.1 Power Storage	0.47		
7	3.2 Distribution Conditioning, Regulation & Cont	0.20		
7	3.3 Subsystem Engineering	(1)		
6	4. Environmental Control & Life Support	15.04	12.18	2.86
7	4.1 Contamination Control (Internal)	0.63		
7	4.2 Temperature & Humidity	(1)		
7	4.3 Pressure & Atmospheric Composition,Mon & Cont	3.42		
7	4.4 Ventilation & Cabin Air Distribution	0.84		
7	4.5 Potable Water Supply	2.93		
7	4.6 Waste Management Subsystem	0.38		
7	4.7 Trash Collection & Disposal	3.90		
7	4.8 Equipment & Module Cleaning	2.94		
7	4.9 Subsystem Engineering	(1)		

TABLE 5-2 DDT&E COST ESTIMATE FOR SAAX0307 (Cont'd)

LEVEL	WBS ELEMENT TITLE	COST(M$) TOTAL	COST(M$) NON-RECURR	COST(M$) RECURR
6	5. Crew Accommodations	1.65	1.34	0.31
7	5.1 Restraints(Crew mounted, e.g.,3rd arm)	0.23		
7	5.2 Tool Kits	0.16		
7	5.3 Special Purpose Lighting	0.15		
7	5.4 Personal Hygiene Subsystem	0.35		
7	5.5 Emergency Medical Kits	0.31		
7	5.6 Human Engineering	0.45		
6	6. Command & Data Handling Subsystem	25.43	20.60	4.83
7	6.1 Displays & Controls	9.69		
7	6.2 Instrumentation	0.53		
7	6.3 Communications Interfaces	0.50		
7	6.4 Command & Data Handling	0.53		
7	6.5 Data Storage	14.18		
7	6.6 Subsystem Engineering	(1)		
6	7. Contamination Control (External)	1.03	0.83	0.20
7	7.1 Effluent Control	0.11		
7	7.2 Window Cleaning Apparatus	0.73		
7	7.3 Shields & Covers	0.19		
6	8. System Test Hardware	1.82	1.47	0.35
7	8.1 Mechanical Test Equipment	(1)		
7	8.2 RF Test Equipment	(1)		
7	8.3 Electrical Test Equipment	(1)		
7	8.4 Alignment Equipment	(1)		
7	8.5 Thermal Test Equipment	(1)		
7	8.6 Vacuum Thermal Equipment	(1)		
7	8.7 Mass Properties Measurement Equipment	(1)		
7	8.8 Equipment Interface Simulation	(1)		
6	9. Integration, Assembly & Checkout	4.16	3.37	0.79
7	9.1 Integration & Assembly Hardware	(1)		
7	9.2 Checkout Console & Supporting Hardware	(1)		
7	9.3 Design Maintenance & Liaison	(1)		
7	9.4 Tool Planning, Design & Fabrication	(1)		
6	10. Product Assurance	2.27	1.84	0.43
7	10.1 Safety	(1)		
7	10.2 Reliability	(1)		
7	10.3 Quality Assurance	(1)		
7	10.4 Maintainability	(1)		
6	11. System Test Operations	21.57	17.47	4.10
7	11.1 Electrical	(1)		
7	11.2 Vibration & Acceleration	(1)		
7	11.3 Thermal	(1)		
7	11.4 EMI	(1)		
7	11.5 EMC	(1)		
7	11.6 Alignment	(1)		
7	11.7 Calibration	(1)		
7	11.8 Thermal Vacuum	(1)		
7	11.9 Acoustic	(1)		
7	11.10 Simulation Modeling	(1)		

TABLE 5-2 DDT&E COST ESTIMATE FOR SAAX0307 (Cont'd)

LEVEL	WBS ELEMENT TITLE	COST(M$) TOTAL	COST(M$) NON-RECURR	COST(M$) RECURR
6	12. Flight Software	2.54	2.06	0.48
7	12.1 Data Handling & Processing	(1)		
7	12.2 Command	(1)		
7	12.3 Communication	(1)		
7	12.4 Applications Interface	(1)		
7	12.5 Fault Isolation & BITE	(1)		
6	13. Ground Logistics Support Equipment	9.57	7.75	1.82
7	13.1 Preflight	(1)		
7	13.2 Inflight(Includes ground control ops/POC eqt)	(1)		
7	13.3 Postflight	(1)		
6	14. Systems Engineering & Integration	27.87	22.57	5.30
7	14.1 Hardware Development Planning	(1)		
7	14.2 Configuration Control	(1)		
7	14.3 Mission Analysis	(1)		
7	14.4 Interface Requirements (Subsystem & Software)	(1)		
7	14.5 Specifications	(1)		
7	14.6 Engineering Data	(1)		
7	14.7 Engineering Analyses(Thermal, dynamics, etc.)	(1)		
6	15. Program Management	15.07	12.21	2.86
7	15.1 Project Management & Coordination	(1)		
7	15.2 Planning & Scheduling	(1)		
7	15.3 Controls	(1)		
7	15.4 Subcontractor/Vendor Liaison	(1)		
7	15.5 Management Data	(1)		
7	15.6 Reviews	(1)		
7	15.7 Design to Cost	(1)		
6	16. General Purpose Facilities & Equipment	71.44	57.87	13.57
7	16.1 Module Specific Equipment	30.86		
8	16.1.1 General Purpose Work Station	4.37		
8	16.1.2 Laboratory Centrifuge	0.19		
8	16.1.3 Refrigerator/Freezer(-20 deg)	0.90		
8	16.1.4 Freezer (-70 deg)	0.74		
8	16.1.5 Research Computer	0.88		
8	16.1.6 Cleanup facilities	0.69		
8	16.1.7 Small mass measurement device	0.39		
8	16.1.8 Dissection kit	0.59		
8	16.1.9 Dosimeter	0.75		
8	16.1.10 Video recorder/camera	3.62		
8	16.1.11 Physiological amplifier	2.24		
8	16.1.12 Strip chart recorder	3.32		
8	16.1.13 Gas analyzer/Mass spectrometer	4.90		
8	16.1.14 Spectrophotometer	4.09		
8	16.1.15 Oscilloscope	2.00		
8	16.1.16 pH/Ion analyzer	0.54		
8	16.1.17 Microscope	0.42		
8	16.1.18 Dissection microscope	0.23		

TABLE 5-2 DDT&E COST ESTIMATE FOR SAAX0307 (Cont'd)

LEVEL	WBS ELEMENT TITLE	COST(M$) TOTAL	COST(M$) NON-RECURR	COST(M$) RECURR
7	16.2 Life Sciences Equipment	40.58	32.87	7.71
8	16.2.1 Rodent Standard Holding Facility	7.66		
8	16.2.2 Rodent Artificial Gravity Holding Facility	19.68		
8	16.2.3 Egg Incubator Holding Facility	0.47		
8	16.2.6 Small Plant Holding Facility	4.10		
8	16.2.7 CELSS Holding & Test Facility	3.77		
8	16.2.8 Incubator-CO2	0.90		
8	16.2.9 Animal Physiological Monitoring System	4.00		
6	17. Operations	8.30	6.72	1.58
7	17.1 Training	1.95		
7	17.2 Logistics	0.53		
7	17.3 Airborne Support Equipt (ASE)	4.79		
7	17.4 Maintenance & Servicing	0.40		
7	17.5 Mockups	0.23		
7	17.6 Ground Operations (Pre-, In-, & Post-flight)	0.27		
7	17.7 Flight Operations (Including scheduling)	0.13		
7	17.8 Recovery (End-of-Life Disposal)	TBD		
6	18. Station Equipment	5.27	4.27	1.00
7	18.1 Safe Haven Equipment	0.12		
7	18.2 Secondary Controls Equipment	5.15		
7	18.3 Lighting	(2)		
7	18.4 Caution & Warning	(2)		
7	18.5 Fire Detection & Suppression	(2)		
7	18.6 Work Stations	0.00		
6	19. Customer Accommodation Hardware	5.57	4.51	1.06
7	19.1 Experiment Equipment I/F (Elect,data,thermal)	2.27		
7	19.2 Pointing System	1.22		
7	19.3 Optical Window	0.22		
7	19.4 Scientific Airlock	0.67		
7	19.5 Rapid Specimen Return	1.19		
6	20. Ground Software	7.63	6.18	1.45
7	20.1 System Test	(1)		
7	20.2 Inflight Verification & Checkout	(1)		
7	20.3 Data Handling & Processing	(1)		
7	20.4 Telemetry & Command	(1)		
7	20.5 Communications	(1)		
7	20.6 Applications Interfaces	(1)		
7	20.7 On-orbit Interface (Real time)	(1)		
6	21. Spares	2.27	1.84	0.43
7	21.1 Batteries	(1)		
7	21.2 Filters	(1)		
7	21.3 Light Bulbs	(1)		

(1) Included elsewhere

(2) Part of Common Module

TABLE 5-3 COST ESTIMATE FOR SAAX0302

LEVEL	WBS ELEMENT TITLE	COST(M$) TOTAL	COST(M$) NON-RECURR	COST(M$) RECURR
5	Science Laboratory Module	309.50	250.70	58.81
6	1. Structure	6.32	5.12	1.20
7	1.1 Primary	(2)		
7	1.2 Secondary	5.70		
7	1.3 Mechanisms	0.00		
7	1.4 Tanks (Pressurized & Unpressurized)	0.62		
7	1.5 Subsystem Engineering	(1)		
6	2. Thermal Control	2.52	2.04	0.48
7	2.1 Radiators	(1)		
7	2.2 Insulation	(1)		
7	2.3 Liquid Cooling System	(1)		
7	2.4 Gas Cooling System	(1)		
7	2.5 Sensors & Controls	(1)		
7	2.6 Heat Pipes	(1)		
7	2.7 Thermionics	(1)		
7	2.8 Cold Plate	(1)		
7	2.9 Subsystem Engineering	(1)		
6	3. Power	1.34	1.09	0.25
7	3.1 Power Storage	0.94		
7	3.2 Distribution Conditioning, Regulation & Cont	0.40		
7	3.3 Subsystem Engineering	(1)		
6	4. Environmental Control & Life Support	17.67	14.31	3.36
7	4.1 Contamination Control (Internal)	0.63		
7	4.2 Temperature & Humidity	(1)		
7	4.3 Pressure & Atmospheric Composition,Mon & Cont	3.42		
7	4.4 Ventilation & Cabin Air Distribution	0.84		
7	4.5 Potable Water Supply	5.56		
7	4.6 Waste Management Subsystem	0.38		
7	4.7 Trash Collection & Disposal	3.90		
7	4.8 Equipment & Module Cleaning	2.94		
7	4.9 Subsystem Engineering	(1)		
6	5. Crew Accommodations	3.30	2.67	0.63
7	5.1 Restraints(Crew mounted, e.g.,3rd arm)	0.46		
7	5.2 Tool Kits	0.32		
7	5.3 Special Purpose Lighting	0.30		
7	5.4 Personal Hygiene Subsystem	0.70		
7	5.5 Emergency Medical Kits	0.62		
7	5.6 Human Engineering	0.90		
6	6. Command & Data Handling Subsystem	29.68	24.04	5.64
7	6.1 Displays & Controls	12.91		
7	6.2 Instrumentation	1.06		
7	6.3 Communications Interfaces	1.00		
7	6.4 Command & Data Handling	0.53		

TABLE 5-3 COST ESTIMATE FOR SAAX0302 (Cont'd)

LEVEL	WBS ELEMENT TITLE	COST(M$) TOTAL	COST(M$) NON-RECURR	COST(M$) RECURR
7	6.5 Data Storage	14.18		
7	6.6 Subsystem Engineering	(1)		
6	7. Contamination Control (External)	1.32	1.07	0.25
7	7.1 Effluent Control	0.22		
7	7.2 Window Cleaning Apparatus	0.73		
7	7.3 Shields & Covers	0.37		
6	8. System Test Hardware	2.44	1.98	0.46
7	8.1 Mechanical Test Equipment	(1)		
7	8.2 RF Test Equipment	(1)		
7	8.3 Electrical Test Equipment	(1)		
7	8.4 Alignment Equipment	(1)		
7	8.5 Thermal Test Equipment	(1)		
7	8.6 Vacuum Thermal Equipment	(1)		
7	8.7 Mass Properties Measurement Equipment	(1)		
7	8.8 Equipment Interface Simulation	(1)		
6	9. Integration, Assembly & Checkout	5.30	4.29	1.01
7	9.1 Integration & Assembly Hardware	(1)		
7	9.2 Checkout Console & Supporting Hardware	(1)		
7	9.3 Design Maintenance & Liaison	(1)		
7	9.4 Tool Planning, Design & Fabrication	(1)		
6	10. Product Assurance	3.05	2.47	0.58
7	10.1 Safety	(1)		
7	10.2 Reliability	(1)		
7	10.3 Quality Assurance	(1)		
7	10.4 Maintainability	(1)		
6	11. System Test Operations	23.05	18.67	4.38
7	11.1 Electrical	(1)		
7	11.2 Vibration & Acceleration	(1)		
7	11.3 Thermal	(1)		
7	11.4 EMI	(1)		
7	11.5 EMC	(1)		
7	11.6 Alignment	(1)		
7	11.7 Calibration	(1)		
7	11.8 Thermal Vacuum	(1)		
7	11.9 Acoustic	(1)		
7	11.10 Simulation Modeling	(1)		
6	12. Flight Software	2.97	2.41	0.56
7	12.1 Data Handling & Processing	(1)		
7	12.2 Command	(1)		
7	12.3 Communication	(1)		
7	12.4 Applications Interface	(1)		
7	12.5 Fault Isolation & BITE	(1)		
6	13. Ground Logistics Support Equipment	12.83	10.39	2.44

TABLE 5-3 COST ESTIMATE FOR SAAX0302 (Cont'd)

LEVEL	WBS ELEMENT TITLE	COST(M$) TOTAL	COST(M$) NON-RECURR	COST(M$) RECURR
7	13.1 Preflight	(1)		
7	13.2 Inflight(Includes ground control ops/POC eqt)	(1)		
7	13.3 Postflight	(1)		
6	14. Systems Engineering & Integration	36.89	29.88	7.01
7	14.1 Hardware Development Planning	(1)		
7	14.2 Configuration Control	(1)		
7	14.3 Mission Analysis	(1)		
7	14.4 Interface Requirements (Subsystem & Software)	(1)		
7	14.5 Specifications	(1)		
7	14.6 Engineering Data	(1)		
7	14.7 Engineering Analyses(Thermal, dynamics, etc.)	(1)		
6	15. Program Management	19.97	16.18	3.79
7	15.1 Project Management & Coordination	(1)		
7	15.2 Planning & Scheduling	(1)		
7	15.3 Controls	(1)		
7	15.4 Subcontractor/Vendor Liaison	(1)		
7	15.5 Management Data	(1)		
7	15.6 Reviews	(1)		
7	15.7 Design to Cost	(1)		
6	16. General Purpose Facilities & Equipment	98.24	79.57	18.67
7	16.1 Module Specific Equipment	32.45		
8	16.1.1 General Purpose Work Station	4.37		
8	16.1.2 Laboratory Centrifuge	0.19		
8	16.1.3 Refrigerator/Freezer(-20 deg)	1.52		
8	16.1.4 Freezer (-70 deg)	1.71		
8	16.1.5 Research Computer	0.88		
8	16.1.6 Cleanup facilities	0.69		
8	16.1.7 Small mass measurement device	0.39		
8	16.1.8 Dissection kit	0.59		
8	16.1.9 Dosimeter	0.75		
8	16.1.10 Video recorder/camera	3.62		
8	16.1.11 Physiological amplifier	2.24		
8	16.1.12 Strip chart recorder	3.32		
8	16.1.13 Gas analyzer/Mass spectrometer	4.90		
8	16.1.14 Spectrophotometer	4.09		
8	16.1.15 Oscilloscope	2.00		
8	16.1.16 pH/Ion analyzer	0.54		
8	16.1.17 Microscope	0.42		
8	16.1.18 Dissection microscope	0.23		
7	16.2 Life Sciences Equipment	65.79	53.29	12.50
8	16.2.1 Rodent Standard Holding Facility	9.19		
8	16.2.2 Rodent Artificial Gravity Holding Facility	19.68		
8	16.2.3 Egg Incubator Holding Facility	0.47		

TABLE 5-3 COST ESTIMATE FOR SAAX0302 (Cont'd)

LEVEL	WBS ELEMENT TITLE	COST(M$) TOTAL	COST(M$) NON-RECURR	COST(M$) RECURR
8	16.2.4 Rodent Breeding Holding Facility	8.74		
8	16.2.5 Large Primate Holding Facility	6.87		
8	16.2.6 Small Plant Holding Facility	6.87		
8	16.2.7 CELSS Holding & Test Facility	3.77		
8	16.2.8 Incubator-CO2	0.90		
8	16.2.9 Animal Physiological Monitoring System	4.00		
8	16.2.10 Rodent Metabolic Facility	4.76		
7	16.2.11 Primate Handling Kit	0.54		
6	17. Operations	10.00	8.10	1.90
7	17.1 Training	1.95		
7	17.2 Logistics	0.53		
7	17.3 Airborne Support Equipt (ASE)	6.42		
7	17.4 Maintenance & Servicing	0.40		
7	17.5 Mockups	0.30		
7	17.6 Ground Operations (Pre-, In-, & Post-flight)	0.27		
7	17.7 Flight Operations (Including scheduling)	0.13		
7	17.8 Recovery (End-of-Life Disposal)	TBD		
6	18. Station Equipment	10.41	8.43	1.98
7	18.1 Safe Haven Equipment	0.12		
7	18.2 Secondary Controls Equipment	10.29		
7	18.3 Lighting	(2)		
7	18.4 Caution & Warning	(2)		
7	18.5 Fire Detection & Suppression	(2)		
7	18.6 Work Stations	0.00		
6	19. Customer Accommodation Hardware	10.25	8.30	1.95
7	19.1 Experiment Equipment I/F (Elect,data,thermal)	4.54		
7	19.2 Pointing System	2.44		
7	19.3 Optical Window	0.22		
7	19.4 Scientific Airlock	0.67		
7	19.5 Rapid Specimen Return	2.38		
6	20. Ground Software	8.90	7.21	1.69
7	20.1 System Test	(1)		
7	20.2 Inflight Verification & Checkout	(1)		
7	20.3 Data Handling & Processing	(1)		
7	20.4 Telemetry & Command	(1)		
7	20.5 Communications	(1)		
7	20.6 Applications Interfaces	(1)		
7	20.7 On-orbit Interface (Real time)	(1)		
6	21. Spares	3.05	2.47	0.58
7	21.1 Batteries	(1)		
7	21.2 Filters	(1)		
7	21.3 Light Bulbs	(1)		

(1) Included elsewhere

(2) Part of Common Module

<u>Funding Profiles.</u> Funding profiles for LSRF Missions SAAX0307 and SAAX0302 were constructed to evaluate funding requirements from program initiation through first launch. The profiles (Fig. 5-12 and Table 5-4) are generated based upon 7 year programs. It is recognized that 307 and 302 start in different years, so the profiles are shown as dollars vs. years prior to launch. The profiles are based upon the DDT&E costs detailed in Section 5.3.1 using the same assumptions defined in Section 5.3.

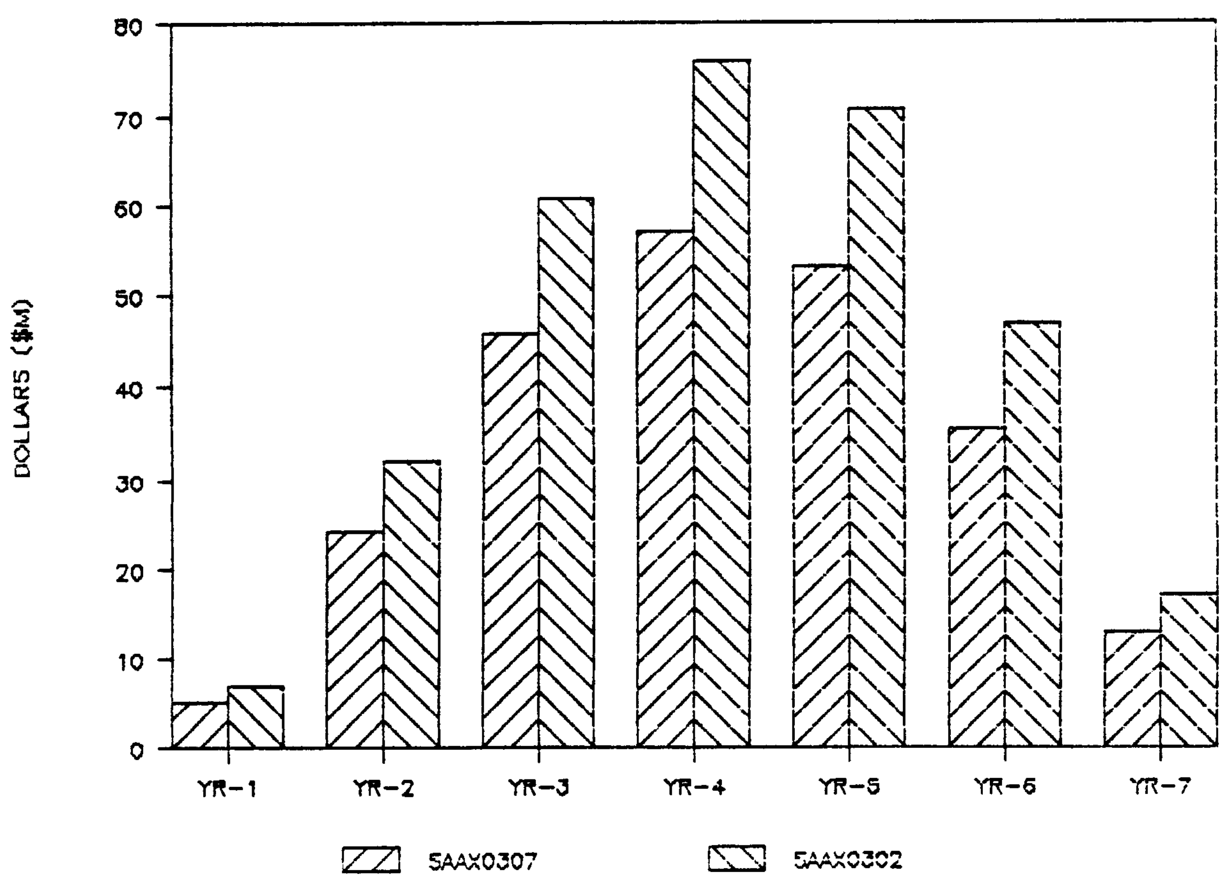


Figure 5-12 Funding Profiles

TABLE 5-4 FUNDING PROFILES FOR SAAX0307 AND SAAX0302 FOR A 7 YEAR PROGRAM

COST (M$)

YEAR	SAAX0307	SAAX0302
1	5.1	6.8
2	24.1	31.9
3	45.8	60.7
4	57.2	75.8
5	53.3	70.6
6	35.5	47.0
7	12.9	17.0

5.3.2 Annual Operations Cost Estimate

Annual operations costs for pre-launch, on-orbit, and post-return operational activities involving the LSRF portion of the combined lab (SAAX0307) and the dedicated animal-plant vivarium lab(SAAX0302) are presented in this section. The groundrules and assumptions made in developing the annual operating costs are as follows:

- o Costs are in constant year FY 1987 dollars
- o Estimates are for the 45 foot module in the racetrack configuration
- o Costs for STS transportation assume a pro-rated cost of $5.27K/kg/flight based on a shuttle roundtrip cost of $91M and a payload capability of 17,270 kg
- o The Space Station resupply period is 90 days requiring four resupply flights per year

- o The factors and rationale used for estimating are based on engineering judgement

Annual operations costs for SAAX0307 and SAAX0302 are shown in Table 5-5. Costs are broken down into nine WBS elements agreed upon by the LSRF project participants. The annual operations costs for SAAX0307 are asumed to be 50% of those for SAAX0302 owing to its reduced amount of equipment. The methodology and rationale for the SAAX0302 estimate are given below.

TABLE 5-5 OPERATING COSTS SAAX0302 AND SAAX0307

Level	WBS Element Title	COST ($M)	
		SAAX0302	SAAX0307
17.0	Operations	62.99	31.51
17.1	Training	2.31	1.16
17.2	Logistics	37.14	18.57
17.3	Airborne Support Equipment	0.27	0.14
17.4	Maintenance and Servicing	5.09	2.55
17.5	Mockups	0.11	0.06
17.6	Ground Operations	6.69	3.35
17.7	Flight Operations	8.38	4.19
17.8	Recovery (End-of-Life Disposal)	TBD	TBD
17.9	Program Management	3.00	1.50

Two full-time crewmembers are rotated every 90 days, totaling eight per year. Assuming backup training for eight crewmembers at half level, and a one-to-one ratio of instructors to crew 24 people/year are required. Therefore, the total training cost is equal to 24 x $75K/yr = $1.80M/yr. There is also a cost for maintaining current training hardware which is equal to 20% of the DDT&E cost for LSRF training hardware (0.2x$2.55M = $0.51M/yr). The total is 1.80 + 0.51 = $2.31M/yr.

The logistics costs cover the STS resupply transportation of crew, equipment changeout, specimen consumables, and operation spares.

The SAAX0302 crew costs over two persons/flight at 90 kg each, totaling 180 kg/flight. Consumables are charged to the hab module. Changeout and update of equipment equivalent to three equipment racks per flight is assumed at 700 kg/flight. The specimen consumables consist of 205 kg of food and 549 kg of water totaling 754 kg/flight. The cost of these three areas of resupply is equal to $8.61M/yr (180+700+754 = 1634kg/flt x $5.27 k/kg = $8.61M =/yr) Assuming four resupply flights per year the total resupply cost equals $34.44M.yr. The operation spares are estimated at 50% of the initial spares cost ($5.39M). Therefore, the total logistics cost is $34.44M plus $2.7M or $37.14 M/yr.

The airborne support equipment is estimated at 20% of DDT&E GSE hardware cost ($1.36M). This equals $0.27M/yr.

Maintenance and servicing is estimated at 10% of recurring flight hardware cost ($50.94M). This equals $5.09M/yr.

Maintaining mockups is estimated at 20% of the DDT&E cost for mockups ($0.54M). This equals $0.11M/yr.

Ground operations consists of five separate areas. The first is rapid recovery. Assuming four recoveries per year at $0.51M/recovery, and four recovery capsules at $0.29M/capsule, total recovery costs are $3.16M/yr. Configuration management and sustaining engineering are estimated at 20 people at $75k/year totaling $1.5M/yr. Preflight and postflight operations are estimated at 5 people at $75K/yr = $0.38M/yr. Quality assurance consists of 2 people at $75K/yr equaling $0.15M/yr. CDOS has 20 people at $75k/yr equaling $1.5M/yr. The total ground operation is $3.16 + $1.5 + $0.38 + $1.5 equaling $6.69M/yr.

Flight operations consists of the flight crew and scheduling. The flight crew has 2 people on a 90 day rotation. Therefore, there are a total of 8 people per year each at 1M/yr totaling $8M/yr. Scheduling is estimated at five people per year at 75K/yr equaling 0.38M/yr. The total flight operations cost of $8.0 + 0.38 = $8.38M/yr.

Recovery is still to be determined. Management is estimated at 5% of the total of all previous costs. The total of all areas in operating costs equals $62.99M/year.

5.4 PRELIMINARY SCHEDULES AND PLANS

The LSRF program plan encompasses a phased approach, consistent with the Space Station phasing, to accomplish the requirements definition, design, development, assembly, verification, integration and all aspects of mission support. The purpose of the plan is to: (1) provide a comprehensive plan for developing the LSRF for inclusion in Space Station; (2) help establish necessary resources for LSRF; (3) summarize management and supporting responsibilities; (4) summarize implementation of key development activities; and (5) identify interfaces necessary for conducting all project elements.

The following LSRF program plan sections address: science management, development and implementation engineering, LSRF operation and mission planning, equipment changeout and resupply and training; a project summary of activities associated with LSRF developmental phases; and LSRF project schedules that are phased with the overall SS schedule. These sections, taken together, provide a generalized overview of an end-to-end LSRF system.

5.4.1 Science Management

Initial Experiment Requirements. The initial experiment requirements for the IOC LSRF will be derived from the NASA sponsored "Life Sciences Planning Meeting" held June 10-12, 1985 at Arlington, VA. At this time this document is unofficial but represents the current viewpoint of NASA, academia, and industry. Pending review by NASA, it is assumed that the Life Sciences Planning Meeting "Redbook" will eventually serve as the LSRF Science Requirements Document.

New Requirements. New requirements or changes to existing requirements will be derived from either Applications Notices (ANs), Announcements of Opportunity (AOs), Research Technology Operations Plans (RTOPs), or letters of solicitation. Proposed investigations which have undergone strategic plans committee review, appropriate peer review, and upon recommendation of the JSC Science Steering Committee, should be incorporated into the LSRF Science Requirements Document. New requirements may be scheduled for follow-on missions or may bump existing experiments dependent upon priority and Space Station/Shuttle mission schedules.

LSRF Experiment Data Base. Each investigation area contained in the LSRF requirements document needs to be analyzed to determine equipment, protocol, and support requirements. These experiment data can be stored in an automated format addressable by Principle Investigators, mission and payload planners, and LSRF mission control. The experiment data base could become a portion of the LSRF Planning Support Data Base, which is a relational data base, supporting rapid assessment of experiment combinations and Space station operational demands.

LSRF IOC Mission Requirements. The specific experiments to be performed on the IOC Mission will be determined from an analysis of SLM LSRF apportionment, crew time allocation, and experiment priority. It is suggested that the relational data base support this and other subsequent determinations at a point in time sufficiently far down line to insure that high priority investigations are accomplished with the best equipment available.

Experiment Protocol Development Once selected for a mission, each experiment to be performed will be required to have a fully defined experiment protocol. These Principal Investigator (PI) developed protocols will be delivered to the LSRF Mission Production Center (MPC) for use in planning, training, verification, fine tuning, time-lining, and failure analysis during later phases. Additionally, the fully defined protocol will become an integral part of the LSRF Planning Support Data Base so as to permit ease of review and/or update.

5.4.2 Implementation Engineering

General Hardware/Instrumentation Definition. The LSRF system will consist of three basic types of modular and transportable hardware. These equipment types are CORE, Life Science Laboratory Equipment (LSLE), and Experiment Unique Equipment (EUE). CORE equipment is defined to be semi-permanent, experiment independent in use, i.e., data recorders, audio-visual, refrigerator-freezer, storage cabinets and trays, etc. LSLE equipment is defined as general experiment equipment with a broad range of application, i.e., body mass measuring device, exercise equipment, urine collection system, spectrophotometer, blood kits, etc. EUE equipment is defined as that which is experiment unique or limited in use to a specialized set of experiments, i.e., gamma counter, microscope and stain kit, cell counter, olfactometer, freeze dryer, etc. The development, use, handling and storage of this equipment will be discussed throughout later paragraphs.

Preliminary Engineering/Operations Requirements. The equipment identified as a result of the LSRF Science Requirements analysis and the equipment operating parameters will form a preliminary Engineering/Operations Requirements Document. While it is recognized that not all experiments could be performed on any single mission, it is recognized that the SLM could contain any combination of CORE, LSLE, and EUE at any given time. Thus, SLM module development must address maximum loads. As with the LSRF Science Requirements document, the Engineering/Operations Requirements Specification should be updated as approved new science requirements enter the system.

Facilities. Development of facilities to support the LSRF system is based on the following assumptions:

(a) The IOC mission integration of the LSRF will be performed at KSC if the SLM is launched as a "fully equipped" module.

(b) Exclusive of the IOC mission as defined in (a) final LSRF equipment integration, checkout, and flight packaging will be done at the customer location.

(c) LSRF Mission Planning, training, command and control, and equipment maintenance/servicing will be performed at GSFC or ARC.

(d) Experiment equipment and expendables, exclusive of CORE equipment, will be stored at GSFC or ARC. CORE equipment, after initial certification, will be housed and maintained at KSC.

LSRF development and implementation will require facilities to accommodate several SLM "look-alike" modules. The degree of "look-alike" will vary with function to be performed. As a minimum, it is currently envisioned that KSC will require a full flight module to accomplish integration and check-out under the concept of loaded SLM lanuch. It is suggested that three additional SLM modules reside at GSFC or ARC. One, a module in the Space Station integrated test bed assembly (i.e., 1g trainer), would be low fidelity and would support overall Space Station engineering training needs. A second SLM unit, the Engineering Development Unit (EDU) would be of very high LSRF fidelity and would serve the combined function of integration test facility, command and control, and experiment protocol trainer. A third unit, an Advanced Development Unit (ADU), would serve as an engineering test bed supporting future LSRF development.

Operations Facilities. At a minimum LSRF operations facilities will consist of a Payload Operations Control Center (POCC) and a Space Station Support Center (SSSC). The POCC functions include:

- Managing and performing normal payload operations and commanding
- Coordination center for cooperative or related investigations or activities
- Center for payload performance analysis

The SSSC provides: assembly, integration and checkout, logistics, NSTS interface, strategic operations and commanding, rendezvous and proximity operations, and POCC coordination and monitoring functions.

Logistics Facilities. Initial planning should provide for two controlled logistics facilities: one facility at KSC in which LSRF CORE equipment not required on the current mission is stored and a second facility at GSFC or ARC which provides primary storage for LSLE and mission expendables. The second facility supports "next mission" payload preparation, equipment maintenance, and QA requirements.

5.4.3 LSRF Operation

Training. Training on laboratory start-up procedures, equipment change-out, on-orbit maintenance, experiment protocol, data collection/recording and logistics handling will be accomplished at GSFC or ARC using the high fidelity EDU. Additional training can be conducted on the Space Station Systems Trainer (SSST) where nominal and contingency systems management, trajectory and navigation support, activity planning, maintenance, logistics, communications useage and emergency training is available.

On-orbit Operations. Operationally, the LSRF is planned to function in either of two modes: One, fully ground supported and in near-parallel operation with the POCC and SSSC; and the other, a semi-autonomous mode with little or no ground intervention. The rationale behind this approach is the recognition that, at least initially, engineering constraints, equipment reliability, instrument calibration and other general unknowns will delay the highly desired objective of semi-autonomous operation and force a period of near-parallel operation. Parallel operation will allow the PI to monitor protocol, verify instrument performance, assess results and make adjustments during the experiment as opposed to experiment reflight, which is considered more costly than parallel operation.

In the semi-autonomous mode the crew, having received training in experiment protocol and having audio-visual training aids available, will be left to conduct the investigation independent of ground interface, except as may be requested to clarify certain aspects of the investigation. Real time communication and/or data transfer would be kept to a minimum.

In the parallel operations mode, each aspect of experiment conduct would be performed on-orbit and simultaneously in the EDU, with the PI and the LSRF engineering staff evaluating function and result. This mode will undoubtedly place higher demands on the LSRF and Space Station communication systems.

Data Processing and Communications. The LSRF will be equipped with data processing and communication tools capable of supporting both of its operational modes. These tools will be in the form of (a) access to the Space Station main computer for both data processing and storage, (b) LSRF dedicated micro-computers to handle special analog/digital processing requirements, (c) data recorders to serve as interim storage devices and permanent records archiving, (d) time scheduled voice and data channels within the Space Station communications system for downlink of data, and (e) audio-visual equipment to display/replay experiment protocol training films.

The specific configuration of communication and processing will be a function of the experiment plan. Principal system components will be interfaced to permit remotely controlled data dumps, thus offloading crew time demands. Permanent records (tapes, cassettes, etc.) will be returned on the next resupply flight.

Ground Mission Support. Operational ground support for the LSRF will be through the POCC using the EDU to monitor and support experiments as needed. The degree of SSSC involvement will be in accordance with the published experiment plans. PIs may opt to participate remotely from their institution/laboratory. Under conditions of remote participation the PI will require a compatible data terminal work station to facilitate data base access and direct communication.

Scheduling. The Mission Production Center (MPC), using approved Science Requirements as a base and Space Station and shuttle schedules as tools, will plan and schedule each investigation in accordance with established priority. The MPC, through its LSRF Engineering Office (EO), will ascertain whether or not the CORE, LSLE, and EUE required is available from internal resources (following IOC). Where investigation needs cannot be satisfied, the EO will be tasked to initiate an R&D effort to acquire, test and deliver the required equipment. In instances where needs can be satisfied, the LSRF POCC will be tasked to perform those functions necessary to launch an LSRF reconfiguration/resupply payload. The MPC will act as the coordinating focal point between EO, POCC, and SSSC to assure that all activities relative to reconfiguration are addressed in a timely manner.

5.4.4 Project Summary

Conduct of the LSRF project is structured with phased project planning guidelines utilizing phase A for preliminary requirements and concept definition; phase B, requirements definition, preliminary design, and development planning; phase C, development, testing, final design, and flight unit preliminary planning, and phase D, flight unit manufacture, flight certification and operational support. Close coordination with the Space Station office and other pertinent participants should be maintained throughout all project phases to assure interface compatibility between the LSRF and the common module, and to optimize operational compatibility with the overall Space Station.

Phase A Study. The work represented in this report, and its predecessors, and the Boeing parallel studies covers a major portion of Phase A. Remaining effort consists of

(1) Continued studies of the Space Station Program to maintain guidelines, constraints, and interfaces pertinent to LSRF development, and to maintain current knowledge of the planned mission and its elements.
(2) Analysis of the headquarters studies of LSRF Science Requirements to determine the discipline oriented experiments, their priorities, and to define their measurements, protocols, equipment, and data requirements.
(3) Initiating efforts to define a data base approach for the material produced thus for and develop an initial operating capability for the planning data base.
(4) Definition of an LSRF System Concept, utilizing the information from (1), (2), and (3) above, and selection of the most promising candidate equipment.
(5) From (4), definition of the split between Space Station-funded generic equipment and LSRF-funded user equipment. This recognizes that much of the $233M for SAAX0307 may be funded by the Space Station organization of NASA (Code S).
(6) Preparation of the LSRF Project Plan.

In deriving Space Station Program guidelines, constraints, and interfaces, the current documentation, concepts, plans and schedules need to be examined to establish Common Module interface requirements, as well as other pertinent aspects (such as crewmember duty tours, philosophies of pre-, in-, and postflight support, maintenance capabilities, communications, data systems, etc.). Additionally, information exchange mechanics will be set into motion among NASA and contractor personnel identified as LSRF project focal points.

Phase B, Requirements Definition, Preliminary Design and Development Planning

Phase B activity will be directed toward producing a more explicit definition of LSRF System Design and Performance requirements, from which Preliminary System Design and Development Plans for Phase C will be prepared. The purpose of the Phase B activities is to synthesize the requirements, preliminary design, and preliminary development plans, so that the Phase C/D contractor selection process will have proper information to proceed effectively and in a timely and efficient manner. The major efforts of Phase B are summarized as follows:

Phase B1, Definition of Science and Engineering Requirements. During Phase B, the Phase A science and engineering requirements will be solidified and transformed into specific hardware and software needs. Current state-of-the-art and advanced technology will be assessed and potential equipment and software for the LSRF will be identified. Technological areas promising innovative advancements worthy of consideration for the LSRF will be identified and pursued with industry. LSRF subsystem concepts will be developed, trade studies performed and the most attractive alternative selected. Development of promising advanced technology/-hardware may be funded. The LSRF configuration for IOC will be established providing for early identification and development of long lead time items.

Phase B2, Analysis and Preliminary Design. Other aspects of Phase B include analyses and tradeoffs of design elements, product candidate selection, materials and product selection, "make, modify, or buy" analyses, Safety, Reliability, and QA activities (such as FMEA and hazard analyses), and interface definitions.

Functional hardware (and software) of key elements may need to be procured, or fabricated, and evaluated for possible modification. Critical hardware may undergo Shuttle/Spacelab flight testing to verify acceptability from microgravity, engineering, and medical/scientific protocol standpoints. Modifications deemed necessary will be incorporated into the preliminary designs.

Phase B3, Development Planning. Phase B3 planning efforts initially will be directed at preparing complete requirements documentation for interface control, science, design, performance, data base, engineering development, testing and operational support. Additional plans for Phase C prepared during the latter part of Phase B will consist of early Phase C preliminary system and subsystem design, specifications development, and testing plans. At this point, all existing project documentation, such as the Project Plan, will be reviewed and updated if required, so that Phase C efforts may proceed unimpeded.

Phase C/D Preparation During preparation for the Phase C/D contractor solicitation and selection, technical information, in depth analyses, product and cost investigations, and other tasks pertinent to support of the LSRF Project Office's preparation of the Phase C Work Statement will be required of the Phase B contractor. It is also planned that the Phase B contractor would be directed to pursue meaningful, productive (to Phase C/D) tasks during the period the Phase C/D contractor is being selected. This is important to assure a comprehensive, orderly transition of project data if the Phase C contractor is not the Phase B contractor, and to permit Phase C productive efforts to proceed without extended delays.

Reviews. Reviews will be conducted at key points during the finalization of Science and Engineering Requirements, the preparation of the Preliminary Design, and preparation of the Development Plans, so that the end items can benefit from in-process critique by teams of Medical, Scientific, Engineering, Manufacturing and Space Station Program experts.

Phase C, System Development, Testing, Final Design and Flight Unit Preliminary Planning.

Phase C shall include finalizing design and performance requirements and conducting the detailed design analyses, make or buy decisions, development, modifications, testing, and verifications that are needed to satisfy requirements of protocols, procedures, vehicle and mission interfaces.

Functional development hardware from Phase B will be evaluated, tested, and modified to its final configuration. This phase will require coordination to assure the final LSRF configuration will comply with all standards and specifications required for Space Station flight hardware.

The use of commercially available, off-the-shelf hardware in the LSRF will be encouraged to minimize costs and facilitate inflight repair/replacement. Development hardware will be procured and evaluated to determine if modifications are required. Required modifications would be coordinated by NASA and performed by the manufacturer, the contractor, or inhouse by NASA, as determined by cost and project effectivity.

Extensive engineering tests will be performed to verify that operational characteristics are appropriate, and to certify that hardware is acceptable for spaceflight (from a materials, safety, reliability, and quality standpoint). Space Station, SLM, and LSRF system interfaces will be tested and verified.

LSRF System Design Drawings will be prepared and Engineering Development Units (EDU) assembled from the Phase B and Phase C development hardware. All LSRF hardware will be tested at the component and subsystem level prior to its integration into the complete EDU system.

Protoflight tests will be utilized throughout the development of the LSRF. These tests will certify the operation of the LSRF from an engineering, medical/scientific, and microgravity standpoint. Performance characteristics of hardware in microgravity many times are unknown, and in some cases have produced unpleasant surprises. Microgravity testing of critical and/or significant components or subsystems may be attempted in the KC-135 or as a formal Shuttle/Spacelab experiment. Proven performance in microgravity is the goal of these tests. Prior to completion of the EDU testing, the comprehensive range of experiment protocols should be verified using timelines.

During the testing of the LSRF, EDU information feedback should enable completion of the drawings and specifications for manufacture and assembly of the LSRF Flight System. As finalized and baselined, these will constitute the IOC flight configuration. Once the EDU is modified to be identical to the Flight System Configuration, it may be used to (1) verify total system compatibility and operation, (2) resolve onboard anomalies, and (3) serve as a high fidelity trainer, (4) fine tune and verify protocols, and (5) establish time lines.

Phase D: Flight Unit Production, Certification, and Operational Support Phase D encompasses the activities required for conducting procurements, manufacture, and flight certification of LSRF unit(s) and the activities for establishing incremental support functions required of mission operations (such as training, refurbishing, modifying, maintaining, etc.).

Initially, the Flight Unit Preliminary Production and Operational Support Plans and documentation produced in Phase C will be finalized, cost plans and schedules prepared, and when approved, the entire process for producing a flight ready LSRF is set into motion.

Concurrent with the system hardware production process, other activities are pursued to develop and implement logistics plans, prepare and implement training plans, develop and implement LSRF acceptance test plans and procedures, and establish and accommodate the incremental operational support needs.

5.4.5 Program Schedules

LSRF Project Schedules have been summarized in Fig. 5-13 through 5-16. They encompass (1) an overall Project Schedule (Phases A, B, C, and D), and (2) individual schedules for Phases B, C, and D.

The LSRF summary IOC schedule time phases LSRF design and development activities to meet key Space Station milestones thereby ensuring that LSRF requirements are integrated in concert with overall Space Station development.

LSRF project plan schedules are structured to: be consistent with key milestones of the Space Station, provide adequate flexibility to facilitate synchronization with changes in Space Station schedules, form the basis for planning resource requirements and provide basic structure for planning project implementation in more detail.

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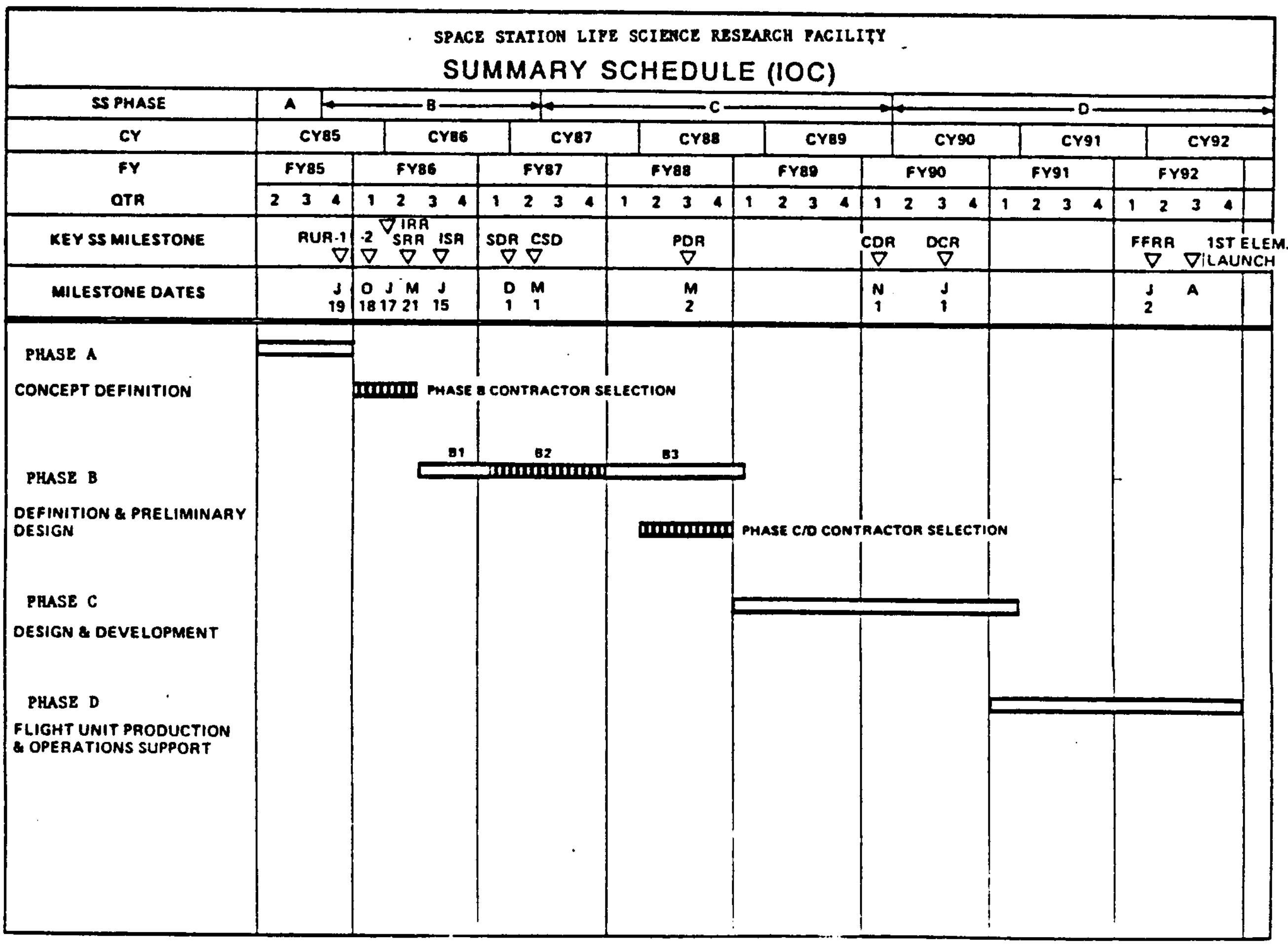

Figure 5-13 Space Station LSRF IOC Summary Schedule

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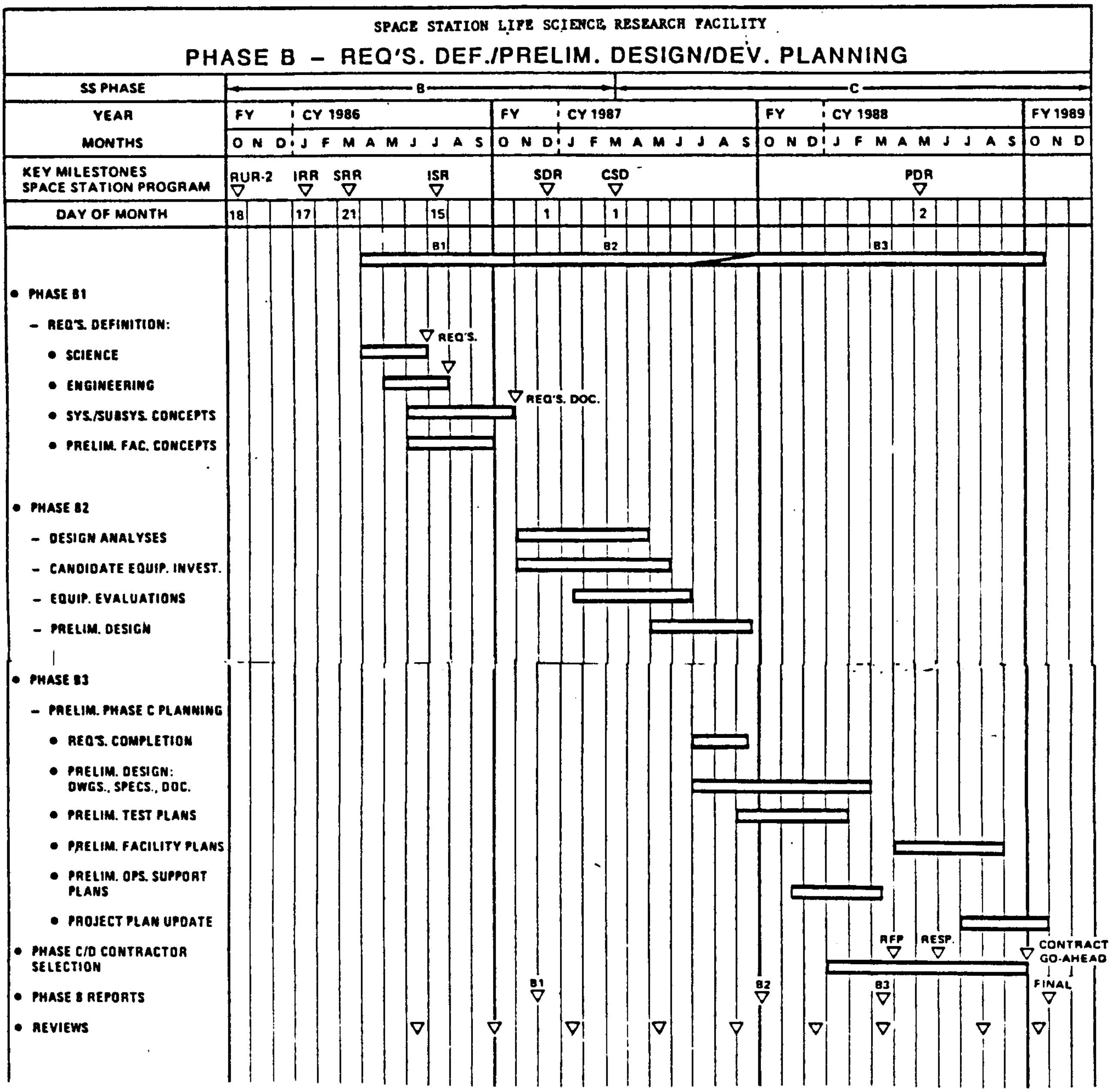

Figure 5-14 Space Station LSRF Phase B Schedule

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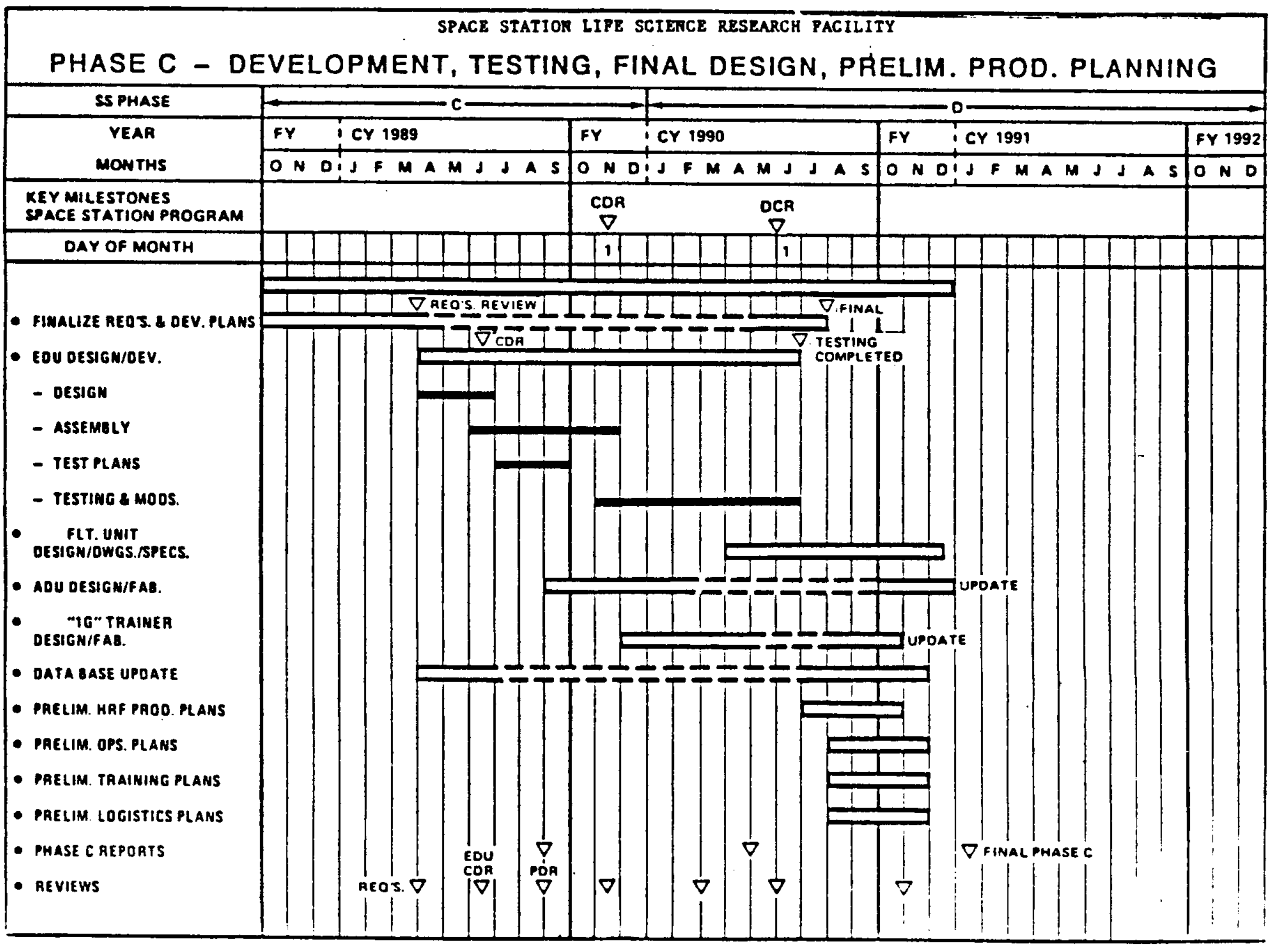

Figure 5-15 Space Station LSRF Phase C Schedule

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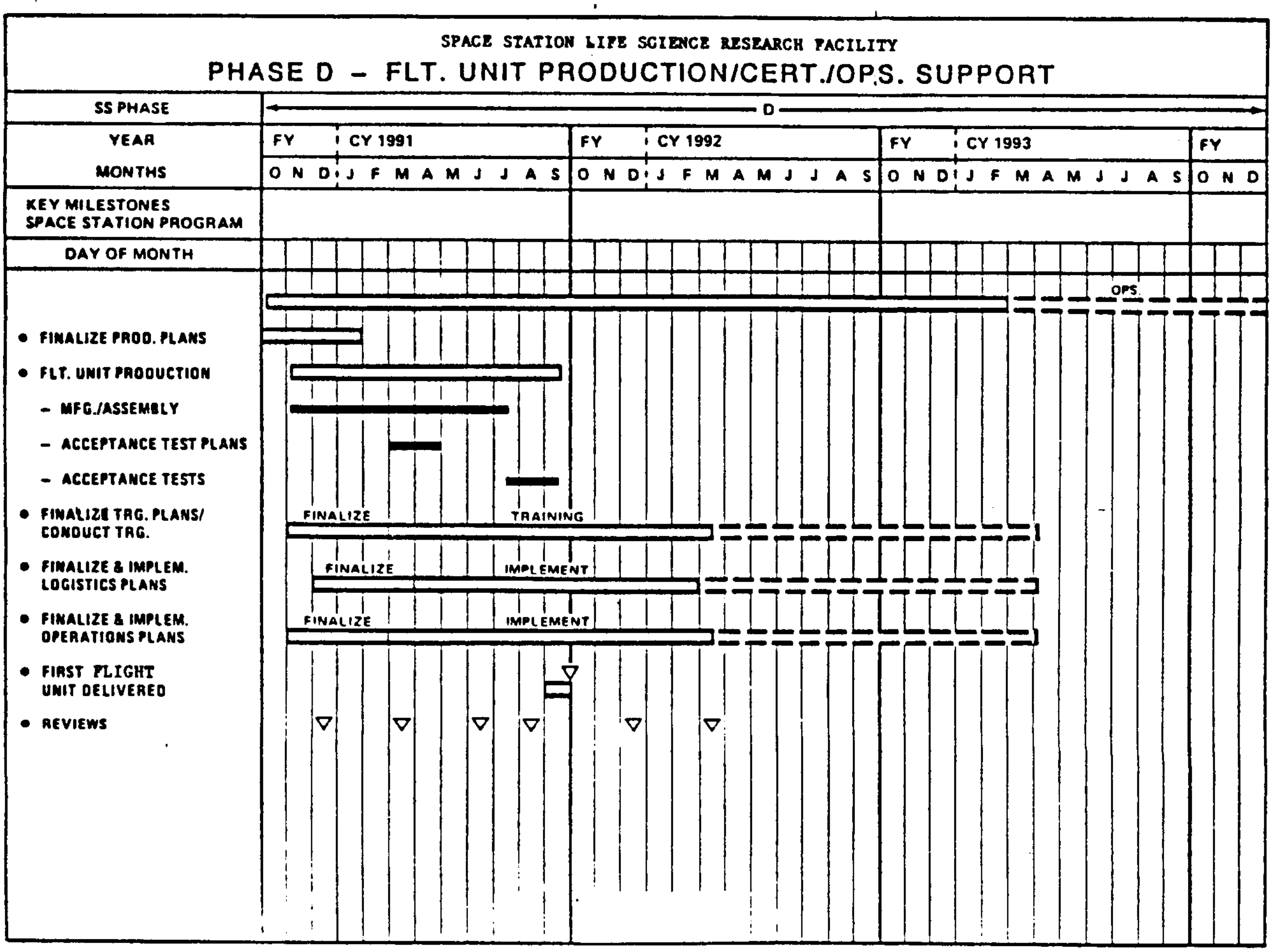

Figure 5-16 Space Station LSRF Phase D Schedule