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MDC G6203

FINAL REPORT
A CONCEPTUAL DESIGN STUDY OF A BIOLOGICAL SPECIMEN HOLDING FACILITY

VOLUME II
Technical Report

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

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FOR CONTRACT NAS8-31490
FOR GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL ASERONAUTICS AND SPACE ADMINISTRATION

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PREFACE

This is one of five volumes prepared to report the results of a Conceptual Design Study of a Biological Speciman Holding Facility, which was performed by McDonnell Douglas Astronautics Company (MDAC) in accordance with the requirements of NASA Contract NAS8-31490. Technical guidance during this study has been provided for NASA by William C. Patterson of Marshall Space Flight Center and by Richard C. Simmonds of Ames Research Center.

The study results are reported in the following volumes:

- I Executive Summary
- II Technical Report
- III Specimen Support and Experiment Requirements and Design Criteria
- IV Programmatics and Cost Analyses
- V Previously Qualified Equipment Data

This is Volume II, Technical Report.

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Section 1
INTRODUCTION

A conceptual design study of a Biological Specimen Holding Facility (BSHF) has been performed by McDonnell Douglas Astronautics Company (MDAC) under contract NAS8-31490 for the National Aeronautics and Space Administration.

The overall objective of the study is to define requirements to be imposed on habitats for living specimens to be used in life science research and to develop a conceptual design for the habitats. The BSHF is a key element of the life science laboratory being designed as a scientific payload for the Space Shuttle.

The specimen habitat to be developed will interface physically and environmentally with the Spacelab for prelaunch, launch, on-orbit, reentry, and postlanding mission segments. The habitat design is to support a nominal 30-day mission. The specimen holding facility includes the environmental control system, food and water system, waste management, lighting, structural system, and specimen instrumentation system. The facility interfaces with the Spacelab data collection and management system, the specimen examining unit, and other elements of the life science laboratory designed for the Spacelab. Included also are the interface and support equipment required for specimen transfer, surgical research, and food, water and waste storage. The adult rhesus monkey (Macaca mulatta) and laboratory rat (Rattus norvegicus) were utilized as design specimens. However, the facility was configured to accommodate a wide range of specimens, ranging from cells and tissue cultures through large mammals, with some modifications to the basic design.

The modularity approach used in this study, both in component and holding unit designs, will enable life sciences laboratory designers to select a wide variety of BSHF configurations, with varying numbers of specimen and mission durations, and to assess the physical and performance characteristics of such holding units. Adequate engineering data, specifications, and technical descriptions are presented to provide the user of this report with the tools needed for the proper selection of the desired BSHF configuration.

Section 2
SUMMARY

The primary objectives of this study included the development of conceptual designs for Spacelab life science research specimen habitats which provide a capability for maintaining biological specimens in relative physiological normalcy and good physical and psychological health. To meet these objectives, the study included a review of proposed life science research programs in space; the specification of requirements for the support of specimens, the performance of research, and the efficient utilization of resources provided by the Life Science Laboratory; the identification of concepts for subsystems capable of meeting these requirements; the performance of trade studies resulting in the selection of the optimum combination of these concepts, and the implementation of an initial baseline design of a BSHF based upon the results of these trade studies. This report describes the engineering and technical aspects of the study, which are summarized below.

2.1 REQUIREMENTS DEFINITION

This section summarizes the flight laboratory resources available to the BSHF, the specimen and experiment requirements and the various mission phase operational requirements. Included also are equipment commonality and the utilization of flight-qualified hardware.

2.1.1 LSL Mission and Configuration Constraints

Three program options, IA, IIIA, and IIIB, were evaluated in the NASA Life Science Laboratory (LSL) Definition Study, under contract NAS8-31367. Mission Mod-IA-3, an early medical emphasis dedicated LSL, which was chosen as the baseline in the LSL Definition Study, has been used as an example to illustrate the applicability of the BSHF to the LSL configuration. The adaptability of the BSHF to the common operational research equipment (CORE) laboratory concept was established and the major LSL configuration constraints applicable to BSHF design were defined. The LSL and Spacelab/ Shuttle support capabilities and resources were also evaluated.

2.1.2 Specimen and Experiment Requirements

Two design organisms were used in this study. These are the rhesus monkey and the adult laboratory rat. The support requirements for these specimens, including cage volumetric characteristics, environmental parameters, and specimen physiological data were defined. Additional requirements pertaining to the support of biological specimen research programs were also established with assistance from the NASA Life Sciences Space Shuttle Payload Planning Working Group.

2.1.3 Impact of Other Specimens

Although the primary focus of the conceptual design study of the BSHF was on the rhesus monkey and laboratory rat, it is desired to eventually provide habitats for a wide variety of specimens including cell and tissue cultures, plants, invertebrates, and other vertebrate forms. Supplementary information is presented in this report to assist in the evaluation of the impact that the accommodation of other specimens would have on a holding facility basically designed for primates and rats.

2.1.4 Operational Requirements

Operational studies show that the specimens must be loaded onboard the Spacelab before launch after the vehicle has been moved to the launch pad. The specimens will be carried in transfer modules and placed into their cages in the Spacelab before launch.

On-orbit studies indicate that the crewmen can accomplish the daily tasks of measuring food and water consumption and replenishing supplies, as well as performing simple unscheduled component replacement if failures occur.

After landing, an experimenter is required to enter the Spacelab within 2 hours. The specimens must be removed before readjusting to the gravity field, and support must be provided (power, cooling, food, water) until they are removed.

2.2 DESIGN DESCRIPTION

The design effort included trade studies to select optimum components, assemblies, and subsystems, as well as layout design and mockups studies.

The subsystems of the BSHF include environmental control, waste management, food and water, lighting, and data acquisition. In addition to the habitats for the primate and rodents, supporting flight equipment includes a control and display panel, water storage, waste collection and storage, signal conditioning, and specimen transfer units to interface with a surgical work bench and other laboratory items.

2.2.1 Subsystems

The environmental control subsystem draws air from the Spacelab cabin, circulates it through the cage, and returns it to the cabin for removal of heat, humidity, and carbon dioxide. Microbial filters are provided at the inlet and outlet of the habitats to prevent interchange of microbes between crew and specimens. Odor and particulate filters are provided before the air is returned to the cabin. Wherever possible, heat from blower motors, signal conditioners, and other components will be rejected to the avionics loop because the Spacelab cabin loop is marginal in heat rejection capacity.

The waste management subsystem operates on the principle of entraining waste material in a recirculated air flow and carrying it to a collector-separator unit at the bottom of the cage. Feces may be collected by vacuum cleaner from a grid. Urine is separated from the air stream and pumped into a waste storage tank. A sample can be collected for later analysis if desired.

Feeding and watering are accomplished by mechanically simple methods which require daily measurement of consumption and replenishment. The lighting subsystem uses 3-watt fluoroscent bulbs designed to be similar to the 12-watt bulbs that were flight-qualified for Skylab.

Data acquisition is provided by FM receivers for telemetered signals from implanted sensors. Also, complete instrumentation is provided for documenting habitat environmental conditions and making specimen behavioral measurements. Data is conditioned for display or transfer to the Spacelab command and data management system (CDMS).

2.2.2 System Design

The habitat designs feature sheet metal construction with polyurethane foam insulation for thermal and acoustic isolation. Cages are sealed to prevent unfiltered air leakage. Glass view windows are provided and doors for access to the specimens. The cages are mounted in standard dual-width Spacelab racks, with room for an 8-rat rodent module, a primate cage, and supporting equipment in each rack. These modules are self-contained and may be used in any desired combination to make up a flexible holding facility for a variety of research requirements.

The habitats are mounted on extendable slides and may be pulled out of the rack and rotated for easy access to the rear-mounted environmental control components. This makes practical in-flight replacement of failed components.

2.3 OPERATIONAL FEATURES

Specimens can be loaded into the Spacelab at about 6 hours before launch by means of a modified airlock hatch cover in the upper aft location in the Spacelab. Transfer modules are carried up to the Payload Changeout Room then transferred through the hatch opening and placed in their cages. Temporary floor components and other transfer equipment are then removed, the hatch cover replaced, and acceptable seal leakage verified. The launch countdown will require about 3.5 hours more than the generalized allocation due to the requirement for late-loading specimens.

While on-orbit, the planned scheduled and unscheduled maintenance activities can be performed by the research crewmen, as well as a normal program of scientific research. Timeline studies show that this can be done by a minimum of four Shuttle crewmen (commander, pilot, mission specialist, and payload specialist) with carefully controlled scheduling. One or two additional crewmen can be carried if desired.

After landing, it is necessary for an experimenter to access the Spacelab via the tunnel to obtain postflight data and prepare the specimens for offloading. The preferred means of off-loading is to install protective and handling GSE in the tunnel, ingress ground transfer units to the Spacelab along with handling personnel, and transfer the specimens out via the orbiter hatch soon after arrival at the Orbiter Processing Facility (OPF).

2.4 RECOMMENDED SUPPORTING RESEARCH AND DEVELOPMENT

An important feature of the conceptual design study has been the use of available components or methods based upon existing technology. However, there are some areas in which additional fundamental design effort is required. A review of the design for these areas has resulted in identification of the following items for supporting research and development.

- A waste management subsystem capable of collecting specimen waste and separating solids and liquids from the entraining air flow in zero-gravity so that samples may be taken for later analysis.
- Methods for obtaining and preserving adequate samples of urine and feces.
- Demonstration of filtration capability for obtaining the required reduction of microbial and radioactive contaminants in cage exhaust air streams to acceptable levels in support of research requirements.
- Design of specimen holding units, probably for small specimens such as rats or mice, which have closed environments in which toxic atmospheric trace contaminants can be used without danger to the balance of the Spacelab atmosphere.
- Design of modified specimen holding units for other specimens, principally cells and tissues, plants, and invertebrates.

2.5 RESEARCH SUPPORT CAPABILITY

An analysis of research support capability of the BSHF design presented in this report shows a broad capability for providing specimens for a number of scientific programs. The types of experimental programs that can be supported include the following:

Cardiovascular/Hemodynamics
Musculoskeletal Research
Fluid/Electrolyte Balance
Hematological Research
Neurophysiology

Metabolic Studies
Behavior and Performance
Pulmonary Function and Respiratory Research
Endocrine/Reproduction Studies
Excretory Research
Injury/Tissue Repair

2.6 OTHER AREAS OF STUDY

In addition to the technical areas of the conceptual design study which are summarized above and covered in detail in this volume, other study areas are covered in companion volumes. These include:

- Volume I: Executive Summary of the study
- Volume III: Specimen Support and Experiment Requirements and Design Criteria, detailing the specimen characteristics and research requirements for the design specimens and the modification required for other specimen types.
- Volume IV: Programmatics and Cost Analyses, which shows the planning documents, the schedules, and the projected program costs for the design, qualification, production, and flight operation of the BSHF.
- Volume V: Previously Qualified Equipment Data, presenting the data sheets resulting from the review of available hardware that was conducted during the initial portion of the study.

Section 3
DEFINITION OF REQUIREMENTS

The requirements for the BSHF were derived during the initial portion of the study reported herein. These requirements are determined by the overall need to provide for the support of living specimens with a minimum of imposed stress, other than that associated with weightlessness, while utilizing the resources available in the vehicle and meeting the imposed operational constraints. The three sources of these requirements are therefore:

A. The results of the Life Science Laboratory definition study which describe the constraints due to mission planning, allowable use of resources, and geometrical limitations of the Spacelab and Orbiter as well as defining the other equipment provided by the laboratory.

B. The necessity to support the specimens in a suitable environment, providing the resources which will enable the planning of a variety of meaningful research programs.

C. The constraints imposed by the prelaunch, on-orbit, and post-landing operations, which limit the times for loading and unloading specimens, impose design requirements and limitations on the BSHF, and determine the need for support equipment.

Additional requirements which affect the BSHF design are those imposed by the need to control program costs and minimize development risk. This results in considering the use of previously flight qualified hardware and/or the use of common components wherever this can be done without compromising the ability of the BSHF to meet other system requirements. These requirements, their sources, and derivation, are discussed in the section following.

3.1 LIFE SCIENCE LABORATORY MISSION AND CONFIGURATION CONSTRAINTS

The primary goal of the Life Science Laboratory project as reported in Reference 3-1 is to develop a general purpose laboratory capability and an inventory of common operational research equipment (CORE) for conducting research and operations. The ultimate capability consists of a Spacelab dedicated totally to life science research. Initially, 7-day missions would be flown, but most of the missions would be extended to a maximum duration of as much as 30 days or longer on orbit.

The study, Definition of Life Science Laboratories for Shuttle/Spacelab, which was performed by MDAC for NASA on contract NAS8-31367, has defined representative dedicated life science laboratories and typical experiment research areas that could be investigated within the laboratory. Smaller minilaboratories (700 to 1,500 pounds) consisting of from one to five Spacelab experiment racks containing life science research equipment have also been defined for possible use on missions shared by several disciplines. These minilaboratories would be limited to a specific series of experiment functions and could fly on 7- or 30-day missions, as appropriate. Laboratories in a third category are called carry-on laboratories (weighing about 50 pounds). They are generally dedicated to the performance of a single experiment and use only a limited amount of Spacelab resources. These laboratories may be planned well in advance or incorporated very late in the preflight operation on an opportunity basis, much like several experiments performed on Skylab.

The equipment contained in the laboratories to support research consists of several types which include the CORE items defined in the referenced study. Regular CORE equipment has a high probability of being common across all life science disciplines and would probably fly on a number of flights (say five or more). The primate cages, rat holding units, and other biological specimen holding facilities and related support are included in the regular CORE. Intermittent CORE items include equipment devoted to research in a single life science discipline or expected to fly on a limited number of missions (less than five). After the initial flight, these items may also be maintained as part of the CORE inventory. The CORE will be developed by NASA and furnished from a NASA inventory.

The LSL mission and configuration constraints applicable to the Biological Specimen Holding Facility are presented as follows:

- Applicable LSL Missions
- Applicable LSL Configurations and Capabilities

3.1.1 Applicable LSL Missions

The current NASA mission plan shown in Figure 3-1 is based on the life science flights 1 and 2 utilizing carry-on laboratories and being launched late in the 1979 calendar year (Shuttle missions 3 and 6), a minilaboratory flight on the first US/ESA Spacelab in 1980 (Shuttle mission 8), and a life science minilaboratory or a dedicated laboratory on a fourth space flight in 1981 (Shuttle mission 12). Tentative NASA plans call for approximately two minilaboratory flights and two dedicated life science laboratory flights in each subsequent year of operations. The three program options evaluated in the LSL Definition Study by NASA/MDAC under Contract NAS8-31367 include the following:

- Option IA - Early Medical Emphasis Program (A NASA baseline program)
- Opteion IIIA- Early Medical Emphasis Program
- Opteion IIIB- Early Biology Emphasis Program

The Program Option IA represents a medical emphasis program based on NASA-provided baseline laboratory definitions. A total of 51 flights are planned over the operational period from 1979 through 1991, averaging 4 flights per year during the latter years. Program Option IIIA is also a medical emphasis program based upon a more gradual buildup from minilabs into the dedicated labs. Program Option IIIB represents a biology emphasis program also based upon a minilab buildup into the dedicated labs in a series development. In all cases, the first four dedicated flights are 7-day missions and all subsequent flights are 30-day missions. Details of these programs and the LSL configurations within each option are presented in Section 3.1.2.

3.1.2 Applicable LSL Configurations and Capabilities

The BSHF equipment is required as part of the CORE for a majority of LSL configurations. The support capabilities and configurations of the life

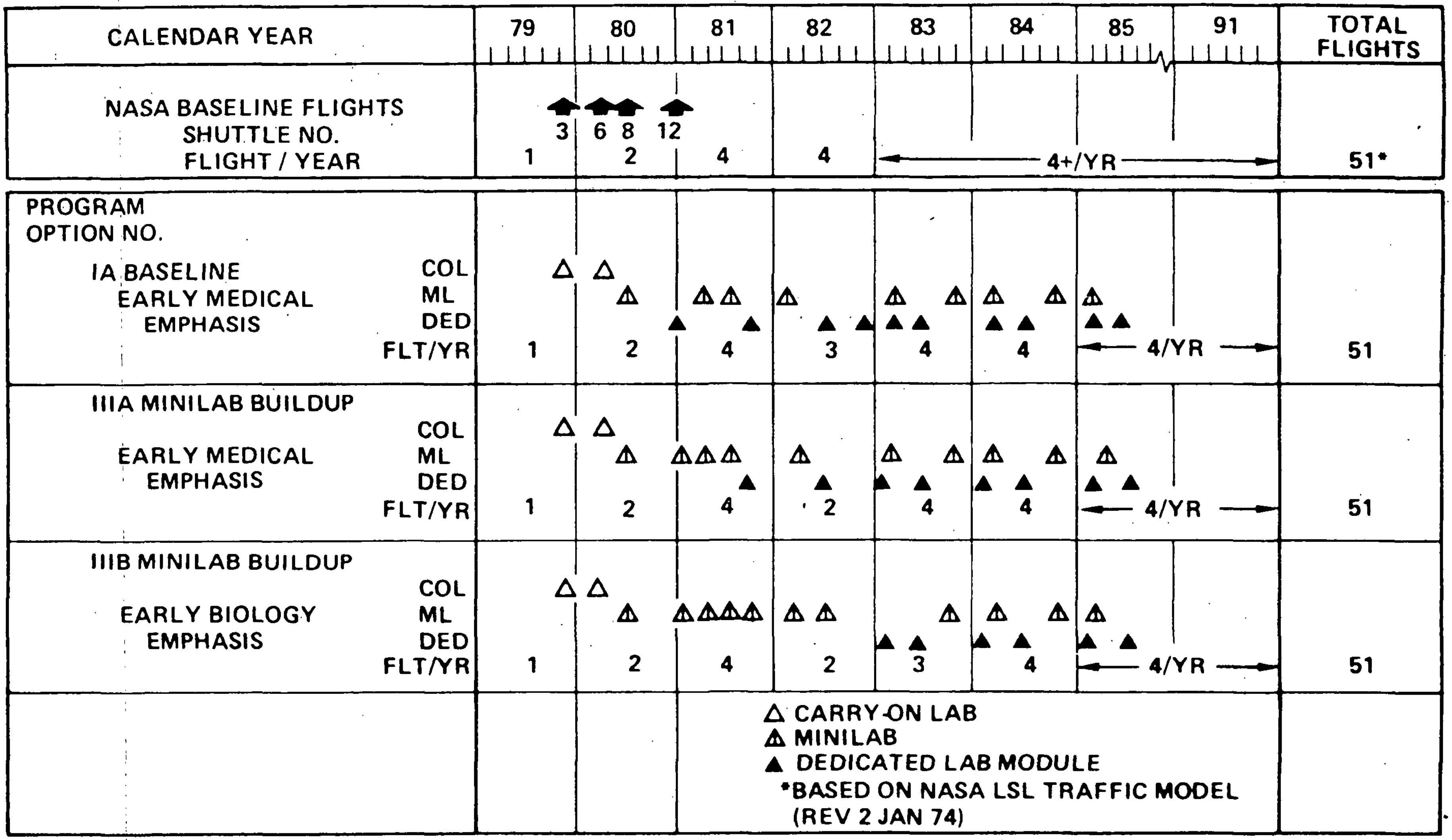


Figure 3-1. Flight Schedules for Life Science Laboratory

science laboratories that support the BSHF configurations are presented as follows:

- Life Science Laboratory concepts that accommodate biological specimen holding facilities
- Typical LSL accommodations for the BSHF
- Spacelab/Shuttle support capability

3.1.2.1 Life Sciences Laboratory Concepts that Accommodate Biological Specimen Holding Facilities

Several Life Science Laboratory types were examined within each of the three indicated options in the NASA/MDAC LSL Definition Study. Table 3-1 shows the laboratory configurations associated with each life science mission for each of the three options studied. Table 3-2 indicates the number and types of biological specimens required on each laboratory for each option. The laboratories containing no specimens are not included on this table. Also, no carry-on experiments containing biological specimens were considered in the three mission options. Small vertebrates such as rats, mice, and hamsters are flown with the greatest frequency, appearing on five labs in program Option IA, six labs on program IIIA and four in IIIB.

Primates appear on nearly as many labs in the three mission models as do the small vertebrates. Plants and invertebrates appear with the least frequency on program Options IA and IIIA, but are equal in frequency to small vertebrates and primates on Option IIIB.

3.1.2.2 Typical LSL Accommodation for the BSHF

A representative LSL layout is shown in Figure 3-2. Configuration MOD-1A-3 was used as the baseline in the LSL definition study to evaluate BSHF and other CORE accommodations. As noted in Reference 3-1, this configuration was used to: (1) establish and compare the CORE design, performance, and accommodation interfaces; (2) evaluate CORE commonality concepts for application to a variety of LSL options to permit ease of reconfiguration and maximum CORE reuse between labs; and (3) evaluate the CORE best grouping arrangement for both research convenience and

Table 3-1

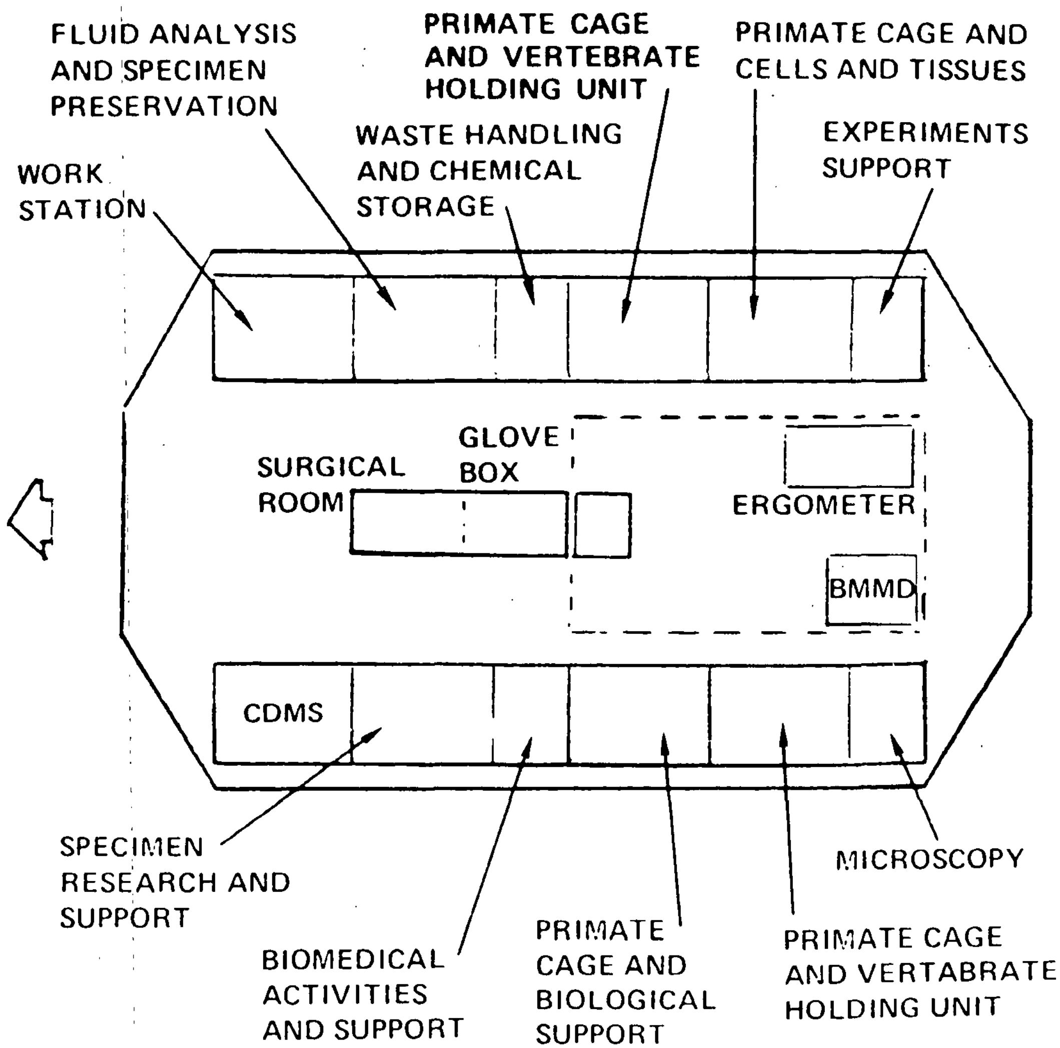
SELECTED MISSION MODELS

Option IA		Option IIIA		Option IIIB	
Laboratory	Mission	Laboratory	Mission	Laboratory	Mission
• COL-2A	1	• COL-2B	1	• COL-2B	1
• COL-3A	2	• COL-3C	2	• COL-3C	2
• ML-1A	3 and 6	• ML-1B	3	• ML-2B	3
• MOD-1A	4 and 7	• ML-3D	4	• ML-2G, ML-2H combined	4
• ML-3A	5, 8 and 11	• ML-2E	5	• ML-3D	5
• MOD-2A	9, 10, 12, and 13	• ML-2E, ML-2F combined	6	• ML-3E	6
• ML-2A	14 and 15	• MOD-1B	7 and 9	• ML-2E	7
• MOD-3A	16, 17, 20, and 21	• ML-3A	8 and 11	• ML-2E, ML-2F combined	8 and 9
• ML-5A	18	• MOD-2A	10, 12, 14, 16	• MOD-2A	10, 11, 13, 15
• ML-4A	19	• ML-2A	13 and 15	• ML-2A	12 and 14
		• ML-5A	17	• ML-5A	16
		• MOD-3A	18 and 20	• MOD-3A	17 and 19
		• ML-4A	19	• ML-4A	18

Table 3-2

BIOLOGICAL SPECIMENS INCLUDED IN LSL PROGRAM OPTIONS

Specimen Types	Laboratories Containing Biological Specimens																	
	Program Option IA					Program Option IIIA							Program Option IIIB					
	ML 1A	MOD 1A	MOD 2A	ML 2A	MOD 3A	ML 1B	ML 2E	ML 2E/2F	MOD 1B	MOD 2A	ML 2A	MOD 3A	ML 2G	ML 2G/2H	ML 2E	ML 2E/2F	MOD 2A	MOD 3A
Primates		4	5		2		1	1	1	5		2			1	1	5	2
Small Vertebrates	8	16	16	16	16		8	8	8	16	16	16			8	8	16	16
Plant units			1		2					1		2	1	1			1	2
Invertebrate units			1		2					1		2	1	1			1	2
Cells and tissues units	1	2	1		2	1				1		2	1	1			1	2
Frog otolith packages	2					2												



- RESEARCH CAPABILITY

  MAN-FLUID AND ELECTROLYTE BALANCE
  - CARDIOVASCULAR
  - RESPIRATION/ENERGY METABOLISM

  PRIMATES AND SMALL MAMMALS
  - MAINTENANCE AND OBSERVATION
  - MANIPULATION AND EXAMINATION
  - ELECTROPHYSIOLOGICAL
  - DISSECTION AND SAMPLE ACQUISITION
  - SAMPLE PREPARATION/PRESERVATION

  CELLS AND TISSUES

- CHARACTERISTICS

  MASS
  - TOTAL LAUNCH 23,000 LBM
  - TOTAL LANDING 21,800 LBM

  POWER
  - PEAK – 3.8 KW
  - AVERAGE – 2.4 KW

  DATA
  - BIT RATE AVERAGE 16 KBS
  - BIT RATE PEAK 40 KBS
  - TOTAL BITS/DAY 1.54 X 10^9

Figure 3-2. Integrated Approach for Dedicated LSL (LSL -MOD-1A:Medical Emphasis) operational efficiency application to all LSL options. The Mod-1A-3 configuration is highlighted to permit a better understanding of the BSHF accommodations as related to the LSL program. Descriptions of the other laboratory concepts are presented in Reference 3-1.

The Mod-1A is designed to support 4 primates, 16 rats, cells/tissues, and all of the 129 regular CORE equipment items. All of the 8 double racks and 4 single racks in the Spacelab are utilized in this configuration. Figure 3-2 presents a plan view of Mod-1A-3 laboratory showing the general location of major equipment. The laboratory research capability and characteristics are also noted in the figure. Figures 3-3 and 3-4 present a more detailed layout of the laboratory including the floor and rack accommodations of all regular CORE equipment items (EI's). The EI numbering system used in these figures is the same as that in Reference 3-1.

A review of the configuration shown in these figures shows that the right side of the laboratory supports two primate cages, two cells/tissue holding units, fluid analysis and specimen preservation, waste handling, miscellaneous experiment support, and monitoring hardware. The floor-mounted equipment provides principally surgical support, body mass measurement, and physiological exercise equipment. The left side of the laboratory supports an additional two primates, 16 rats, microscopy activities, specimen monitoring and research support, biomedical activities and CDMS. A more detailed description of the support capability of the equipment in each cabinet shown in Figure 3-4 is presented in Table 3-3 which also indicates the location and type of each of the cabinets.

The space available for the primate cage and rat holding unit installation in the Mod-1A-3 is shown in Figure 3-5. The arrangement helps provide interface data required to size for interchangeability and ease of reconfiguration within and between life sciences laboratories.

3.1.2.3 Spacelab/Shuttle Support Capability

The Orbiter provides for launch and return of the Spacelab. While in orbit, living accommodations are provided for the specialist crewmen who will perform the research. These include sleeping quarters, food and potable

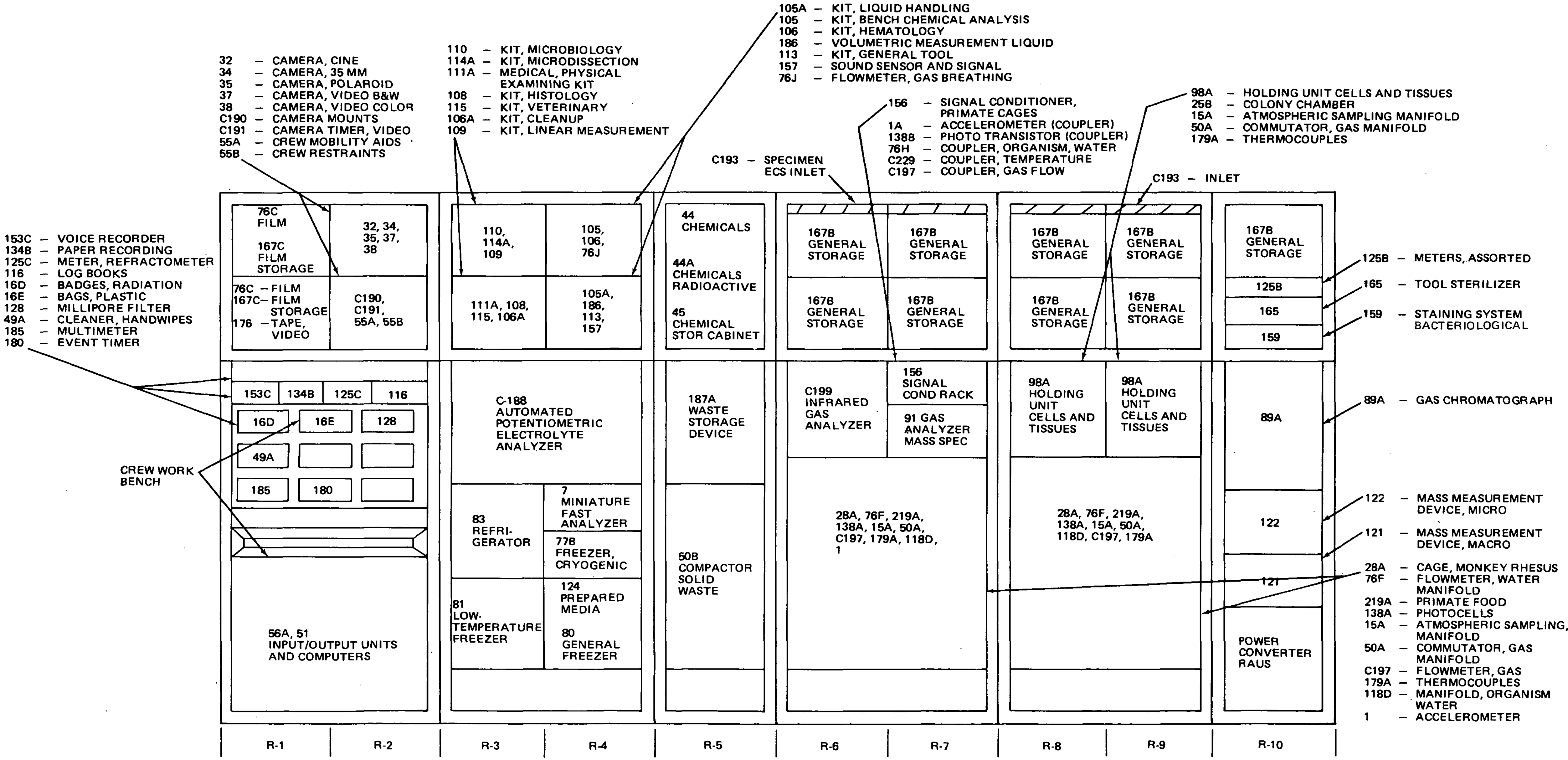


Figure 3-3. Life Science Laboratory Mod-1A-3 Medical Mission Configuration – Right-Hand Side of Laboratory, Facing Forward

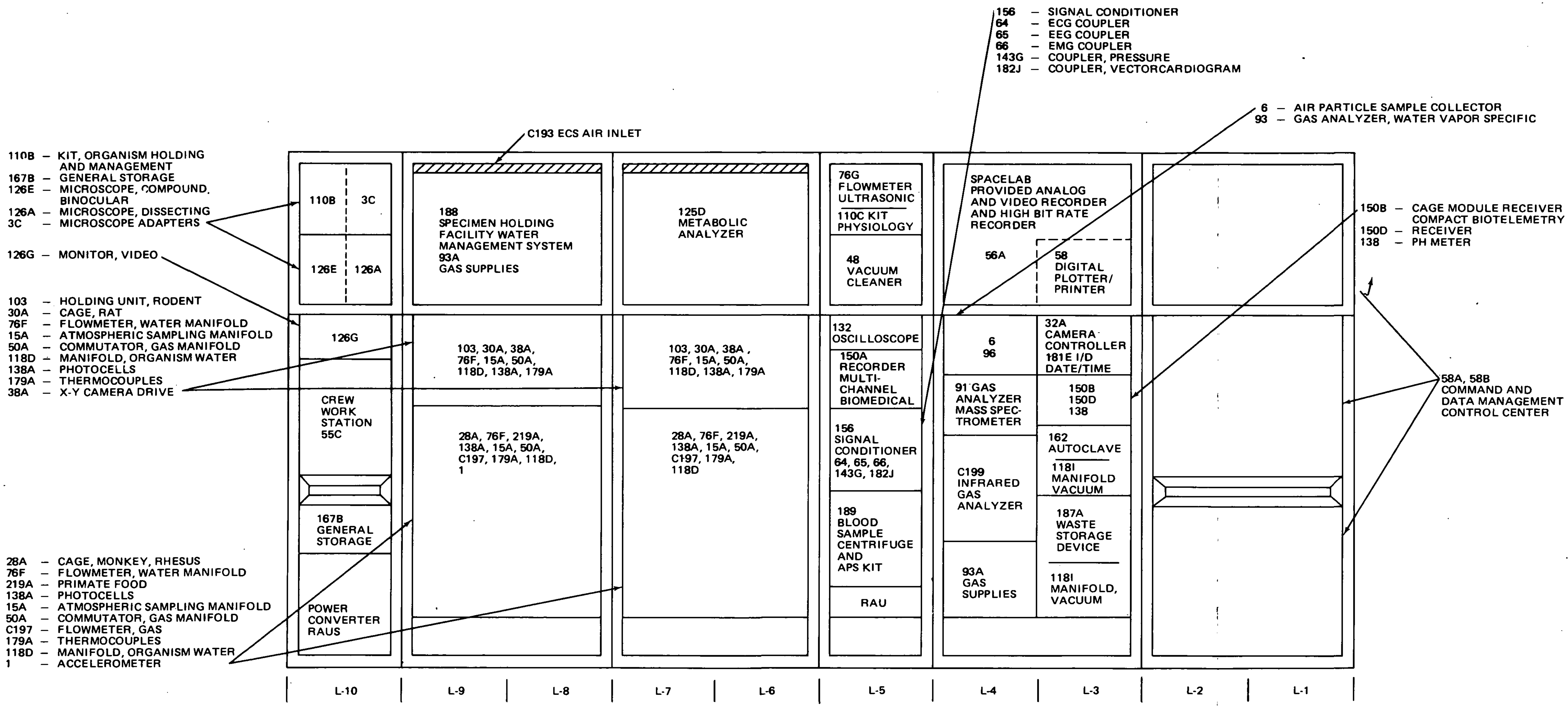


Figure 3-4. Life Science Laboratory Mod-1A-3 Medical Configuration – Left-Hand Side of Laboratory, Facing Forward

Table 3-3

MOD-1A-3 LABORATORY EQUIPMENT

Cabinet/ Location*	Rack Type	Major Equipment Description
R-1/R-2	Double	Crew work station, film valut, cameras, miscellaneous equipment storage, Spacelab I/O units and computers.
R-3/R-4	Double	Refrigerator/freezer, cryogenic freezer, fluid analysis equipment and CORE kit storage.
R-5	Single	CDMS RAU, waste management, radioactive and other chemicals storage.
R-6/R-7	Double	Primate cage and support equipment, IR CO analyzer, mass spectrometer (for O_2, N_2, methane, CO_2, NH_3 and relative humidity)
R-8/R-9	Double	Primate cage, cells/tissues holding unit, storage compartments.
R-10	Single	Micro and macro mass measurement units, power inverter/converter and RAU interface units.
L-1/L-2	Double	Spacelab command and data management system.
L-3/L-4	Double	Spacelab-provided analog and video recorder, cage monitoring receivers, gas analyzers, carrier gas storage, waste storage.
L-5	Single	Signal conditioners, oscilloscope, recorder, RAU, vacuum cleaner.
L-6/L-7	Double	Primate cage, signal conditioners, metabolic analyzer, specimen food and biotelemetry.
L-8/L-9	Double	Primate cage, small vertebrate holding unit, water supplies.
L-10	Single	Crew work station, microscopes, RAU's.
Floor-installed equipment	---	Surgical work bench, body mass mreasurement device, ergometer.

*NOTE: Locations are designated by R or L (right or left side of aisle) and a number. The number indicates the distance, in single rack widths, from the entry end of the Spacelab.

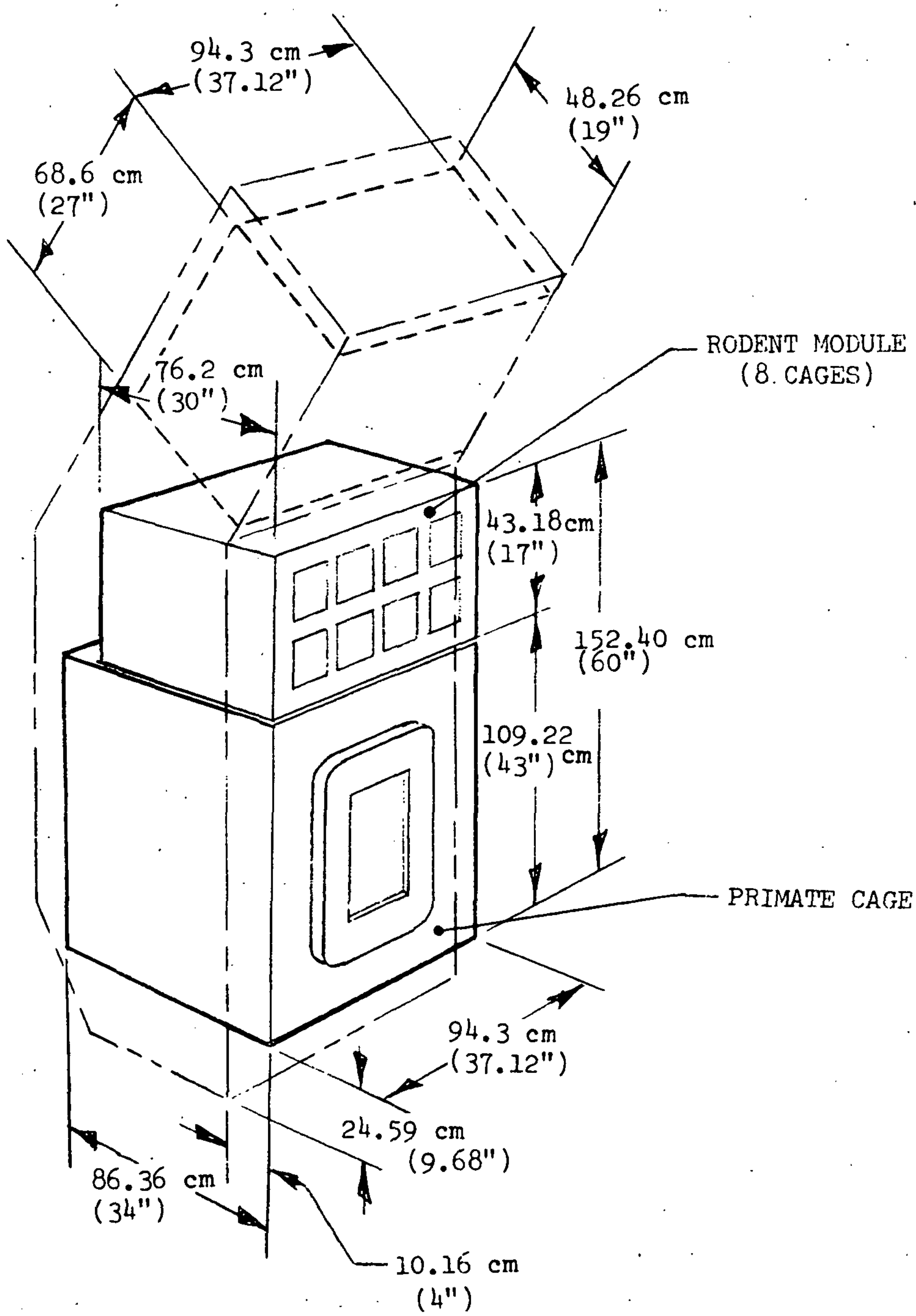


Figure 3-5. Primate Cage and Rodent Module Size for Spacelab Double Rack

water facilities, and waste management. The Orbiter also receives heat generated in the Spacelab and rejects it to outer space by means of radiators or to expendable refrigerants. It includes fuel cell power plants and reactants which will provide up to 7 kW of electrical power, continuously, and 12 kW for short periods. All communications with the ground stations, including transmission of telemetered data, are handled by the Orbiter.

The Spacelab, in the Life Science Laboratory configuration, consists of a dual pressurized module connected to the Orbiter by means of a crew transfer tunnel. This assembly is retained in the Orbiter payload bay during the mission and provides a facility in which the research equipment is carried and the experimental procedures are conducted.

Heat rejected by the BSHF will be transferred either to the Spacelab cabin air loop or the avionics air loop. The cabin air loop has a limited capability for heat removal, with a maximum of 1 kW above the metabolic loads of the 3-crewman design level. The avionics air loop can accept up to 4 kW total, but the temperature ranges up to 40°C (104°F). The Spacelab also conditions and distributes electric power, provides for data acquisition and management with a dual-width rack devoted to controls and displays, and provides crew work space. An independent atmosphere control is provided with N_2 stored on-board and O_2 taken from the Orbiter. CO_2 and humidity removal is performed on the cabin air loop.

More details of the support capability of the Spacelab/Shuttle to the BSHF are provided in subsequent sections of this report in appropriate areas. A detail description of these resources is given in Reference 3-2.

3.2 SPECIMEN SUPPORT AND EXPERIMENT REQUIREMENTS

The holding facility for biological specimens onboard the life science Spacelab must serve two principal functions. It must support biological specimens during the period of the mission (up to 30 days) in a condition of good health and baseline normalcy; and it must accommodate as wide a variety of experimental measurements and procedures as feasible within the constraints of design limitations, cost effectiveness, and Spacelab/Orbiter operations. The design characteristics of the holding facility must, therefore, be compatible with requirements derived from these two functional categories—support and experiment.

3.2.1 Specimen Support Requirements

Requirements specified in this section are those needed to maintain the health and normalcy of the specimens and are derived primarily from the physiological and behavioral characteristics of the specimens.

Specimen support requirements were determined and are designated for the two design organisms specified for this study — the rhesus monkey (Macaca mulatta) and the laboratory rat (Rattus norvegicus). Section 3.2.3 contains additional information which may be useful in assessing the impact on the design characteristics of the holding facility of accommodating specimens other than the two design organisms.

Specimen characteristics and support requirements were derived from information contained in a number of documents relating to the care and use of primates and rats as laboratory animals and experimental subjects. Values specified in the various sources were compared and evaluated, and the most consistent and agreed-upon values were selected for use in this study.

Extrapolation to the specified body weights of the design organisms (14 kg for the rhesus, 350 grams for the rat) were made where required. The various reports, handbooks, and other publications used in this survey are listed as References 3-3 through 3-34.

The values for the support requirements specified in this section are the result of two reviews by NASA personnel. The requirements were initially submitted to the Life Sciences Space Shuttle Payload Planning Working Group (LSSSPPWG); changes recommended by this group were then discussed with NASA representatives at the study's mid-term briefing and were incorporated as advised.

Facility characteristics and capabilities influenced by specimen support requirements include the size of the holding unit or "cage" in which the specimen is contained, the atmospheric composition of the holding unit, environmental characteristics, and specimen metabolic characteristics which govern or influence life support system capabilities. Examination of the values specified in the reference sources indicated that the required atmospheric composition and other environmental characteristics are essentially identical for both the rhesus monkey and laboratory rat. The required cage size and the specimens' metabolic characteristics are, naturally, quite dissimilar.

3.2.1.1 Atmospheric Composition

The atmospheric composition for both the rehesus and rat holding units should closely resemble the atmosphere to which the animals had been exposed in the laboratory during the collection of baseline data. This atmosphere is essentially "room air" with the following composition and allowable ranges:

Total Pressure:	101.3 kPa (760 torr) ±1.3 kPa (10 torr)
O_2 Partial Pressure:	22.0 kPa (165 torr) ±1.7 kPa (13 torr)
CO_2 Concentration Limits:	nominal - 0.67 kPa (5 torr) maximum - 1.01 kPa (7.6 torr)
Diluent Gas:	nitrogen

The composition specified for the Spacelab atmosphere is compatible with these requirements.

3.2.1.2 Additional Environmental Characteristics

In addition to atmospheric composition, certain other environmental parameters can potentially affect physiological characteristics of the specimens and should, therefore, be controlled within the holding facility. These include the following:

Air Temperature:	Selectable in the range 293 to 299K (20-26°C) controllable within ±1°K
Relative Humidity:	A value in the range of 40 to 65 percent, controllable within ±10% with not more than a 5% change in a 4-hour period
Illumination:	Type - cool white fluorescent controllable from 0 to 860 lm/m^2 with selectable cycles; normally 12 hours light/12 hours dark
Acoustic Noise:	Nominal, on-orbit - in accordance with Nc 50 curve maximum, launch - 120 db overall
Air Flow:	Nominal, 10 to 15 air changes per hour maximum, 60 ft per minute

3.2.1.3 Size and Dimensions of the Design Organisms

The size and dimensions of the rhesus monkey and laboratory rat selected for the design organisms will affect both the cage size and the metabolic characteristics of the animals.

A. Primate size and dimensions — In the 1974 NASA-ARC Conference, "Non-Human Primates in Space", the male, 14.0 kg (11 to 14 kg) rhesus was selected as the model for the initial design of the Shuttle animal maintenance hardware for nonhuman primates. Following this selection, a set of dimensions for the 14-kg male rhesus, measured directly from a research animal, were supplied by Dr. R. C. Simmonds of ARC. These dimensions are set forth in Figure 3-6 and will be used as the standard for this study.

B. Rat size and dimensions — In the ARC document, "Maintenance Requirements for Biological Specimens in Spacelab," supplied with the RFP for this study, the adult laboratory rat (Rattus norvegicus) weighing 350 grams was specified as the small mammal design organism. Dimensions for this specimen were not needed, since cage sizes are characteristically specified in the literature on the basis of body weight rather than on specific dimensions.

3.2.1.4 Specimen Holding Unit Dimensions

Cage space requirements identified in the literature (References 3-5, 3-8, 3-14, 3-18, 3-23, 3-25, 3-28, and 3-30) generally follow those specified by either the Institute of Laboratory Animal Resources (ILAR) "Guide for the Care and Use of Laboratory Animals," or the Department of Agriculture Requirements. These requirements are specified for animals maintained in a terrestrial holding facility for long periods and are not necessarily completely applicable to experimental cages or to the zero-g situation. It was, however, decided that until other criteria are established by actual experience, these requirements should generally govern the design characteristics of the Spacelab holding facility.

The various considerations and calculations which were involved in determining the required cage dimensions are described in the Volume III of this report. Only the resulting dimensions will be included here.

A. Primate Holding Unit Dimensions:

Width:	76.2 cm (30 in)
Depth:	61.0 cm (24 in)
Height:	86.4 cm (34 in)
Floor Area:	0.46 m^2 (5.0 ft^2)
Unit Volume:	0.40 m^3 (14.2 ft^3)

B. Rat Holding Unit Dimensions

Width:	20.3 cm (8 in)

NOTE: Dimensions in inches (cm)

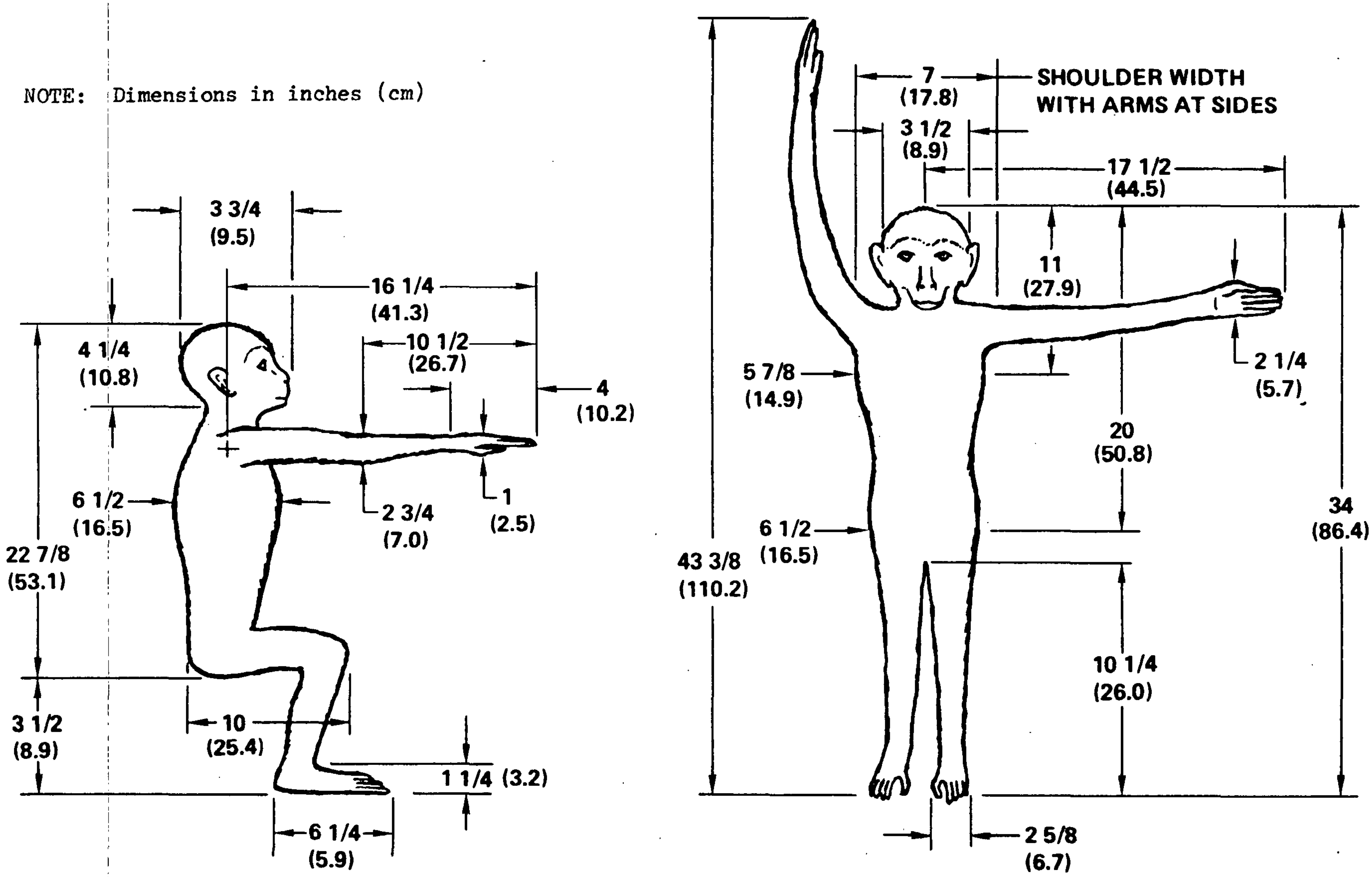


Figure 3-6. Standard Dimension of a 14-kg Male Rhesus (Macaca Mulatta)

Depth:	30.5 cm (12 in)
Height:	15.2 cm (6 in)
Floor Area:	619 cm^2 (96 in^2)
Volume:	9411 cm^3 (576 in^3)

The rats, unlike the rhesus, may be housed individually or in groups. Groups as large as 25 may be housed together but generally the group size is limited to 10.

Mature adult rats in excess of 300 grams require 40 square inches of floor space per animal; immature rats from 200 to 300 grams require 29 square inches of floor space per animal. The smallest recommended cage size even for one rat is 8 by 12 in. in floor dimensions and 6 inches in height. This cage size, however, is also sufficient for two 300+ gm rats or three 200 to 300 grams rats.

3.2.1.5 Specimen Metabolic Characteristics

The amount of oxygen that must be delivered to specimens within the holding facility and the amounts of heat, CO_2, and water vapor that must be removed, as well as other life support factors such as food and water supply and waste management, are directly related to the metabolic characteristics of the specimens. These characteristics were selected from a survey of the values identified in the literature and adjusted for the sizes of the design organisms.

The procedures and calculations used in determining the values listed below are described in the previously mentioned MDAC requirements report (Vol III).

A. Primate Metabolic Characteristics (based on the 14-kg male rhesus monkey)

O_2 consumption	0.30 kg (222 l) O_2/day
CO_2 production	0.38 kg (202 l) CO_2/day
total metabolic heat production	4.40×10^6 Joules (1050 kcal)/day
sensible heat	3.08×10^6 Joules (735 kcal)/day
latent heat	1.32×10^6 Joules (315 kcal)/day
evaporative water loss	525 g H_2O/day
food consumption	300 g of food pellets/day
water consumption (total)	1,300 g/day (1.3 liters/day)

urine volume	840 g/day (0.84 liters/day)
fecal mass	86 g/day
fecal water	66%
fecal bolus consistency	semifirm
fecal bolus size (grid size permitting passage 1.5 by 1.5 in)	

B. Rat Metabolic Characteristics (based on the 350-gram laboratory rat)

O_2 consumption	0.03 kg (22 l) O_2/day
CO_2 production	0.037 kg (20 l) CO_2/day
total metabolic heat production	4.54×10^5 Joules (109 kcal)/day
sensible heat	3.04×10^5 Joules (13 kcal)/day
latent heat	1.50×10^5 Joules (36 kcal)/day
evaporative water loss	59.7 grams (day)
food consumption	25 grams/day
water consumption (total)	64 grams/day (64 ml/day)
urine volume	13 grams/day (13 ml/day)
fecal mass	9 grams/day
fecal water	65%
fecal bolus consistency	firm
fecal bolus size: (grid size permitting passage 1/2 by 1/2 in)	

3.2.2 Specimen Experiment Requirements

In addition to holding facility design requirements derived from the physiological characteristics of the specimens and directed toward the maintenance of their physiological normalcy, other design requirements are related to the particular use of the specimen as an experimental subject and the requirements imposed by the experimental protocol. A survey of experiments included in the literature, which were recommended for future flights or used as examples in feasibility studies, was used to identify the most frequent experimental variables that require special holding facility design characteristics. These variables, characteristic of past recommended experiments, are expected to be representative of those of future actual experiments.

A total of 82 experiments using non-human primates or rodents were analyzed for experiment requirements. The documents in which the experiments were described are References 3-34 through 3-44. A number of factors were considered in determining which experimental requirements should be included, as a baseline, in the holding facility design and which should be regarded as experiment specific and incorporated only when required by a specific experiment protocol. These factors included the percent of the experiments surveyed which required a particular facility capability, the increased facility cost resulting from the incorporation of the capability, and the technical problems involved in the incorporation. The MDAC requirements report (Vol III) and the concept selection report detail the procedures and results of these analyses; only the conclusions will be presented in this report. The selected experiment requirements were reviewed by NASA concurrent with the specimen support requirements and the recommendations made during the mid-term briefing have been incorporated.

3.2.2.1 Number of Specimens Per Holding Unit

The number of specimens usually required as subjects by experiments involving the rhesus monkey or laboratory rat was examined to determine the desired number included in a holding unit.

A. Number of Primates - "Agressive" behavioral characteristics in the rhesus dictated that they be housed one individual to a cage. It will generally be necessary, therefore, to include a separate holding unit for each unrestrained primate experimental subject. It is possible, however, to situate two restrained primates or two or more immature specimens to each holding unit.

B. Number of Rats - The number of rats used in the reviewed experiments usually ranged from 6 to 30 rats, discounting ground controls. In general, rats were used in multiples of 6, with 6 and 18 being the most commonly observed subject number. Each 6 rats should be supplemented, in most cases by two "standby" rats that could be used as substitute subjects in the event that one or two of the primary subjects were not usable.

A holding unit sized for 8 rats, individually caged, should serve as the basic unit. The cage size dimensions, as indicated in Section 3.2.1.4, will accommodate additional specimens if colony caging is allowed by the experiment protocol.

3.2.2.2 Experiment Duration

For both primates and rats, life support and experiment expendables should be sized for an experiment duration of 30 days as a baseline.

3.2.2.3 Specimen Observation

The design of both the primate and rat holding units should provide for visual observation of all specimens without disturbing the unit.

3.2.2.4 Photographic or Video Recording

The holding unit should provide the capability for photographic or video recording of all specimens through a view port or window with an externally mounted or hand-held camera. Capability for mounting a camera internally within the unit is not considered a baseline requirement.

3.2.2.5 Specimen Access

A. Access to Primates - Provisions are required for restraint of the primate within the holding unit in order to allow close visual or manual inspection, the administration of drugs and anesthetics or the collection of blood or urine samples. Complete access for manipulation or removal should be provided to the anesthetized or tranquilized primate.

B. Access to Rats - Provision should be made for removal of the rat from the holding unit. No requirement is foreseen for restraint or manipulation of the rat within the cage module.

3.2.2.6 Specimen Removal and Transfer

Removal of the rat or the anesthesized rhesus from the cage module for transfer to some other experimental area may be accomplished without isolating the specimen from the Spacelab environment. If the experiment protocol requires that the primate remain unanesthetized during the transfer, the use of a transfer unit would be mandatory. The attachment of a transfer unit to the holding unit for such a purpose would constitute an experiment specific modification.

3.2.2.7 Specimen Food and Water Intake Measurement

A means should be provided for the measurement of the food and water consumption of the primate and the individually housed rat. The measurement will normally be made on a 24-hour basis, but shorter time intervals may also be required.

3.2.2.8 Waste Collection and Sampling

Provisions should be made for the separate collection of feces and urine. The collection and retention of the total urine volume in a liquid form with little evaporative loss would be the most desirable from an experimental point of view; absorption of urine in a wicking material which may be removed and stored for chemical analysis would be an acceptable alternate. The design should minimize the cross-contamination of urine and feces as much as possible, and at least to the extent encountered in terrestrial specimen cages.

3.2.2.9 Biotelemetry

The baseline design of the holding facility should provide for the telemetry of signals from sensors implanted within the animals. The sensor and transmitting unit should be the responsibility of the investigator; the holding unit, however, should provide the necessary shielding, incorporation of the antenna, and the subsequent equipment necessary for conducting the signal to the Spacelab data management system.

Telemetry of a number of signals from the primate holding unit should be provided for. Signals from the rat will probably be restricted to body temperature and the electrocardiogram.

3.2.2.10 Specimen Activity Levels

The measurement of specimen activity within the holding unit should be provided for both the primate and the rat.

3.2.2.11 Behavioral Measurements

The measurement of conditioned behavior in either the primate or rat by methods other than visual observation and photographic or video monitoring should be considered experiment specific and not be included in the baseline unit designs.

3.2.2.12 Special Atmospheres

The supply of special atmospheres to the holding units requiring a closed environmental control system should not be included in the baseline design.

3.2.2.13 Specimen Restraint During Launch and Landing

No provisions are required for restraint of either primates or rats during Spacelab launch, reentry, or landing operations.

3.2.2.14 Microbial Filtration of Holding Facility Air

Provisions should be included for the filtration of air both entering (inlet air) and leaving (exhaust air) the holding unit. The filtration capability should equal that used in disease-free and infectious disease, land-based, animal holding facilities — 0.7 to 0.9 micron with a particle retention efficiency of at least 99%. The capability for air circulation without filtration should also be included.

3.2.2.15 Use of Radioisotopic Tracers

The design of both the primate and rat holding units should be compatible with the maintenance of specimens containing any of a variety of radioisotopic tracers normally used in biological experimentation. It is not recommended that the tracers be administered within the holding unit. All other procedures should be in accordance with safety regulations normally observed in ground facilities including the approval of a radiation safety officer. The design of the holding units should include the capability of incorporating scrubbers for the removal and isolation of CO_2 and H_2O from the unit atmosphere when either ^{14}C or ^{3}H are included in the tracer material.

3.2.3 Impact of Other Specimens

Although the primary focus of the conceptual design study of the BSHF was on the rhesus monkey and laboratory rat, it is desired to eventually provide habitats for a wide variety of specimens including cell and tissue cultures, plants, invertebrates, and other vertebrate forms. The following information is presented to assist in the evaluation of the impact that the accommodation of other specimens would have on a holding facility basically designed for primates and rats.

3.2.3.1 ILAR Group 3 Monkeys Other than the Rhesus

This group contains Macaques and other large African species up to a body weight of 15 kg. Any member of this group may be accommodated within the primate holding unit without any modification of the unit.

3.2.3.2 Smaller Primates - Cebus and Squirrel Monkeys

The specimens would be accommodated in the primate holding units. Cebus and squirrel monkeys tolerate colony better than the Rhesus and may be housed two or three to a cage.

Only minor modifications of the primate holding unit would be necessary to accommodate the smaller monkeys: the nipple on the water dispenser changed to a smaller size and a pellet dispenser capable of dispensing smaller sized pellets installed. All other design characteristics of the holding unit should be compatible with the accommodation of these specimens.

Both cebus and squirrel monkeys are new-world primates which normally inhabit a more tropical environment than that of the rhesus. A significantly higher humidity (~70%) may, consequently, be required for these specimens. Since the Spacelab ECS will not produce humidity of this magnitude, some means will have to be incorporated for moisturizing the cage air.

Because of the smaller size of the fecal bolus of these primates, waste management (fecal entrainment) may be able to be carried out with equal efficiency to that of the Rhesus with a significantly decreased air flow.

3.2.3.3 Cats, Dogs, Small Swine, and Mini-goats

These specimens would be accommodated in the primate holding units. Normally only one individual would be housed per unit.

Some modifications to the primate holding unit would be required although the major elements of the unit such as the environmental control system and the waste management system appear to be satisfactory in their present design.

Important modifications would include the following:

A. Replacement of the pellet dispenser with an alternate feeding method.

B. Replacement of the water dispenser with an alternate method for specimen watering.

C. Replacement of the primate unit flooring with a metal grid compatible with both specimen foot support and with passage of the fecal bolus.

D. Installation of a restraint system, such as cables and take-up reel, which will hold the specimen to the cage floor.

E. Alternate approaches to waste management should be investigated in the case of dogs or cats, both of which may be trained in this regard.

3.2.3.4 Mice, Hamsters, Gerbils, and Guinea Pigs

These specimens would be accommodated in the rat holding units. Any of these specimen types may be caged individually or in colonies. Each rat cage will accommodate 5-10 mice, 1-6 hamsters, or one quinea pig with a body weight of 350 grams or less. If accommodations for larger guinea pigs are desired or larger colony cages for the other rodents, significant modifications would have to be made in the holding unit structure: the cage module walls would have to be repositioned and the ducting for ventilation would have to be reconfigured.

Hamsters, gerbils, and guinea pigs should be able to use the water and food pellet dispensers designed for use by rats; mice, however, will require that the water dispenser to replaced by one of a smaller size, and the food system adapted to the smaller size of the animal.

The flooring grid size selected for rats should be satisfactory for all of the other rodents except mice which will require a floor with smaller sized grids.

3.2.3.5 Rabbits

The floor area of the primate cage would be sufficient to accommodate one rabbit larger than 4 kg, or two rabbits of 2 to 4 kg, or four rabbits of less than 2 kg. Modifications of the primate unit required to effect the accommodation of rabbits would include: replacement of the water and food dispensing systems; a change in the floor grid size and configuration; and the installation of some form of restraint, similar to that described for cats and dogs, to hold the rabbit to the cage floor.

The total specimen volume available in the rat unit (34 by 12 by 16 in) would be sufficient to accommodate one rabbit of 4 kg or less. However, the extensive modifications that would be required in the structure and ventilation system would appear to make it impractical for this purpose.

3.2.3.6 Nonaquatic Plants

A variety of plants have previously been used or recommended for space experiments. These include Tradescantia (spiderwort), Tritium (wheat) seedlings, Capsicum (bell pepper), Tayetes (Dwarf marigold), pine seedlings, Arabidopsis (mouse-ear cress), and Cucumis (cucumber vine), all of which vary widely in physical characteristics and growth patterns. Despite these variations, all of the above plants and most other potential specimen types can be accommodated within the dimensions occupied by a rat holding unit, 17 in high by 36 in wide by 24 in deep. The following modifications would, however, be required for their accommodation.

A. Internal Configuration - The divisions between the cage modules and the environmental control and ventilation system would have to be removed to clear the unit for plant accommodation. Holders for plant containers and other support devices should be installed on an experiment specific basis considering the differing physical characteristics of the potential plant specimens.

B. Atmospheric Supply - Spacelab air is not acceptable in many plant experiments. Bottled gas might be substituted as a supply source for plant atmospheres. A closed ECS is not recommended because of potential buildup of toxic contaminants. Minimal air turnover requirement should allow dumping of used gases into Spacelab air. The holding unit should be sealed to prevent inboard leakage of Spacelab air.

C. Temperature and Humidity - Insufficient selectability and control of temperature and humidity are available in the design of the small vertebrate unit ECS. A redesign of the system will be needed to meet plant requirements.

D. Illumination - Insufficient illumination levels are available in the small vertebrate unit to meet plant requirements. Additional lighting units must be installed to yield up to 1,000 f-c at plant surface. Some flexibility of arrangement of lights should be available to principal investigators. Lights must be cooled without ventilation air impinging on specimens. Rerouting of unit ventilation air will be required.

E. Holding Unit Material - An examination of the outgassing characteristics of the small vertebrate holding unit materials will have to be made to ensure that no products toxic to plants will result.

F. Nutrition and Water - A capability must be provided for plant watering.

G. Photography and Video Monitoring - Provisions should be made for the installation of video or photographic cameras within the holding unit. The present design does not include this capability.

H. Environmental Monitoring - Sampling and analysis of the atmosphere for component gases and selected trace contaminants is necessary at frequent intervals.

Temperature sensing will be required at several locations within the unit to ensure thermal homogeneity. Additional sensors may have to be installed for this purpose.

The installation of acceleration and vibration sensors will also be required if they are not already installed on the unit proper.

A. Prelaunch and Postlanding Operations - Plant geotropic growth and movements would be significantly influenced by any reorientation of the specimen in the earth's gravitational field. Prelaunch operation would produce such a reorientation for plants whose containers are located on the "floor" of the holding unit. For experiments in which this would be a problem, other arrangements of plants within the unit would be required.

B. Environmental Control System Requirements - The dwarf marigold (Tayetes patula) has been selected as the design organism for plant research; its metabolic and environmental characteristics will serve to exemplify the requirements that the environmental control and life support system must be designed to meet.

C. Oxygen - Carbon Dioxide Exchange - Plants exhibit two forms of O_2 - CO_2 exchange, respiration and photosynthesis, which are normally conducted simultaneously during most phases of the plant's diurnal cycle.

Respiration, which supports plant metabolism, requires the intake of oxygen in order to catabolize stored carbohydrate to produce the energy required to maintain the plant's vital functions. The process includes the release of carbon dioxide as a metabolic byproduct. When the plant is maintained in a relatively constant temperature it will exhibit a fairly steady respiratory (metabolic) rate which, in the case of the dwarf marigold is in the order of:

Oxygen consumption: Approx. 0.3 to 0.5 ml/plant/day

CO_2 production: Approx. 0.2 to 0.4 ml/plant/day

Photosynthesis, observed most prominently in leafy, green plants, involves the use of photic energy to manufacture carbohydrates from atmospheric carbon dioxide with the release of oxygen. The rate of photosynthesis is affected to a much greater extent by environmental factors such as light intensity and CO_2 concentration than is respiration. Values given in the "Handbook of Biological Data" indicate that, under optimal natural conditions, the sunflower (Helianthus annuus) can fix by photosynthesis approximately 1.25 to 5.5 times the amount of carbon dioxide produced by respiration; under optimal artificial conditions, however, (4460 ft-c of light and 5% CO_2) the rate of CO_2 fixation increased to about 18 times the respiratory CO_2 production rate.

Sufficient atmospheric exchange should always be provided to satisfy the plants respiratory (metabolic) requirements. The amount of ventilation required to supply the plant's photosynthetic needs is experiment dependent and should be preplanned to suit the needs of each individual experiment.

D. Atmospheric requirements

1. Atmospheric pressure - 760 torr, same as Spacelab
2. Oxygen partial pressure - 165 torr ±13 torr, same as Spacelab
3. Carbon dioxide concentration limits - 0.300 torr maximum (this constitutes a significantly lower limit than allowed for Spacelab air)
4. Temperature - 24° ± 1°C, at least, 90% of the time; 5°C - 32°C the other 10% (Note: The accurate control of temperature with selection within the range 20 to 30°C is more important with plants than most other specimens.)
5. Relative humidity - 70% ±10% for 90 percent of flight (selectability within the range of 40 to 80% is also desirable

6. Air fow - cannot impinge on specimens or specimen modules

E. Other environmental characteristics

1. Illumination - fluorescent (3,500 to 8,000A), up to 16,146 lumens/sq meter at plant surface
2. Noise - not greater than 130 db
3. Acceleration and shock - less than 30g/11 m sec
4. Gravitational acceleration - 10^{-5} g desired for 95% of flight, maximum limit 10^{-3}g continuous

3.2.3.7 Nonaquatic Invertebrates

A variety of invertebrates have previously been used or recommended for space experiments. These include: Habrobracon (parasitic wasp), Drosophila (fruit fly), Tribolium (flour beetle), Periplaneta (cockroach), Musca (housefly), Araneous (spider), and Dyschirius (beetle). Although the physical characteristics of these and other potential candidate invertebrates vary extensively from one species to another, most forms will require small-sized containers for their housing. A holding unit volume approximately one-half that occupied by the rat holding unit would be sufficient, in most instances, to accommodate all invertebrates required by the experiments on a single mission. The following additional alterations would be necessary for the accommodation of invertebrates.

A. Internal Configuration - The individual containers housing the invertebrate specimens should be designed by the principal investigator to suit the purposes of his experiment. The container holders installed within the holding unit should, likewise, be experiment specific.

B. Atmospheric Supply - Same as that described for plants.

C. Temperature - Controllable at any point within the range of 5 to 30°C ± 0.5°C.

D. Humidity - Controllable at any point within the range of 40 to 80 percent ±5% relative humidity.

E. Holding Unit Material - Must be examined for outgassing characteristics of potential toxicity.

F. Nutrition and Water - Crew access to containers necessary for replenishment of food and water supply.

G. Environmental Monitoring - Same as that described for plants.

H. Environmental Control System Requirements - The fruit fly (Drosophila melanogaster) is the design organism for invertebrate research. The characteristics and requirements of the fruit fly will exemplify environmental control and life support requirements for the invertebrate holding unit.

I. Metabolic characteristics

1. Oxygen consumption: 0.03 ml/fly/day
2. Carbon dioxide production: 0.024 ml/fly/day
3. Food consumption: 0.04 mg/fly/day
4. Water consumption: contained in food

J. Atmospheric requirements.

1. Atmospheric compositon: same as that described for plants
2. Temperature: 19° - 24°C ± 2°C
3. Relative humidity: 40 to 60% ± 10%
4. Air flow: 10 to 15 ml/day/container (just sufficient to maintain atmospheric characteristics)

K. Other environmental characteristics

1. Illumination: 5-75 ft-c for observation, cycling required
2. Gravitational considerations: 10^{-5}g desired 95% of flight, 10^{-3}g maximum allowable continuous acceleration.

3.2.3.8 Aquatic Specimens

Aquatic specimens may include vertebrates, invertebrates, plants, and protists. Regardless of the specimen type, the experiental organisms will be contained in unique containers specifically designed by the principal investigators. A supply of air or 100% oxygen must be available from the holding unit to each container unit. Some means of changing or circulating the water in order to remove metabolic waste products must be included. The installation of the containers into the holding unit should be specific to the container design.

Either the plant or invertebrate holding units would be satisfactory for aquatic specimen containers as long as an air or oxygen supply was available directly to the container. The method of oxygenating the aquatic medium and removing waste products of the specimens would be experiment specific.

3.2.3.9 Cells and Tissues

Microbial specimens, cell and tissue cultures, protozoans, and other protists may be included as experiment subjects. An incubator unit capable of supplying both aerobic and anaerobic atmospheres will be required. It would appear that the modifications of the rat holding unit required to accommodate these specimens are sufficiently extensive to warrant its replacement by a specifically designed cells and tissues holding unit.

Volume requirements would not be expected to exceed one-half of that occupied by the rat holding unit. Experiment specific containers and container units would hold the organisms with installation requirements specific to each container type. A thermostatically controlled heater would heat incoming air or holding unit air to the required temperatures. If aerobic and anaerobic organism were used simultaneously, sealed sections of the unit would have to be incorporated for each type with separate gas supplies to each section.

A. Temperature - controllable at any point within the range of 20° to 40°C ± 0.5°C.

B. Humidity - controllable at any point within the range of 40 to 80% ± 5% RH

C. Light - Fluorescent with a selectable intensity between 0 to 5,382 lumen/sq meter and a cycle programmable at 30-minute intervals.

D. Atmospheric Supply - May require closed recyclable system.

E. Gas Composition - nominally, cabin air, may require capability for other gas mixtures.

3.3 OPERATIONAL REQUIREMENTS

Operational requirements and constraints which influence the design and operational use of the Life Science Laboratory are imposed by the scientific community, NASA Program Office, NASA Centers, and Shuttle and Spacelab Systems. The requirements and constraints from these sources and from study results are defined herein by mission phase as they pertain to the design and/or operation of the Biological Specimen Holding Facility and associated support equipment and as they impact Orbiter/Spacelab interfaces.

3.3.1 Prelaunch Operations

The basic requirements and constraints that dictate acceptable prelaunch operational concepts are defined by the Access Requirements formulated by the NASA Life Science Space Shuttle Payload Planning Working Group and the KSC-developed Shuttle/Spacelab turnaround allocations and ground rules (References 3-45, 3-46, and 3-47).

Life Science Working Group access requirements which pertain to prelaunch specimen loading are summarized as follows:

A. From the time that specimens are loaded, the Orbiter/Spacelab system must provide a habitable atmosphere, means for specimen sustenance, and continuous monitoring of specimen condition until the specimens are offloaded.

B. Continuous power is required for ECLSS and data management system operations from the time of specimen loading.

C. Specimens should be loaded as late as possible prior to launch.

D. Specimen data and samples are required within 6 hours before lift-off.

E. If specimens are loaded prior to launch day, daily access for two men for 4 hours per day is required at the same time each day.

F. If specimens are loaded prior to launch minus 12 hours, two-man access is required for a contingency or final visit of 2-hour duration.

G. The maximum time from last access prelaunch to first access on orbit is 12 hours (8 hours desired), and first access on orbit will not be later than launch plus 2 hours.

H. Experimental specimen data is required before specimens adapt to zero gravity.

The KSC Shuttle pad allocation for payloads loaded in the Operational Processing Facility (OPF) is shown in Figure 3-7. This 24-hour pad allocation is the basic plan for prelaunch activities which must be considered when studying means to provide for loading of live specimens at the launch pad.

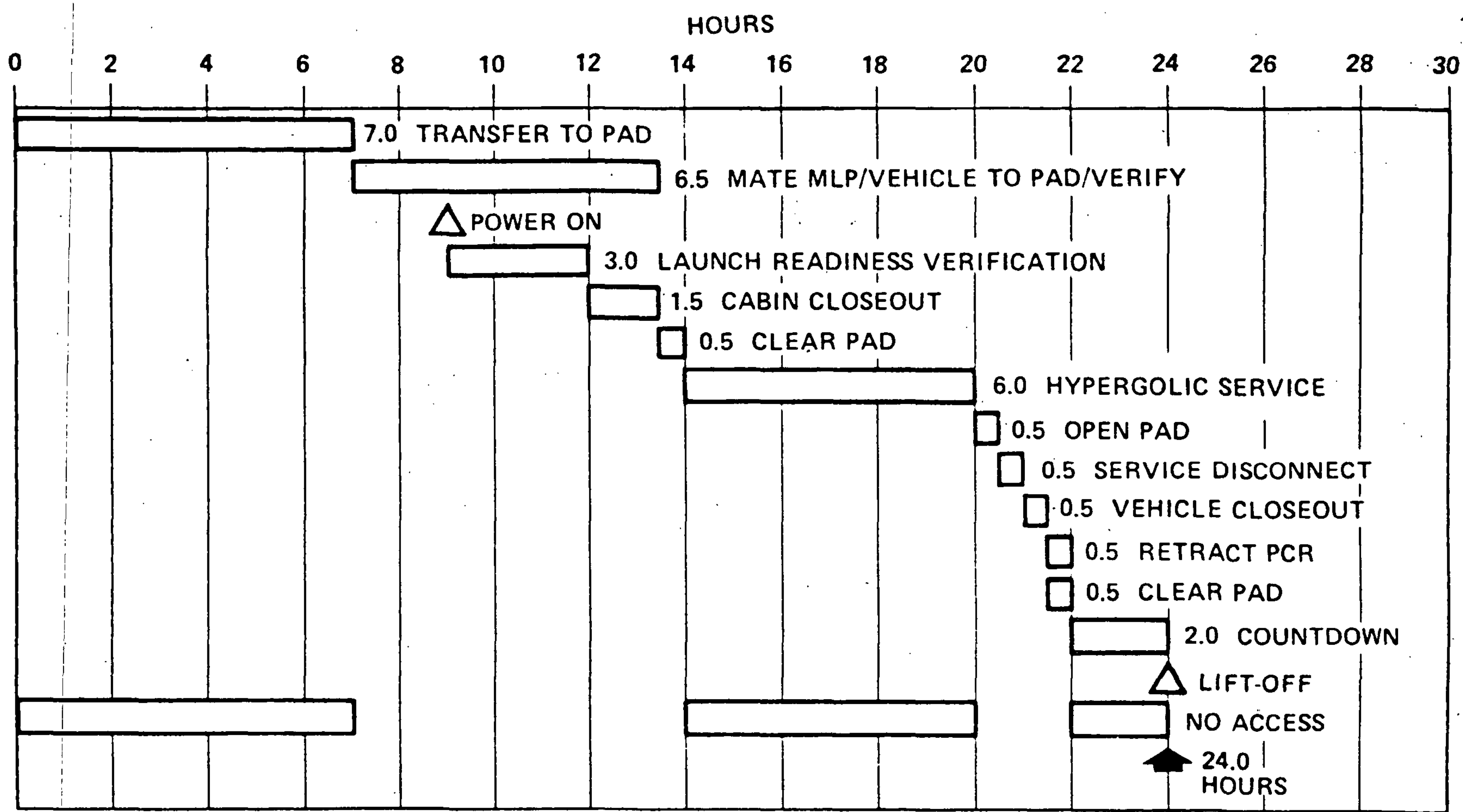


Figure 3-7. Shuttle Prelaunch Pad Allocation

Pertinent KSC Shuttle turnaround allocation ground rules applicable to prelaunch operations are as follows:

A. Launch pad operations are performed on a nominal "around-the-clock" basis. Operations at other work stations are on a nominal two shift, five day per week basis.

B. Payload installation/changeout capability exists in the vertical mode on the launch pad and in the horizontal mode in the OPF.

C. A system is powered down if a failure occurs and a component is removed and replaced.

D. There are no power, ECLSS, or data capabilities during rollout from the VAB to Pad.

The foregoing requirements and constraints were used to develop a preferred operational loading concept. In this concept the specimens were loaded while the Spacelab is in the vertical position on the launch pad. Loading will be during a 3.5-hour hold initiated at T-3.5 in the KSC launch pad allocation. Loading the specimens in this concept will be accomplished in ground transfer cages which have the overall dimensions of approximately 12 by 18 by 36 in. The primates will be placed on a couch and restrained while in the cage and the cages will be provided with air from a portable air conditioning unit. The primate will be supplied with a bottle of water but will not be given any food during transfer. Specimen monitoring while in the cage will be limited to visual observation. Entry is accomplished through the scientific airlock with the Orbiter/Spacelab vertical on the pad. An access platform is used in the Payload Changeout Room (PCR) for loading the specimen transfer cages into the Spacelab.

The transfer cages are loaded on a loading ramp (or via a monorail) that projects through the airlock hatch and into the Spacelab. Once inside, the transfer cage is handled by two men standing on a temporary floor. The primate is tranquilized and transferred from the transfer cage into the flight cage. The transfer cage is then disconnected and removed from the Spacelab. The maximum projected duration for the specimens in the transfer cages is 4 hours.

The following study-developed operational requirements, constraints, and interface impacts ensure BSHF design and support to permit effective and safe mission operations:

A. The BSHF must provide for waste management of specimen urine and feces for up to 6 hours with the BSHF rotated 90 degrees from the normal "up/down" orientation. Also food and water subsystems must provide for a 1-g ad libitum feeding of specimens during this same period.

B. Specimen transfer units are required to hold specimens for approximately 4 hours during movement from the ground laboratory until loaded into the BSHF. The units must provide temperature and humidity control, a flask-type water supply, and provision for visual monitoring of the specimens.

C. Spacelab interior design must take into account the specimen loading GSE which will be installed inside the Spacelab prior to loading the specimens. The specimen GSE and the Spacelab interfaces must be designed to permit safe transport of specimens from the airlock hatch area to the BSHF. All associated GSE must also be designed for easy and quick disassembly and off-loading through the airlock hatch.

D. The Orbiter/Spacelab communications system must provide for loading crew communications with the KSC and JSC control rooms during loading when the specimen instrumentation and monitoring is being verified.

E. The scientific airlock hatch design must include quick opening and latching and facilitate leakage checks of the sealing system.

F. Specimen loading activities may impact the PCR design. Sufficient space must be provided for handling of transfer units, possibly for transferring specimens from one unit to another, and for manipulating specimen handling GSE when it is removed from the Spacelab.

G. A specimen loading simulator will be required for crew training and practice in order to assure safe operations in a minimum time during the prelaunch period.

H. Power and cooling are required for ECS and data management system operations prior to loading specimens and continuously until specimens are off-loaded.

3.3.2 On-Orbit Operations

A Life Science Laboratory designed for a medical emphasis mission (Mod-1a), as described in Section 3.1, was used as the baseline mission for definition of operational on-orbit activities associated with specimen handling and experimentation. During this mission, the Shuttle crew of four, consisting of the commander, pilot, mission specialist, and payload specialist, were assumed to perform life science research over a 7-day period during a nominal 10-hour research day. Crew operational functions and interfaces identified with on-orbit implementation of research functions are presented in Table 3-4.

The BSHF and ancillary equipment must satisfy the following operational design requirements in order for the crewmen to efficiently and safely perform the desired research activities.

A. All BSHF systems must operate in a one-g and zero-g environment.

B. Design of the primate and rat BSHF must provide for easy crew access for daily maintenance tasks and must permit access to the cage interior without excessive contamination of the cabin air.

C. Individual BSHF unit food and water supply must provide for a minimum of 24 hours without replenishment. Direct readout or daily measurement of the quantity consumed is desired.

3.3.3 Postlanding Operations

As in prelaunch operations, the basic requirements and constraints that dictate acceptable postlanding operational concepts are defined by the access requirements formulated by the NASA Life Sciences Working Group and the KSC developed Shuttle/Spacelab Turnaround Allocation and ground rules.

Life Sciences Working Group Requirements applicable to postlanding operations are:

A. Orbiter/Spacelab system must provide a habitable atmopshere, means for specimen sustenance, and continuous monitoring of specimen conditions until specimens are off-loaded.

B. Experiment specimen data is required before specimens readapt to 1-g.

C. Postlanding access to obtain data and/or samples from specimens is required within 2 hours of completion of landing roll.

Table 3-4

CREW FUNCTIONS/SPECIMEN INTERFACES

Crew Function	Interfaces
Specimen in Cage (Unrestrained)	
A. Monitor environmental parameters	Spacelab display and control Mission specialist work station
B. Monitor specimen health	TV monitor, holding unit
C. Monitor electrophysiological readouts	Spacelab display and control station Mission specialist work station
D. Restrain specimen	BSHF restraint device, leather gloves
1) Blood sample	Veterinary kit, BSHF, centrifuge, freezer.
2) Rectal temperature	Veterinary kit, BSHF
3) Blood pressure	Veterinary kit, BSHF
4) Injections	Veterinary kit, BSHF
E Fecal sample	BSHF waste management system, mass measurement device, drying device, fecal collector, fecal sample container, stowage compartment
F. Urine sample	BSHF waste management system, collection device, sample container, freezer
G. Food management	Food stowage, BSHF feeder, food counter
H. Water management	Orbiter water supply, portable water tank, BSHF water distribution system, pressure and quantity readout, N_2 pressure source, H_2O purification kit
I. Photograph	Still and movie camera equipment
J. Cage cleaning	Cleaning tools and wipes, BSHF restraint device, BSHF, waste storage unit, vacuum cleaner
Specimen Removal from Cage (Anesthetized)	
A. Obtain primate transfer unit (PTU)	Storage, PTU

Table 3-4

CREW FUNCTIONS/SPECIMEN INTERFACES (Page 2 of 2)

Crew Function	Interfaces
B. Restrain specimen	BSHF
C. Anesthetize the specimen	Veterinary kit, BSHF
D. Place specimen in PTU	PTU, BSHF
E. Remove PTU and specimen from cage	PTU, BSHF

The KSC Shuttle turnaround allocation for postlanding operations is presented in Figure 3-8. This allocation is the basic plan for postlanding activities which must be considered when providing for postlanding experiment specimen evaluation and off-loading of specimens.

KSC turnaround allocation ground rules applicable to postlanding operations are:

A. The flight crew will be egressed and the ground crew ingressed while the Orbiter is on the landing strip.

B. ECLSS coolant and air purge support equipment will be connected prior to towing orbiter to the OPF.

C. All payload and orbiter live ordnance will be removed/safed in the OPF during safing operations.

D. There will be no delay in tow of orbiter to OPF due to safety requirements.

E. Returned payloads will be removed in the OPF after safing operations.

These basic requirements and constraints were used to develop a preferred operational concept: off-load specimens in the OPF at landing plus 5 to 7 hours. The specimens are off-loaded via the tunnel using transfer cages and tunnel cart with adapter. The specimens are tranquilized and transferred from the flight cages into the transfer cages which are then transported through the tunnel via a monorail type fixture. Two men will be required to handle each transfer cage through the tunnel. The cages will be tethered during the tunnel transfer to preclude any inadvertent damage to the tunnel structure.

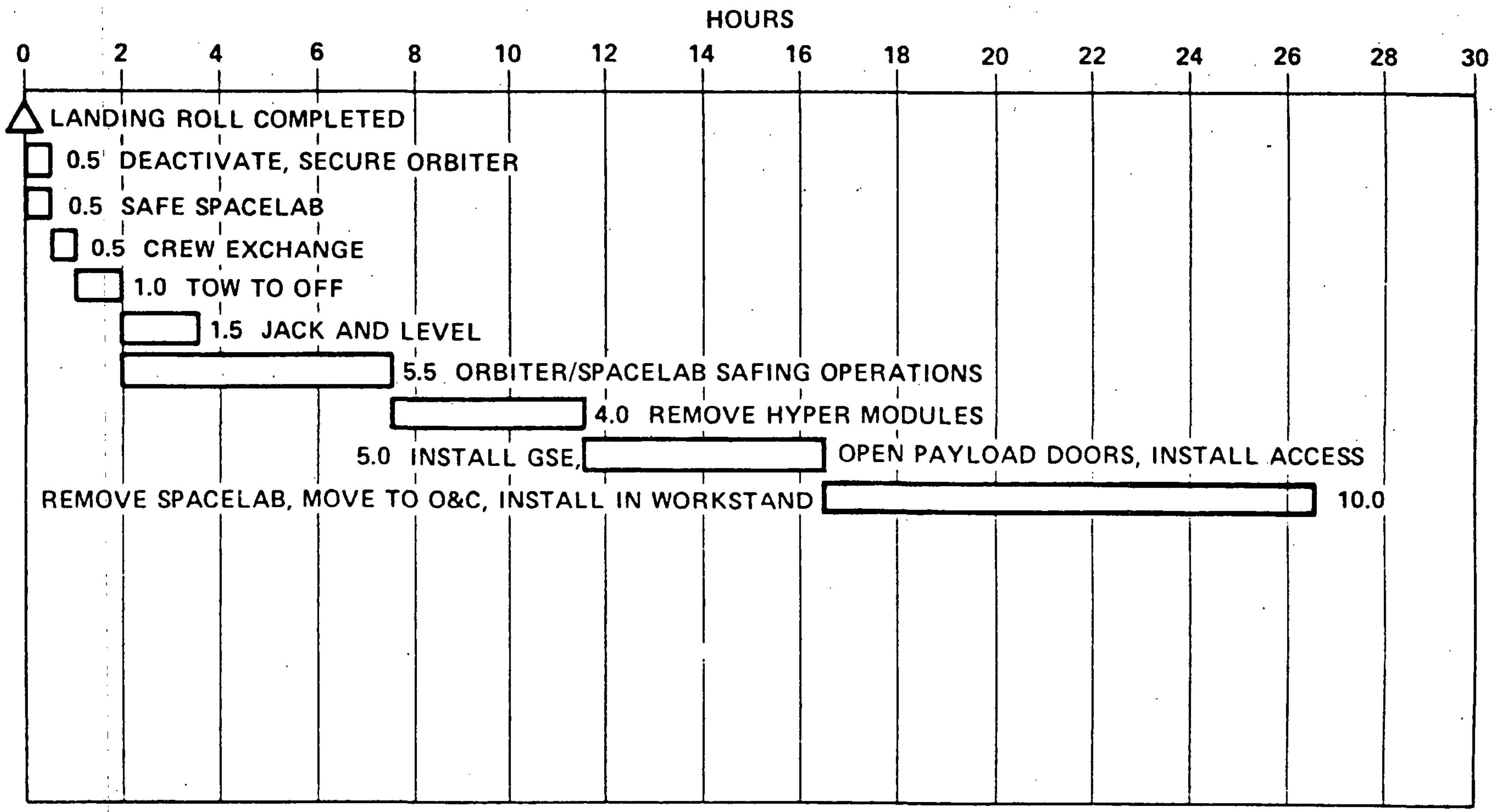


Figure 3-8. Postlanding Turnaround Allocation

The study-developed operational requirements, constraints, and interface impacts presented below ensure that BSHF and ancillary hardware provide for effective and safe crew operations.

A. The BSHF must provide for an operable waste management system, food and water systems, and data management system until the specimens are off-loaded. (Approximately 7 hours based on KSC impacted turnaround allocations.)

B. Since access to the Spacelab and off-loading of specimens will be through the tunnel, the tunnel design will require a 1-g load capability and primate transfer cages will have to be provided since it is not possible to remove the BSHF flight cages through the tunnel. These transfer cages may be the same as those used for prelaunch loading of the primates.

C. Power and ground cooling GSE will be required for Spacelab systems operation to permit up to three personnel in the Spacelab until the specimens are off-loaded.

D. Safety requirements will have to be waived to permit experimenter access to Spacelab during tow to the OPF and during initial OPF operations.

3.4 USE OF FLIGHT-QUALIFIED AND COMMERCIALLY AVAILABLE HARDWARE

During the design of the BSHF it is necessary to evaluate the use, wherever possible, of previously qualified flight hardware. In some instances it may be possible to utilize available components with some change in performance. In these cases it is necessary to compare the penalties associated with such performance changes, in terms of weight, power consumption, or volume with the cost savings that would be achieved.

In order to provide guidance in the selection of previously qualified hardware, a survey was made of available ECS components from previous flight programs. The results of this survey were tabulated and are presented as equipment data sheets in Volume V of this report. Each equipment data sheet includes the following: (1) title of component, (2) original space program on which it was used and date of flight, (3) name of manufacturer, (4) component part number, and (5) technological area indicating the type of subsystems in which the component is used. The descriptive data include:

(1) unit description and principles of operation, (2) physical characteristics, (3) performance characteristics, (4) suitability analysis, and (5) estimated delivery time.

While conducting the survey, contacts were made with ECS manufacturers which indicated the following:

A. Flight-qualified components are not usually kept in stock.
B. Design drawings and tooling of important components are usually kept by some manufacturers for periods of up to 10 years.
C. Any of the components whose tooling and drawings are on file may be produced and qualified at a fraction of the cost of new components.

Where flight-qualified hardware is not available, the use of newly designed equipment using previously demonstrated principles should be considered in order to eliminate the development risk. Also, the availability of suitable commercial hardware should be investigated which can be used directly or readily modified to provide the required performance at minimum cost.

It is noted that subsequently during the conceptual design study it was not found to be possible to use any of the components listed in Volume V, although the data presented valuable reference material. The reasons why these equipment items were not usable, in general, are as follows.

Performance requirements for the Spacelab installation required different configurations. For example, a number of fans and blowers are listed in Volume V. These are cooled by the through-flow air stream. However, in Spacelab it was found to be important to reject motor heat to avionics air while compressing air from the cabin loop, therefore minimizing cabin air heat loads. This necessitated different blower configurations than those previously used.

Temperature controls in Volume V are for liquid loops. However, the BSHF temperature controls are required to modulate air flows since the Spacelab features environmental control by air circulation.

A number of heat exchangers are listed. However, to date the BSHF does not include heat exchangers. The data presented have, however, been used in trade studies and will undoubtedly be useful in subsequent studies of closed-loop environmental controls.

A number of valves of different types are listed. The conceptual design has not yet reached the point where specific valves have been called out. These may yet be used when more detail design is undertaken.

Similar discussion applies to other items listed in Volume V. It may be that data for Volume V was collected too soon, before actual hardware requirements for the BSHF were adequately defined, and these data would be more effectively used, and possibly collected, later in the program such as during a preliminary design phase.

3.5 COMMONALITY

Common usage of equipment items is a requirement of the BSHF design program. Wherever possible, equipment having similar functional requirements should be evaluated to compare the cost savings incurred by use of identical components with the penalties associated with any loss of performance or increased weight, power, or volume. This incentive to use commonality as a design objective should be extended to the other equipment items of the Life Science Laboratory, the Spacelab, and the orbiter in order to minimize the requirement for spares provisioning and training as well as DDT&E.

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Section 4
DESIGN DESCRIPTION

The baseline BSHF design, derived during the conceptual design study covered in this report, provides for the support of unrestrained rhesus monkeys or laboratory rats. In addition to habitats for the primates and rats, the BSHF includes equipment to provide for environmental control, feeding and watering, waste collection and storage, data collection, and interfaces with the specimen transfer devices, the surgical bench and examination table.

The modular design of the facility allows for use of the habitats in combinations as required to support a broad variety of research programs. For example an early dedicated laboratory is planned to include 4 rhesus monkeys and 16 laboratory rats. In addition, modules to support other specimens such as invertebrates, plants, or cells and tissues can be designed, using many of the components and design principles of the BSHF presently described, to provide support for other research areas as required.

The major features of the monkey and rodent holding units are as follows:

A. Waste collection is accomplished by means of air velocity which sweeps urine and feces into a grid at the bottom of the cage. Air and entrained urine then pass into a phase separator which removes the urine and transfers it into storage or provides for sample collection.

B. Specimen metabolic heat, humidity, and carbon dioxide are transferred to the cabin and removed by the Spacelab ECS along with that generated by the crew.

C. Charcoal beds, particulate and microbial filters are used to prevent odor propagation and cross-contamination of cabin and holding unit atmospheres.

D. Equipment heat from such components as blower and separator motors and data collection units is rejected to the avionics cooling loop of the Spacelab rather than the limited capacity cabin air loop.

E. Food and water are provided in simple dispensers which need daily replenishment by the crew. Consumption is determined by measuring the quantity remaining each day or by counting dispenser switch actuations.

This section describes the results of the design study. This includes the subsystems, the system, installation, and interfaces in the Spacelab.

4.1 SUBSYSTEM DESCRIPTIONS

The subsystems of the BSHF include environmental control, waste management, feeding and watering, data acquisition, controls and displays, and lighting. These subsystems feature conservative design principals, using proven methods and techniques and flight-qualified equipment where possible.

4.1.1 Environmental Control System (ECS)

ECS designs are presented in this section for both the rhesus monkey and the laboratory rat. Included are system description and performance characteristics. In addition, ECS performance specifications are given in Section 6 and ECS reliability is discussed in Section 7.

4.1.1.1 ECS Description

The environmental control system utilizes Spacelab cabin air for temperature, humidity, and CO_2 control, as well as oxygen and nitrogen supply and control. Air is drawn into the cages by exhaust blowers, filters before and after use and then returned to the cabin for further processing with the Spacelab air. A discussion of the primate cage ECS and the rodent module ECS is given in the following.

Primate Cage ECS

The primate cage ECS is shown schematically in Figure 4-1. A 300-CFM recirculation blower is used primarily to introduce a downward velocity in the cage to facilitate the collection of wastes at the bottom of the cage. Cabin air is drawn into the lower portion of the recirculation duct at a pressure below that of cabin atmosphere, through a flow control valve and a

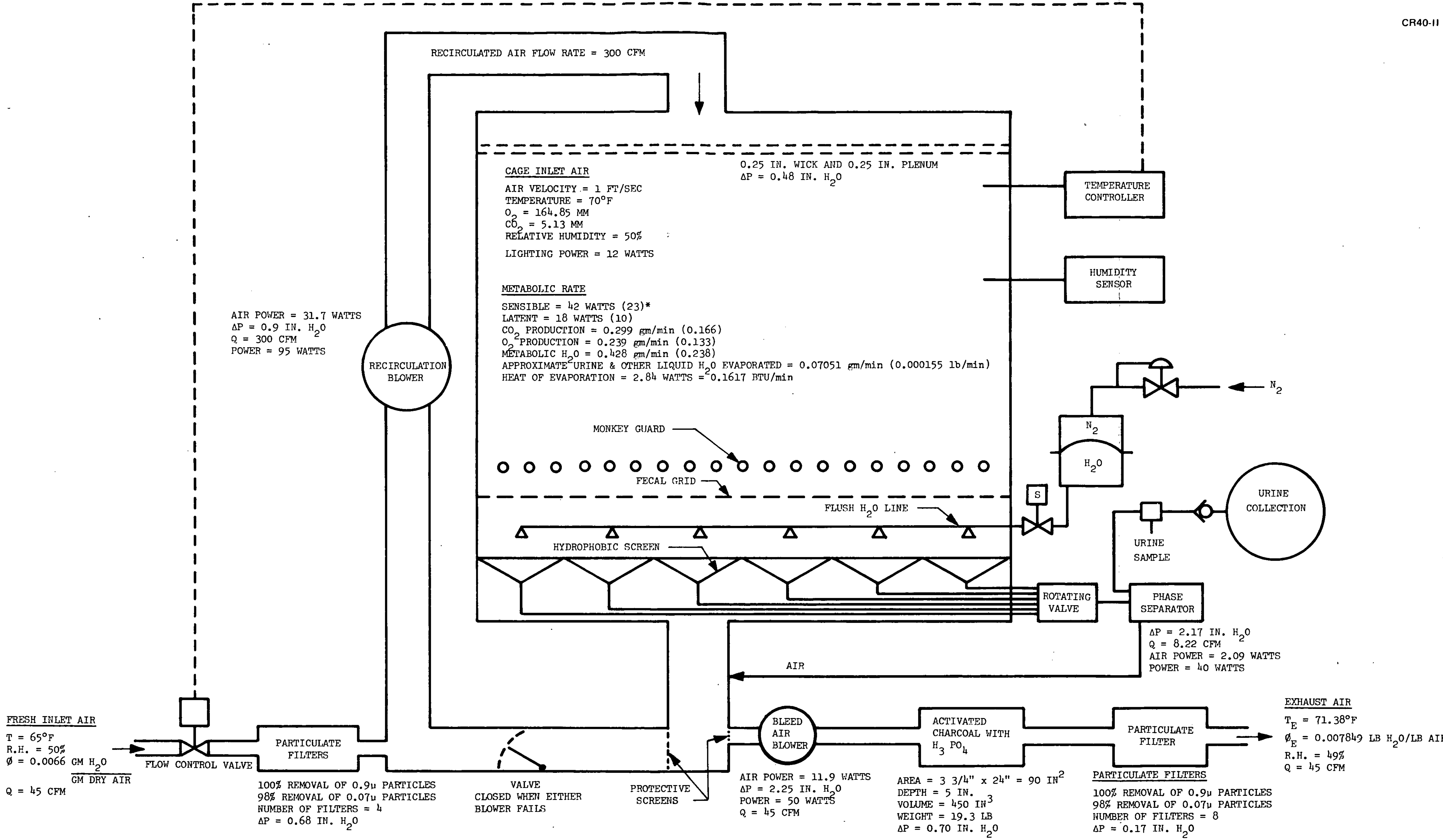


Figure 4-1. Primate Environmental Control Subsystem Schematic

microbial filter. This air is then mixed with the recirculated air and delivered by the recirculation blower into the cage. The exhaust air blower removes an equivalent amount of air from the recirculation duct and returns it to the cabin through treated activated charcoal filter for odor and trace contaminant control and a microbial filter. A temperature controller is used to actuate the inlet air flow control valve. A butterfly-type shutoff valve in the recirculation duct is used when either of the two blowers fails. If the recirculation blower fails, the butterfly valve is closed and bleed air is drawn in through the inlet air valve, microbial filter, recirculation duct and down through the cage, the bleed air blower, charcoal and microbial filter to the cabin. The air flow will be less than the normal bleed air flow but will provide the primate with adequate temperature, humidity and CO_2 control. The butterfly valve is also closed if the exhaust air blower fails. In this case, air is drawn in, also at a reduced rate, by the recirculation blower.

Fresh inlet air is drawn into the recirculation loop to maintain desired levels of temperature, humidity, oxygen, and carbon dioxide. The inlet air is filtered by hydrophobically treated microbial filters to minimize chances of specimen contamination by cabin air. Incoming air is filtered to remove particles greater than 0.7 to 0.9μ (99% particle retention efficiency) for microbial control. Microbial filter data show that pressure drop varies as the square of the air flow. A large air flow results in large pressure drop hence large power requirement. To decrease pressure drop, a larger number of filter cartridges is required for a given air flow but the total weight and volume of the filters increases. The inlet air microbial filter is comprised of four filter cartridges in a filter housing. Each filter cartridge has the following characteristics:

100% removal of 0.9μ particles	
98% removal of 0.7μ particles	
filter cartridge weight	0.6 lb
cartridge mounting weight	0.6 lb
filter cartridge envelope volume (3 inch O.D. x 10 inch long)	90 in^3
hydrophobically treated filter surface	

Eight filter cartridges are used in the exhaust microbial air filter to provide more filtering area and reduce filter air pressure drop. The exhaust microbial air filter prevents the contamination of cabin air with microorganisms generated in the primate cage. The exhaust air is also filtered by activated charcoal and treated with phosphoric acid for odor and trace contaminant control. Protective screens are also used to protect the blowers from damage by large-size particles in the air stream.

Waste management is accomplished by the combination of the recirculation blower, fecal retention grid, hydrophobic screens, and a liquid-air phase separator. The recirculation blower entrains the feces and urine globules and carries them into the fecal grid and the hydrophobic screens. Fecal matter trapped in the fecal grid is manually removed periodically. Studies have shown that an air velocity of 1 ft/sec is required for the monkey waste collection. The waste management system contributes significantly to the recirculating air pressure drop. A 0.25-inch wick and plenum at the top of the cage has a calculated pressure drop of 0.48 inch H_2O at 300 CFM. This wick is used to adsorb any urine that may be directed there and to create a more uniform air flow through the cage. The wick material is rayon viscose and the pressure drop across the wick was calculated from wick material data.

Urine is separated from the recirculation air stream by hydrophobic screens and is drawn away by the liquid-phase separator. The phase separator air is reintroduced into the recirculation loop while the liquid is stored or taken as samples. The hydrophobic screens and liquid-air flush lines are periodically cleaned by flush water. This periodic flushing of the hydrophobic screens helps maintain the hydrophobic property of the screens as this property could deteriorate with the accumulation of urine solids. Flush lines cleaned by flush water will also assure the integrity of each urine sample. The phase separator requires 40 watts to operate, and adds 2.09 watts to the recirculating air which has to be removed by the ECS. The pressure drop across the hydrophobic screen is calculated to be 0.34 in H_2O from data supplied by Chemplast, Inc., the maker of the Zitex hydrophobic material. The ducting is expected to contribute another 0.8 in H_2O pressure drop making a total recirculation loop pressure drop of 0.9 in H_2O.

The maximum amount of evaporation resulting from urine deposited on cage walls was also evaluated to determine its effect on cage humidity control. The Rhesus monkey has an average daily urine output of 840cc. Using an experimentally derived gas-phase mass transfer coefficient of 0.06375 lb-moles/ft^2 hr atm, it was estimated that the urine evaporation rate is 0.07051 g/min for four 210-cc voids totaling 840 cc with a total surface area of 1,753 cm^2 and an air velocity of 1 ft/sec.

Rodent Module ECS

The rodent module ECS is modeled after the primate ECS and has the same type of components and system operating characteristics. Figure 4-2 is a schematic of the system which summarizes the cage inlet air conditions, the metabolic rate of eight 350-gram rats at the nominal waking physiological state, and the essential design features of the specimen environmental control system.

The cage air velocity is 0.5 ft/sec (as opposed to 1.0 ft/sec for the monkey) because the rat fecal bolus, being smaller, has a greater drag per unit mass and therefore requires less air speed to traverse a given distance. The cage is smaller so the transit distance is also smaller. The reduced recirculated air flow rate for waste management control significantly reduces the power requirement for the rat module (122 watts versus 197 watts for the monkey cage).

The rodent module ECS also has the same air filtering component types as the primate cage ECS. Microbial filters, each with four filter cartridges identical to those used in the primate cage ECS, are utilized for inlet and outlet air filtration. Also included in the system are a 160-CFM recirculation blower and a 24-CFM bleed air blower. Due to the lower urine production of the rat (13 cc/day/rat), a thinner plenum wick (0.13 in thick) is used in the rodent module. The pressure drop across the wick/plenum is 0.05 in H_2O. The hydrophobic screens will add a pressure drop of 0.09 in H_2O and the system ducts and manifolds will add an additional pressure drop of 0.06 in H_2O making a total system pressure drop of 0.20 in H_2O.

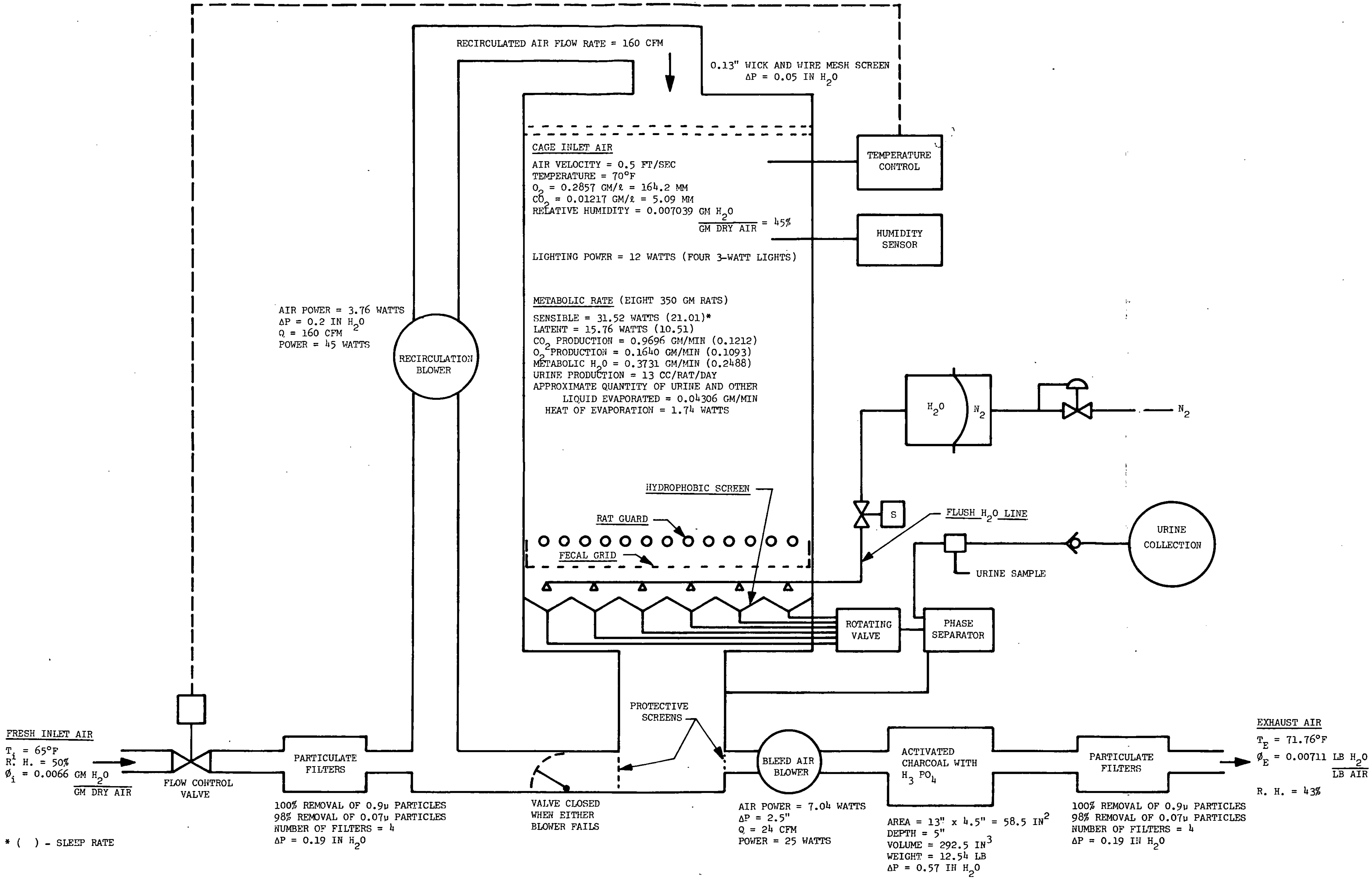


Figure 4-2. Rat Module Environmental Control Subsystem Schematic

4.1.1.2 ECS Performance

The primate and rodent cage ECS design is based on the requirements listed in Section 3. Collection of urine and fecal waste requires a recirculation air flow of 300 CFM in the primate cage and 160 CFM in the rodent cage. The bleed air flow rate was calculated from an assessment of critical environmental variables, such as temperature, humidity, and CO_2 and O_2 partial pressures. As an example, for the primate cage the most critical environmental factor is determined from the following evaluation:

A. Temperature - For a heat load of 54 watts (42 watts as waking sensible metabolic heat and 12 watts lighting), and an allowable range of 5°C (9°F), a temperature rise of 0.56°F is calculated, or 6.2% of the allowable range.

B. Relative Humidity - For a moisture addition rate of 0.498 g/min (0.428 g/min evaporative loss and 0.07 urine evaporation), and an allowable range from 50 to 65% at 70°F, the rise is 0.41% of the allowable range.

C. O_2 Partial Pressure - The waking use rate causes an O_2 depletion of 0.12% of the allowable range (165 to 152 torr).

D. CO_2 Partial Pressure - The waking production rate increases CO_2 partial pressure by 0.56% of the allowable range (5 to 7.6 torr).

The temperature rise was therefore found to be the most critical variable and determined the required bleed air flow rate. The quantity of inlet air is regulated by the flow control valve. A temperature sensor is located in the cage in such a position as to measure the recirculating air temperature. This unit may provide an electronic signal, a vapor pressure, or some other indication of temperature to a control unit. The control unit will compare the signal with a setting established by experimental requirements and modulate the position of the air flow control valve, which will provide the required amount of fresh air added to the recirculating flow.

The quantity of inlet air required is dependent on the fresh inlet air temperature and the habitat temperature setting. Figure 4-3 shows the temperature difference between the inlet air temperature and the cage temperature versus percent of recirculated air that must be exchanged for a given heat load in order that desired cage conditions be maintained. In other words, if during

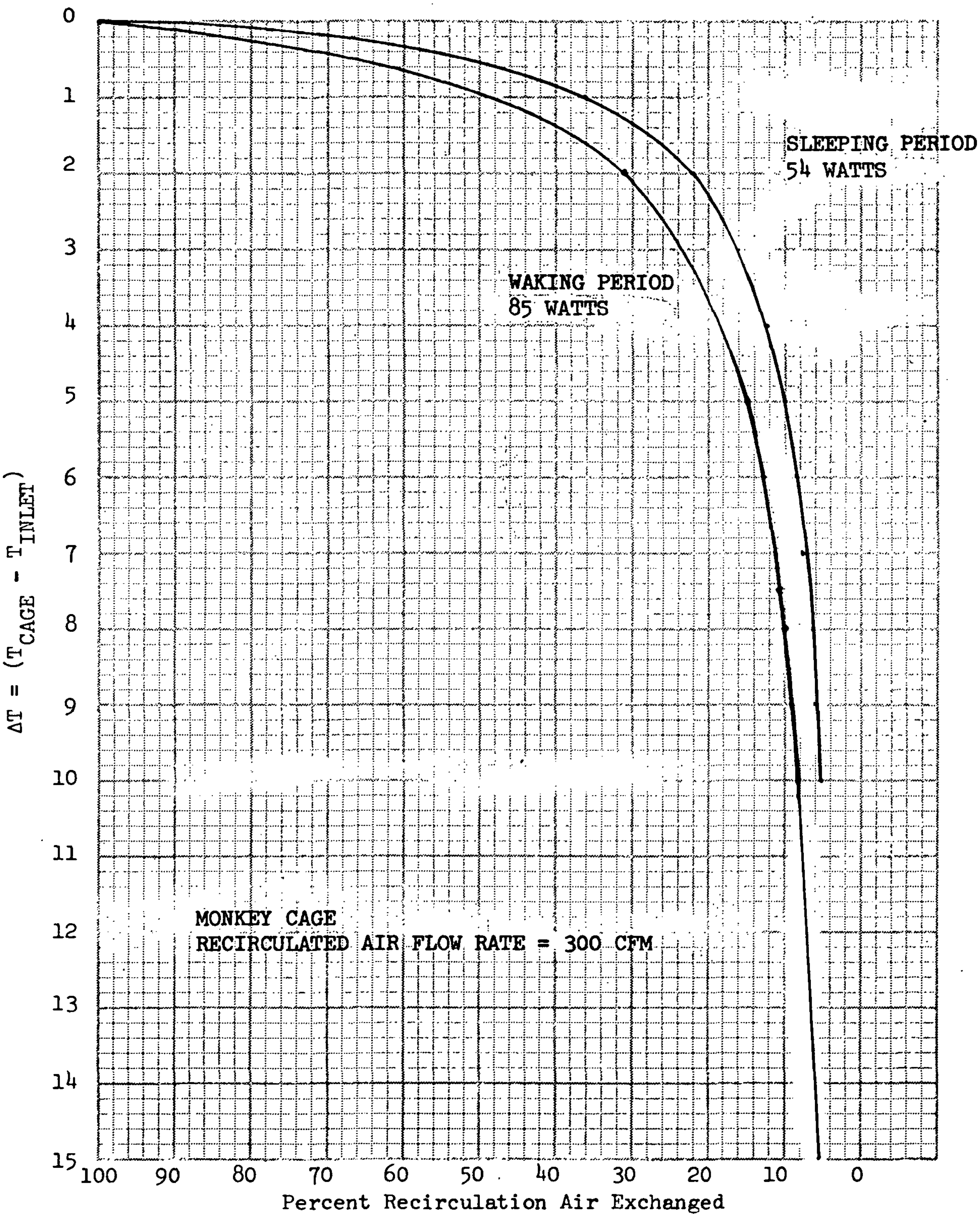


Figure 4-3. Temperature Difference Between Cage Air Temperature and Inlet Air Temperature Versus Percent of Recirculated Air Exchanged

the waking period (heat load of 84.95 watts), a temperature of 70°F is desired in the cage, then a 10% (30 CFM) fresh air flow rate is necessary if the inlet air temperature is 62°F. If the inlet air temperature is 65°F, then a 15% (45 CFM) inlet air flow rate is required.

The power and heat rejection requirements are summarized in Table 4-1. The amount of power required for each monkey cage and each rate module (8 rats) is 197 watts and 122 watts, respectively, during the waking period. The heat rejected to the cabin ECS during this period is 118 watts and 72 watts respectively while the heat rejected to the avionics loop is 139 watts and 97 watts for each module.

For the rat module, Figure 4-4 shows the temperature difference between the cage temperature and the cage inlet temperature (ΔT) versus percent of recirculated air exchanged for a given heat load, i.e., if the air inlet temperature is 65°F and it is desired that the cage temperature be 70°F, then the inlet fresh air flow for the rat cage should be 15% of the 160 CFM recirculated air flow rate, or 24 CFM.

As with the monkey cage, most of the heat generated is removed by avionics air. The rest is rejected into the cabin. Avionics air is ducted to the motors of the recirculation blower, the exhaust blower, and the phase separator. The nominal design rate of heat expelled into the avionics loop is 97 watts for each rat module. The cabin ECS receives 72 watts during the nominal design conditions.

4.1.1.3 Orbiter/Spacelab ECS Interfaces

The Orbiter and Spacelab ECS provide the LSL with atmospheric supply, thermal control, and air revitalization support. The major elements of the Spacelab air revitalization and thermal control systems are shown in Figure 4-5.

The active thermal control of Spacelab is accomplished by four interconnected heat transport loops. The Spacelab cabin air temperature is controlled by the air revitalization system (ARS), the avionics racks are cooled by a separate

Table 4-1

POWER AND HEAT REJECTION

	Power (Watts)				Heat (Watts)					
					Spacelab Cabin ECS					
	Monkey		Rat		Monkey		Rat		Avionics	
	Waking	Sleeping	Waking	Sleeping	Waking	Sleeping	Waking	Sleeping	Monkey	Rat
Air Recirculation Blower	95	95	45	45	31.7	31.7	3.76	3.76	63.30	41.24
Exhaust Blower	50	50	25	25.	11.9	11.9	7.04	7.04	38.10	17.96
Phase Separator	40	40	40	40	2.09	2.09	2.09	2.09	37.91	37.91
Lighting	12	0	12	0	12.00	0	12.00	0	0	0
Metabolic										
Sensible	0	0	0	0	42	23	31.52	21.01	0	0
Latent	0	0	0	0	18	10	15.76	10.51	0	0
TOTAL	197	185	122	110	118	79	72	44	139	97

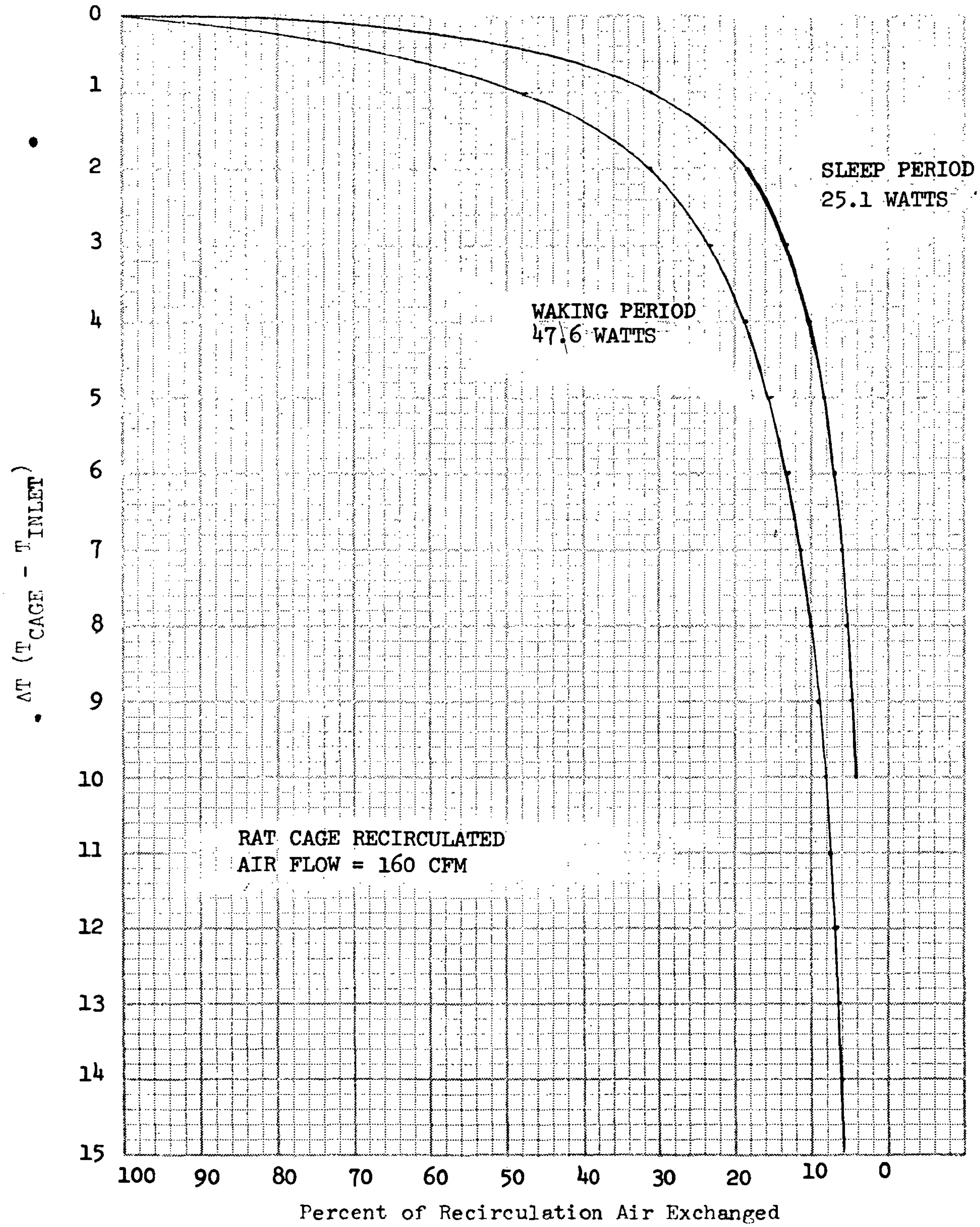


Figure 4-4. Temperature Difference Between Cage Air Temperature and Inlet Air Temperature Versus Percent of Recirculated Air Exchanged

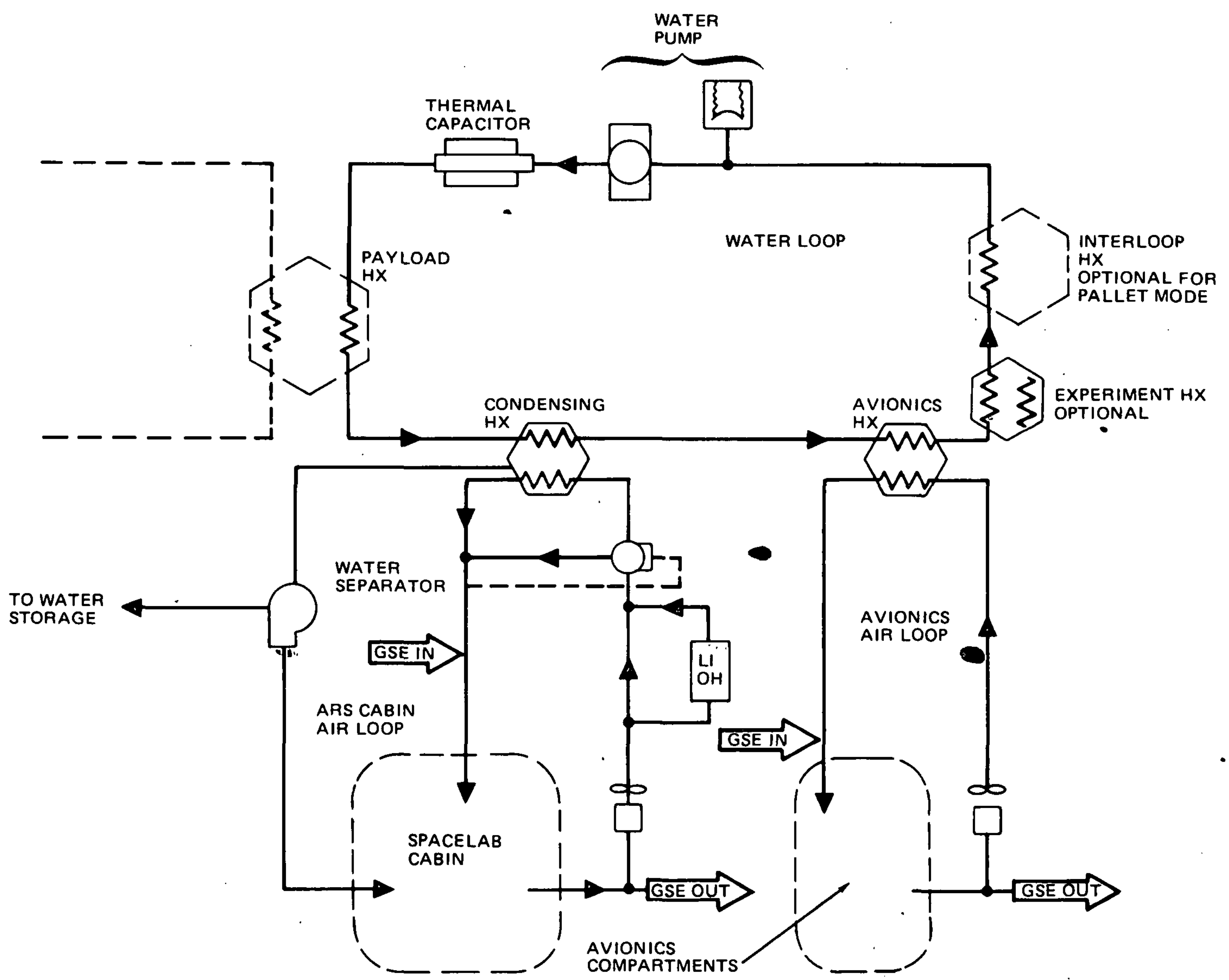


Figure 4-5. Spacelab Water and Gas Transport Loops

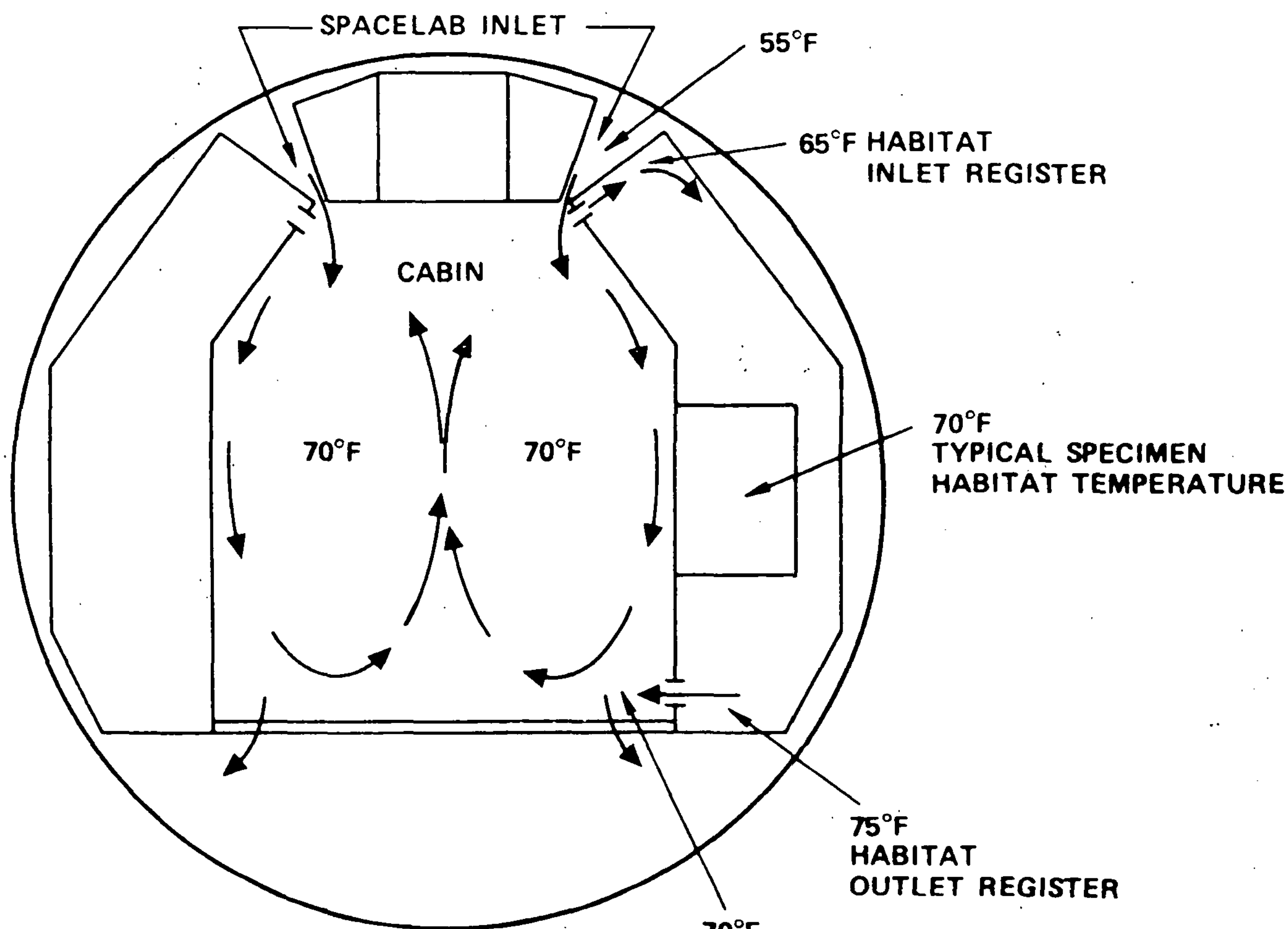
cooling air loop and pallet-mounted components are cooled by a Freon loop. A water loop collects heat from the ARS, avionics loop, pallet Freon loop, and the experiment heat exchanger and transports the heat to the orbiter payload heat exchanger.

Cabin Air Cooling Loop

The cabin air loop shown in the figure collects and removes heat, gaseous CO_2, water vapor and trace contaminants and provides a means to control cabin air temperature between 18 and 27°C (65 and 80°F). The ARS also controls the addition of gaseous N_2 and O_2. The ARS cabin air loop shown in Figure 4-5 consists of a circulation fan, temperature control valve for heat exchanger bypass control, condensing heat exchanger and LiOH unit for CO_2 removal.

The ARS heat exchanger is designed for a sensible load of 2, 505 watts and a latent load of 219 watts (183 metabolic latent heat and 36 watts LiOH canister latent load). This latent heat load removal capability approximates that produced by three persons. A heat load budget of 1 kW has been allowed for removal of heat rejected to cabin air from experiments at the design point temperature of 67°F. An air flow rate of approximately 27 lb/min is provided along the Spacelab length from the overhead area and is exhausted near the rack bottom.

The BSHF is designed to use the cabin cooling loop air for atmospheric supply, purification (principally CO_2 and humidity), and thermal control. At the cabin temperature of 67°F, a requirement of a little over 39% of the 27 lb/min of cabin air is needed for a 75°F specimen habitat temperature for a BSHF holding 4 rhesus monkeys and 16 laboratory rats. The required holding facility air inlets should be at the very top of the rack near the cabin outlet distribution system. This permits the holding facility inlet air to be received at the lowest possible temperature, thereby minimizing both the air flow requirements needed for the holding facilities and the potential impact on the cabin ventilation system. Figure 4-6 illustrates the recommended holding facility air flow inlet and outlet arrangement.



*REFERENCE MDAC BSHF STUDY

Figure 4-6. Spacelab Cabin Representative Air Temperature Profile

The effect of the 1,000-watt limitation in thermal loads imposed on the cabin air loop from the payload is shown in Figure 4-7 for LSL Mod-1A that supports four primates, 16 rats, two cells and tissues holding units, and the other supporting CORE to perform research. A maximum electrical heat load of 315 watts can be rejected to the cabin from other LSL equipment. As indicated in the figure, with a Spacelab occupied by three crew members, all air cooling capabilities are exhausted when the BSHF specimens comprise 4 monkeys and 16 rats. For this reason, all major BSHF ECS and waste management components, such as fans, blowers and water separators, have to be cooled by the avionics cooling loop.

Humidity Control

The Spacelab cabin humidity and dry bulb temperature is equired to fall within the psychrometric comfort envelope defined by 18°C to 27°C dry bulb temperature, a 6°C dewpoint minimum line, and a 70% relative humidity maximum line. The range of cabin dry bulb temperature controllability is a function of the cabin latent and sensible heat loads. For instance, for a total sensible load of 1,000 watts and a latent load of 219 watts (equivalent to three crewmen), the cabin temperature can be set and controlled anywhere between 67°F and 80°F. If the latent load is increased to 400 watts with no change in sensible load, the cabin temperature control range is between 70°F and 80°F.

The above evaluation indicates that reasonable cabin temperature control and humidity level exists for LSL Mod-1A, 2A and 3A. For example, Mod-1A with 3 persons, 4 primates, and 16 rats (approximately 400 watts latent) in the Spacelab, a cabin temperature of about 70°F and a relative humidity of 58% result, if the total cabin sensible heat load is held to the design level of 1,000 watts. Additionally, sensible heat over the 1,000 watts design level can also be accommodated in the Spacelab cabin if the temperature is permitted to vary from 67°F to a higher level.

CO_2 and Odor Control

CO_2 removal and odor control in the ARS is accomplished by a LiOH reaction bed and activated charcoal, respectively. CO_2 level is maintained at or below 5 mm Hg nominal. Spacelab ARS utilizes the Shuttle Orbiter type of

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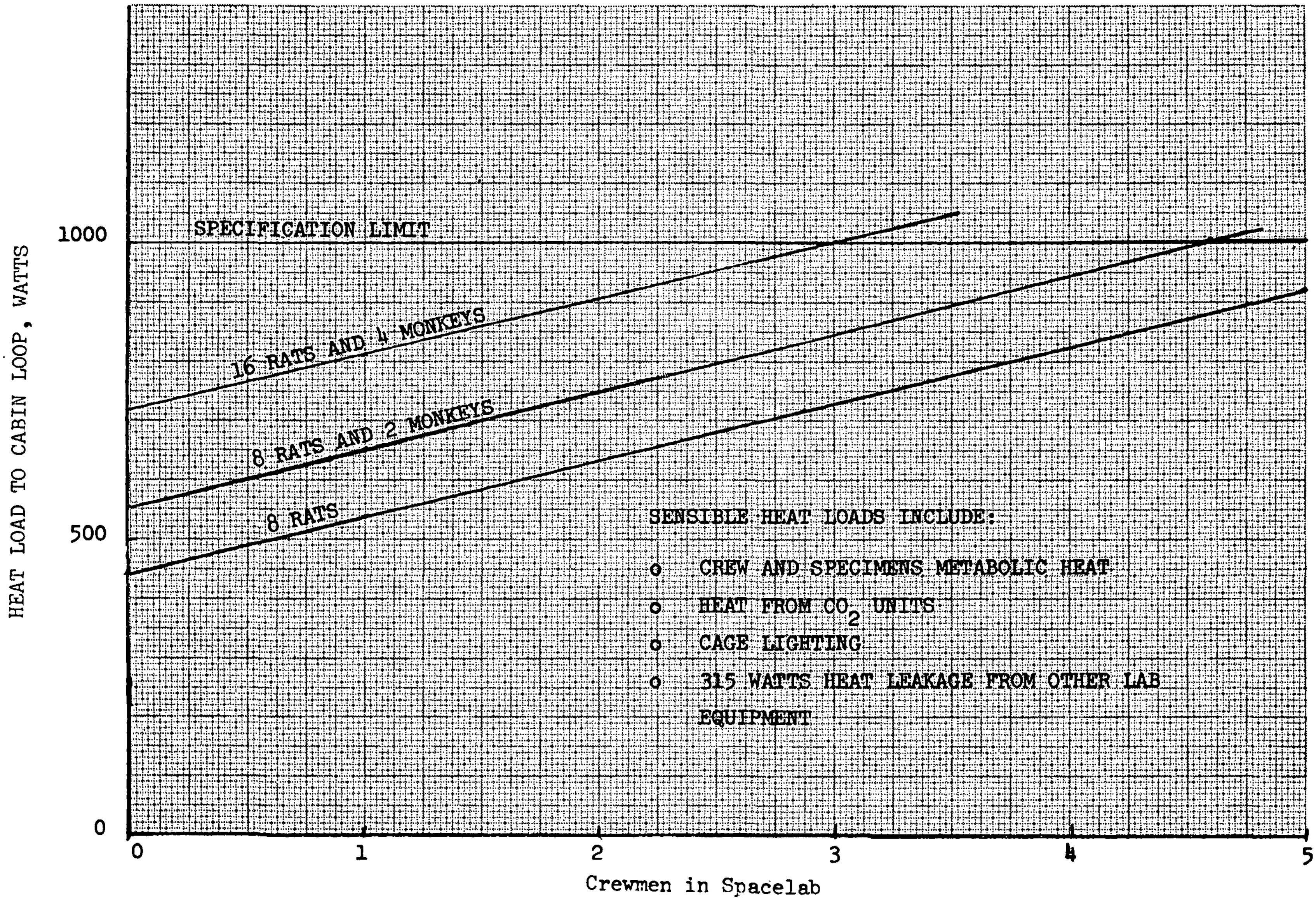

Figure 4-7. Sensible Heat Loads Due to Biological Specimens in Spacelab Cabin

LiOH canisters. The canister is an aluminum cylinder designed for radial flow and contains LiOH, activated charcoal, and purafil for odor removal and a Teflon filter to prevent LiOH dust from entering the air stream. The canister cover is designed with hinged latching covers to permit rapid cartridge replacement. Extra elements are sealed in plastic for onboard stowage protection.

The LiOH system provides for 28 man-days of operation plus 16 man-days of contingency. Additional canisters will be required for the CO_2 removal requirements of specimens or for longer duration missions. The CO_2 production rate for specimens is approximately 0.37 kg/day/primate and 0.037 kg/day/rat. This results in a production rate of 63.4 kg for the example of 4 primates and 16 rats on a 30-day mission. Thirty-two Shuttle-type LiOH canisters will be required for the specimens in such a mission, in addition to the increased crew requirements.

Oxygen-Nitrogen Supply

The baseline design provides oxygen and nitrogen supplies adequate for 28-man days of normal usage and 16 man-days of contingency operation for the support of both Orbiter and Spacelab cabins. Provisions are also made for EVA, cabin repressurization, and emergency leakage.

Specimen oxygen consumption is approximately 0.3 kg/day/primate and 0.03 kg/day/rat. Thus, for the example of 4 primates and 16 rats on a 30-day mission, 50.4 kg of oxygen are required. Oxygen for the specimens may be obtained from the surplus oxygen contained in the added energy kits for electrical power production. Each energy kit provides an additional 25.5 kg (56 lb) of oxygen to the ARS. The number of energy kits required for LSL power requirements will normally provide adequate O_2 for the crew, specimens, and cabin leakage.

Gaseous nitrogen will also be required to pressurize water storage tanks. This may be supplied from a Spacelab nitrogen source. Nitrogen used in tank pressurization will be vented to the cabin resulting in no net loss to the Spacelab system.

Avionics Cooling Loop

The avionics cooling loop uses air as the heat transport medium to collect sensible heat from the rack-mounted equipment. This heat is transferred to the avionics heat exchanger and the cooled air is then recirculated back into the avionics bay. The avionics cooling loop shown in Figure 4-5 consists of a cooling fan, heat exchanger, and distribution and return ducts. The 35 lb/min cooled air is introduced at the bottom of the rack and returned via a second duct located along the rear of each rack. The inlet air duct is routed to supply cooling air to all major BSHF subsystem components, such as fans, blowers, water separators, and data acquisition equipment.

Liquid Coolant Loops

The thermal control water loop collects and transports all Spacelab heat to the orbiter payload heat exchanger from the condensing heat exchanger, the avionics heat exchanger, the interloop heat exchanger, and the major water loop components.

The major components include water pumps, thermal capacitor, orbiter payload heat exchanger, cabin condensing heat exchanger, avionics heat exchanger, and an optional experiment heat exchanger. The pallet heat exchanger which may also be included in the Spacelab was not required for the LSL concepts studied. The optional experiment heat exchanger was reviewed for use by the BSHF. The major need for the experiment heat exchanger would be to provide individual temperature/humidity control at specimen holding unit level and for electronics equipment cold plate cooling. However, the water temperature coming out of the cabin condensing heat exchanger and going into the experiment heat exchanger was on the order of 18°C (64°F) for LSL configurations. This limited capability would not provide humidity control or adequate temperature control in the BSHF and therefore is not usage to the facility.

The maximum continuous payload heat rejected to the thermal control loop cannot exceed a total of 4 kW for the Spacelab design conditions. This heat can be dissipated into the cabin air loop, avionics air loop, the experiment and pallet loops were not required for the LSL configurations as previously noted. The maximum allowable heat absorbed by any one element is shown in Table 4-2.

Table 4-2

PAYLOAD ALLOWABLE HEAT REJECTION

Elements	Maximum Heat from Payload	Condition
Air loop	1 kW	18 to 27°C; air velocity 5 to 12 m/sec (sensible heat ratio not specified)
Avionics	3 kW	1.5 kW max per 19-inch standard rack
Pallet cooling loop (coldplates)	4 kW (module/pallet mode)	1 kW/coldplate (not required for LSL)
Experiment heat exchanger	4 kW	User supplies all plumbing pumps, cooling fluid, and controls (not used for LSL)

4.1.2 Waste Management Subsystem (WMS)

The waste management subsystem is utilized in collecting and removing specimen wastes from the BSHF. The waste materials are collected to maintain the health of the test specimens and to obtain samples for experimental analysis. The sampling system involves collecting feces and urine separately in a condition that allows water balance to be measured and preservation and storage for later analyses that may be required.

The removal methods are designed for simplicity and reliability commensurate with the requirements for urine and feces separation and sampling. The manual segments of the waste management operations are limited to periodic solid waste collection with a vacuum cleaner. The holding facility walls exposed to potential waste deposits are TFE coated and the ECS ducts and components are protected by screens and filters from waste particles.

4.1.2.1 WMS Description

Primate Holding Unit WMS

The primate holding unit waste collection unit is located below the floor of the primate living area as shown in Figure 4-8. The floor of the holding unit

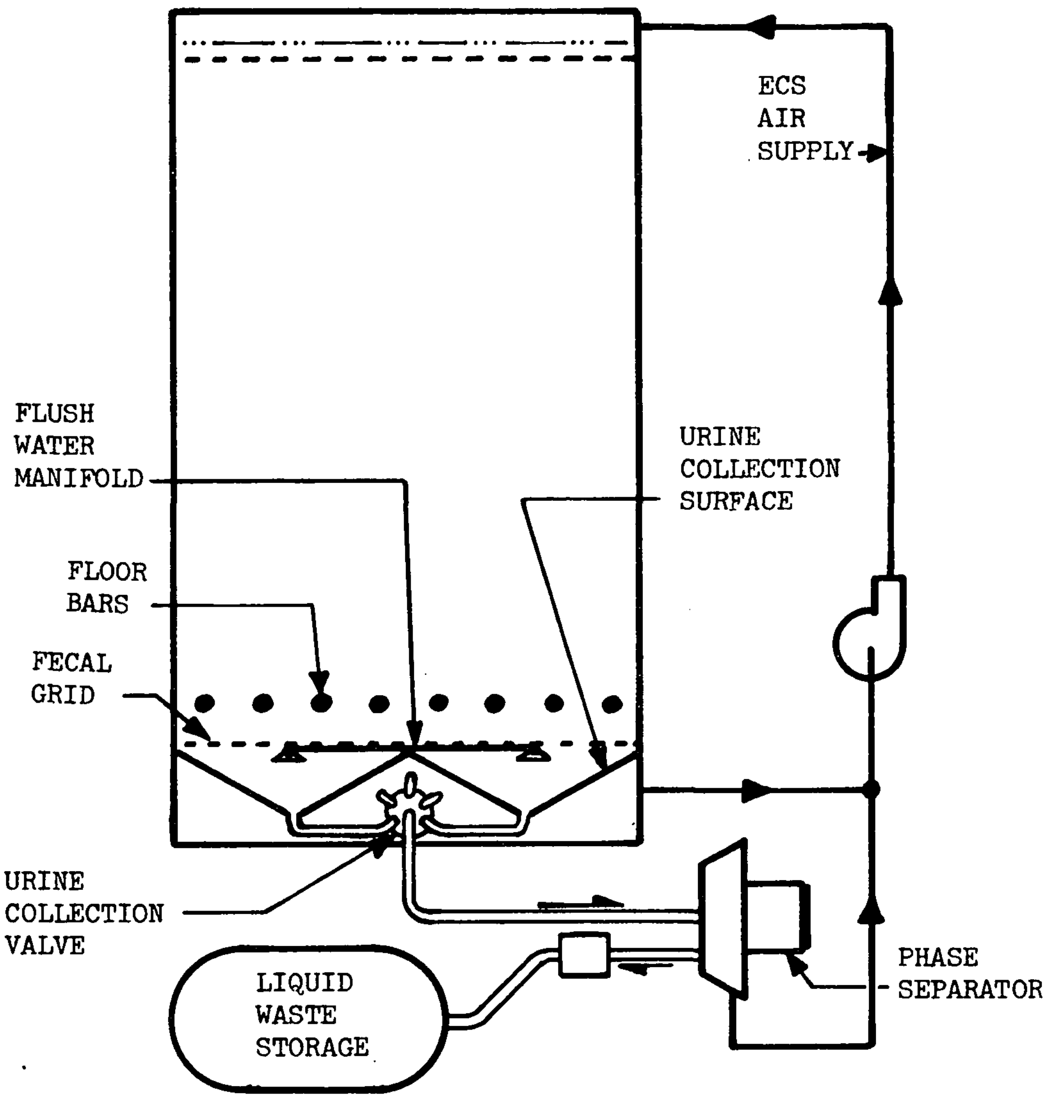

Figure 4-8. Primate Holding Unit Waste Collection Schematic

consists of bars evenly spaced across the living area forming an open end which allows the ECS air flow to carry the urine and feces to the waste management collection section. The specimen will be conditioned during the preflight phase to regard the waste management end of the habitat as the floor so as to direct its wastes in this direction. The walls of the living area will be coated to inhibit the buildup of waste deposits and to facilitate cleaning.

Below the bars of the floor there is a wire grid which will collect the feces and retain them until they are removed by vacuum through an access door at the front of the cage.

The urine will be carried through the fecal grid and deposited on a surface of hydrophobic filter. This hydrophobic filter is configured into six sections, as shown in Figure 4-9, having its center lower than the edges so that there is an approximately 30° slope from the four edges toward the center. When the ECS air stream carries urine onto the hydrophobic surface, the air continues on through the screen and into the return duct. The hydrophobic surface is flushed periodically from a manifold that borders each section. The flush water will be a fixed quantity and the mixture of urine and water will be collected in a manifold connecting the bottoms of all the sections. The flush water is required to maintain the cleanliness of the hydrophobic surface and supply a sufficient carrier volume to remove the urine from the screen surface and to minimize the accumulation of solids which may be deposited as the urine evaporated.

The ECS air moves the flush water and urine to the phases where it is picked up by the manifold. The greater part of the ECS air goes through the hydrophobic surface into the return duct. A small fraction of the circulating air is taken with the urine and water into the collection manifold. The entrained air is removed in the air/water separator and the water and urine mixture is pumped into a storage tank where it may be trated according to the required experimental protocol.

Rodent Module WMS

The rodent module waste collection unit consists of a set of screens and hydrophobic surfaces below the floor screens of the rodent living areas,

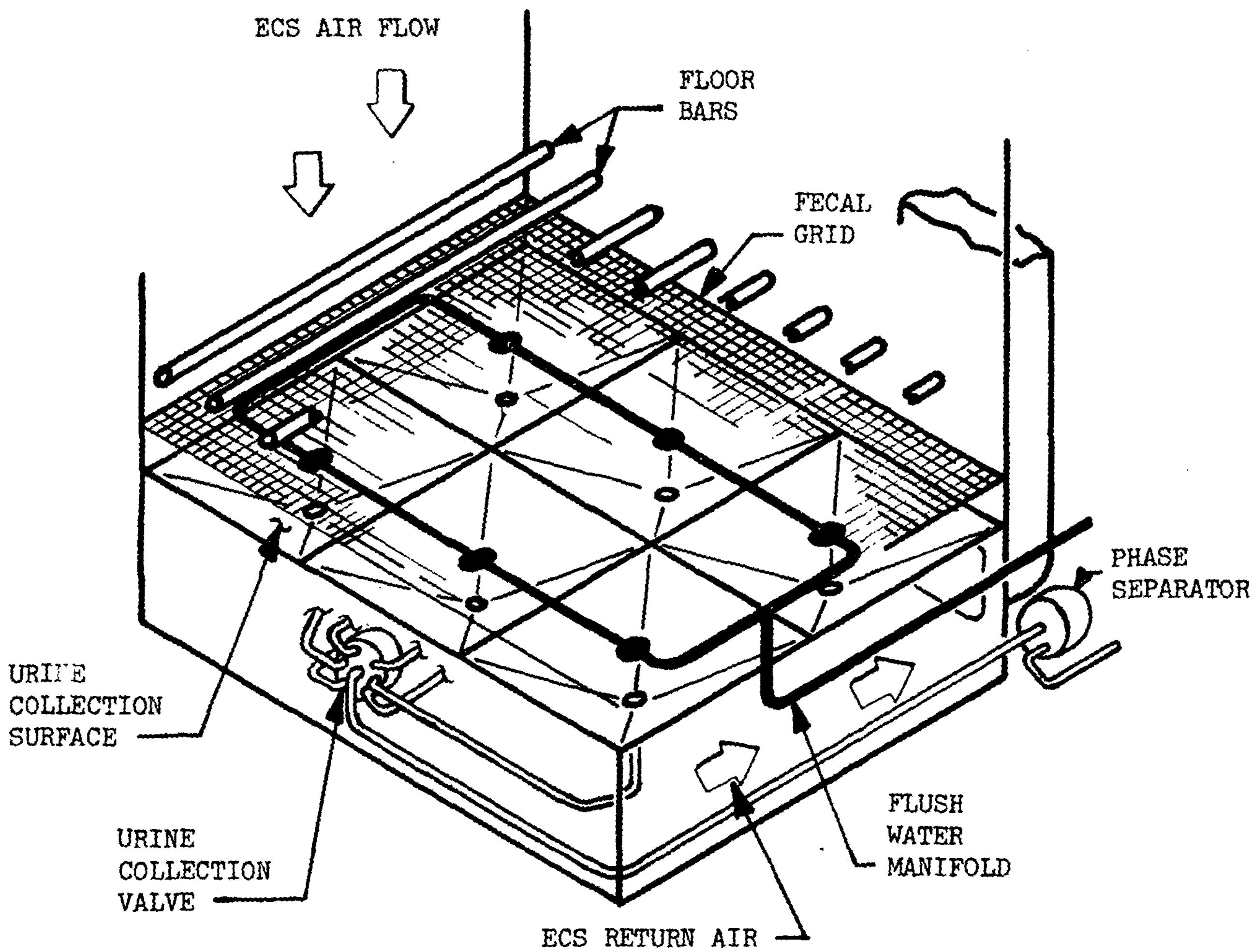

Figure 4-9. Primate Holding Unit Waste Collecting Surface

and a set of flushing and urine collection manifolds that are controlled by selector valves so that each unit may be flushed and the urine drawn out on an individual basis. A schematic of the rodent holding unit waste management subsystem is shown in Figure 4-10. The floor of each individual unit consists of an assembly of two layers of TFE-coated stainless steel screen. The upper layer is open enough to allow the rat feces to pass through and the lower layer will retain it. The assembly can then be removed from the unit and the feces removed by vacuum. This internal floor assembly may have three or four screen walls, as indicated in Figure 4-11, to assist in installing and removing the specimen from the rat module.

Below the above-described floor assembly, there are six filter surfaces that are used to collect urine and flush water and separate them from the ECS air stream. The urine collection assembly is shown in Figure 4-12. The filter surface is hydrophobic and shapes so that the liquids are directed to a collection manifold.

The filter surface is flushed with water from a flush manifold periodically and the deposited urine and flush water are carried by the ECS air stream to a collection manifold. The mixture of liquids and entrained air enter a water/liquid separator, similar to that used in the primate waste management subsystem, where the air is separated from the water and urine mixture. The urine and water are pumped into a holding tank. The holding tank is common to all units in the rodent module. The individual units are flushed and the urine withdrawn separately by means of an eight position valve in each of the flush water and urine collection systems. If individual samples of urine are required, this can probably be accommodated by an experiment-specific device added to the urine transfer line.

Additional advantages of the interior screen wall assembly is that mobility aids are provided to the rat in zero gravity, and temporary wick material may be retained to accommodate the prelaunch period. The sheet of wick material may be located to receive the test specimen's wastes while the module is in the launch position. Upon achieving orbit this wick material may be removed, sealed, and stored.

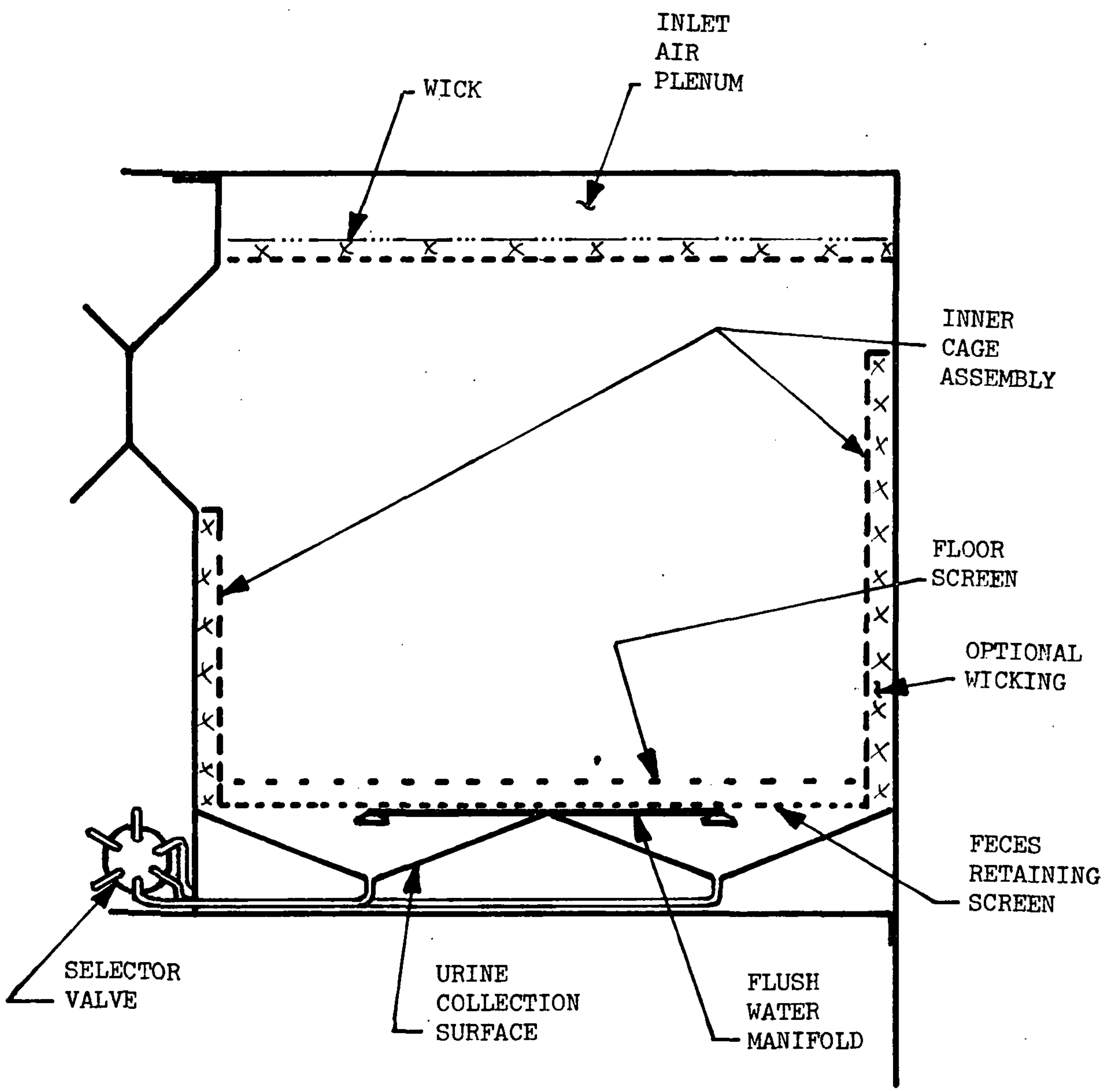

Figure 4-10. Rodent Holding Unit Waste Collection Schematic

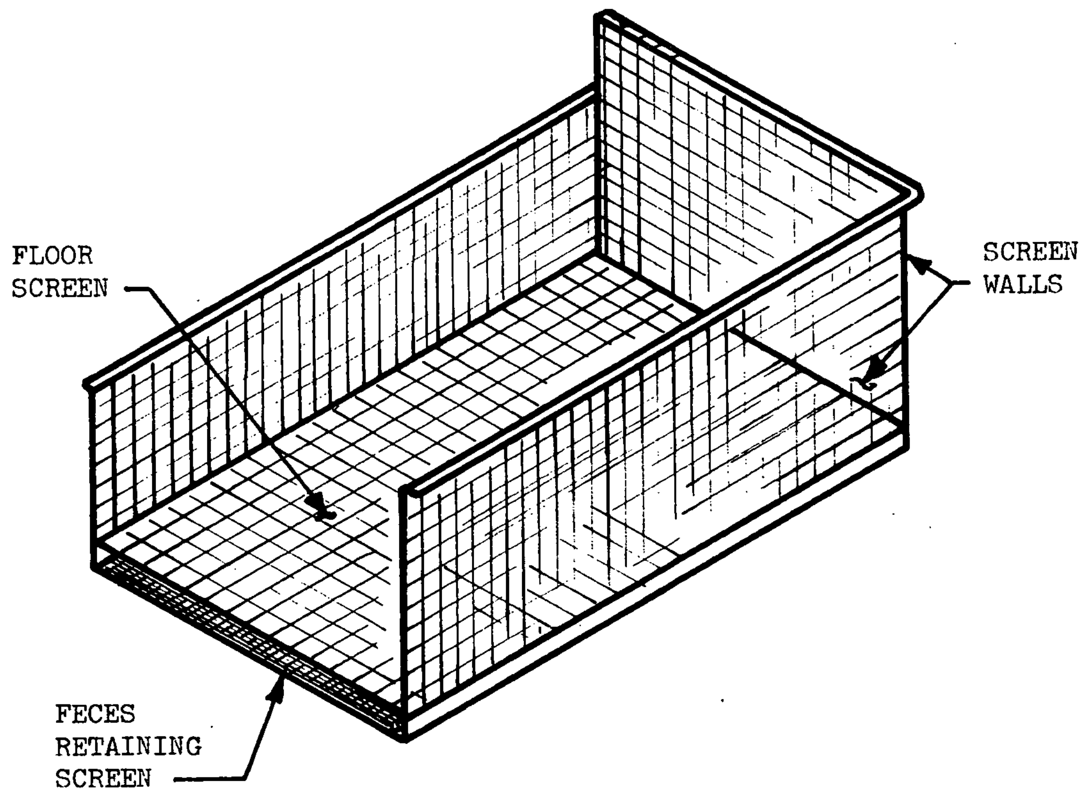

Figure 4-11. Rodent Inner Cage Assembly

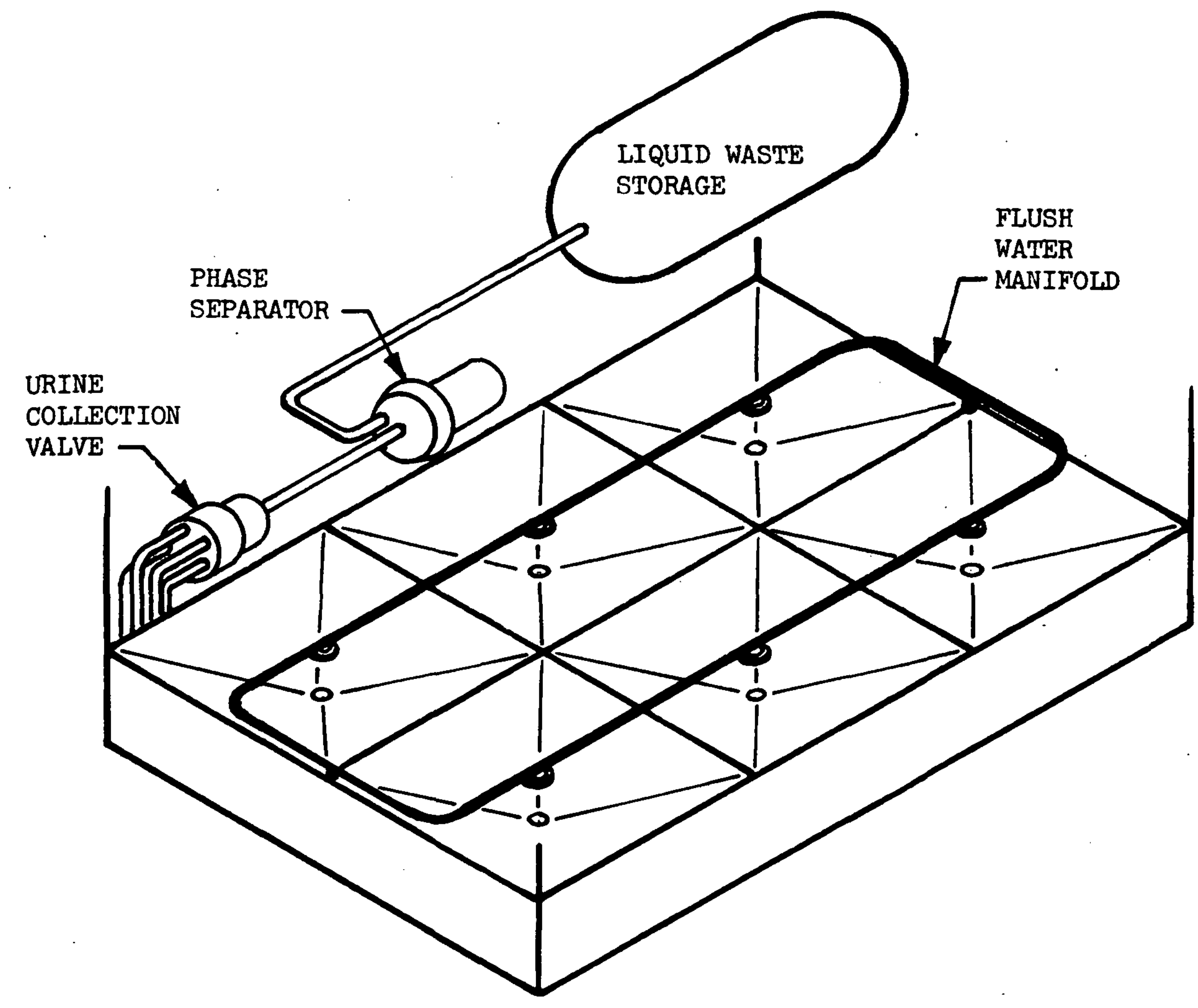

Figure 4-12. Rodent Holding Unit Urine Separation and Collection Schematic

4.1.2.2 Performance and Design Summary

Primate Holding Unit

The primate holding unit waste management design parameters are summarized as follows:

Urine volume - 840 cc/day

Fecal mass - 86 grams/day

Fecal bolus size - can pass through 1.5 by 1.5 inch grid

ECS air velocity - 1 ft/sec (0.36 m/sec)

Holding unit RH - 50%

Flush water volume - 720 cc/day (1 flush/day)

Urine and flush water evaporation rate - 4.23 grams/hour

The expected average daily urine volume of 840 cc/day will be made up from a number of urinations generally of sufficient volume to be collected from the surfaces of the collection filter without requiring additional liquid from flush water. The single flush each day is utilized to clean the residual urine droplets and salts from the filter surface.

The urine will be taken into the collection manifold on a cyclical basis. Each of the depressed sections comprising the collection filter surface has a valved opening to the collection manifold at its lowest point. The valve is opened from a short time for each section and then closed. This cycle allows the urine to collect at the section vertex and then be taken into the urine collection manifold.

This system operating continuously will take in around 8 CFM of air in collecting the 840 cc of urine and 720 cc of flush water per day. The daily total liquid volume of 1,560 cc is expected to lose 85 cc per day in evaporation. Assuming a daily net of 1,475 cc, a 30-day flight will require a waste liquid storage volume of 44.25 liters per specimen.

It is estimated that 10% of the daily urine output, about 85 cc, will evaporate because it will be located so it cannot be entrained by the ECS air stream and carried to the collector surface. It will be distributed in droplets on the floor bars, on the walls, and on other surfaces due primarily to the specimens position at the time of urination. This quantity will require approximately 20 hours per day to evaporate leaving a residue of urine salts on the bars, fecal screen, and walls. This residue may require removal by washing periodically. The wick material in the air supply plenum will be treated with a urea-fixing agent such as phosphoric acid for the treatment of any random droplets of urine, and will be inspected periodically and replaced, if required.

The urine collector surface material will be Zitex, a TFE composition manufactured by Chemplast Inc. This material was used in the Gemini and Apollo programs with considerable success.

The geometric shape of the collection assembly is limited by the space that can be allotted to it. Figure 4-13 shows one section typical of both rodent and primate collectors.

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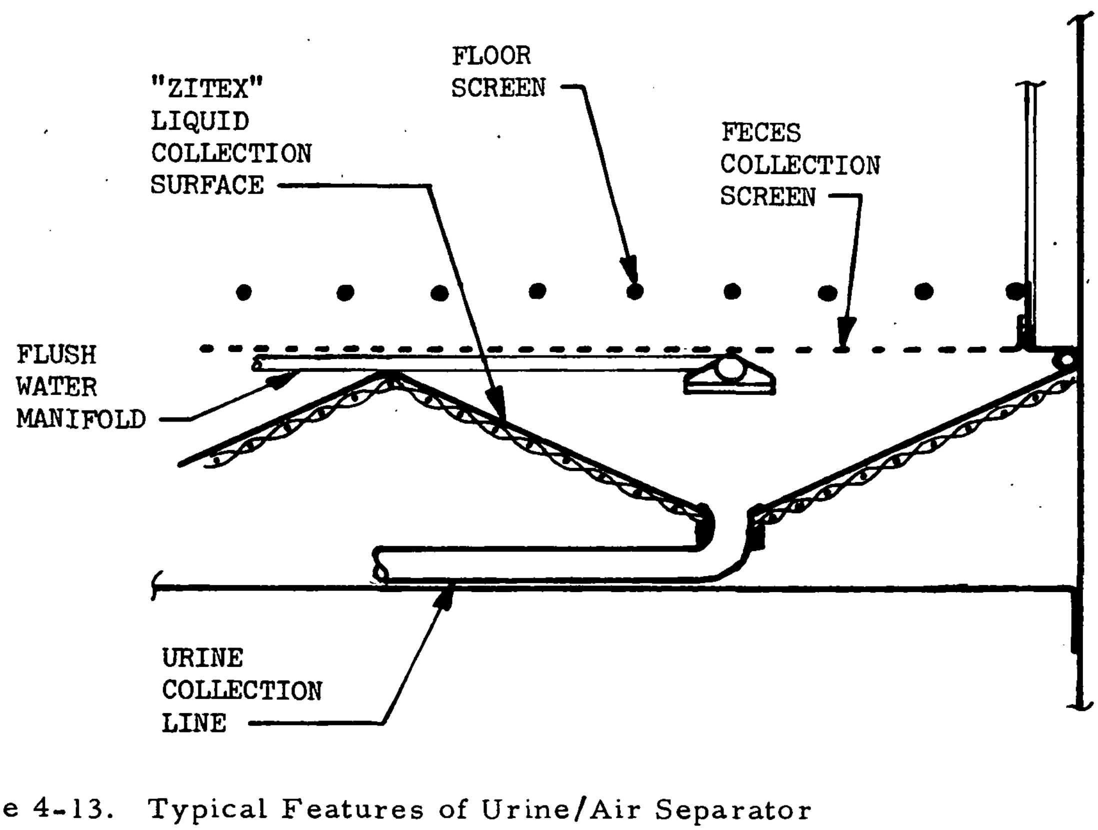


Figure 4-13. Typical Features of Urine/Air Separator

The flush water quantities are estimates of the amount necessary to adequately wash the urine collector surfaces, and may be altered if indicated by testing. The 8 CFM of ECS air collected along with the urine and flush water is determined by the design capacity of the phase separator equipment.

The valved ports in the urine collection manifold will be sized to maintain the required pressure difference between the collector sections and the manifold.

The average daily fecal mass of 86 grams is expected to consist of 5 to 10 boli, 12 to 18 mm in diameter. The floor bars are spaced 38 mm (1.5 inches) apart and take up 23% of the projected floor area. They are TFE jacketed to inhibit the adhesion of urine droplets and feces.

It appears that the ECS air stream velocity of 1 ft/sec is close to the minimum velocity necessary to influence test specimen urine and fecal boli movement and direction in zero-g conditions. It is also apparently close to the maximum velocity tolerable by a primate as a prolonged living condition.

Figure 4-14 shows the calculated transport times for a fecal bolus. The separation height for a 14-kg specimen is estimated to range from 6 to 8 inches so the bolus transport time should range between 10.5 and 12.5 seconds. The boli will be restrained by the screen under the floor bars and can be collected by vacuum on a periodic basis. Fecal storage for a 30-day flight must accommodate a minimum of 2.6 kg of feces per specimen. In the event of use of radioactive isotopic tracers, shielding materials will be incorporated into the waste storage equipment.

Rodent Module WMS

The rodent module waste management subsystem design requirements and metabolic characteristics are summarized for waste management as follows:

- Urine volume - 13 cc/day/rodent
- Fecal mass - 9 grams/day/rodent
- Fecal bolus size - can pass through 1/2 by 1/2 in grid
- Fecal bolus consistency - firm

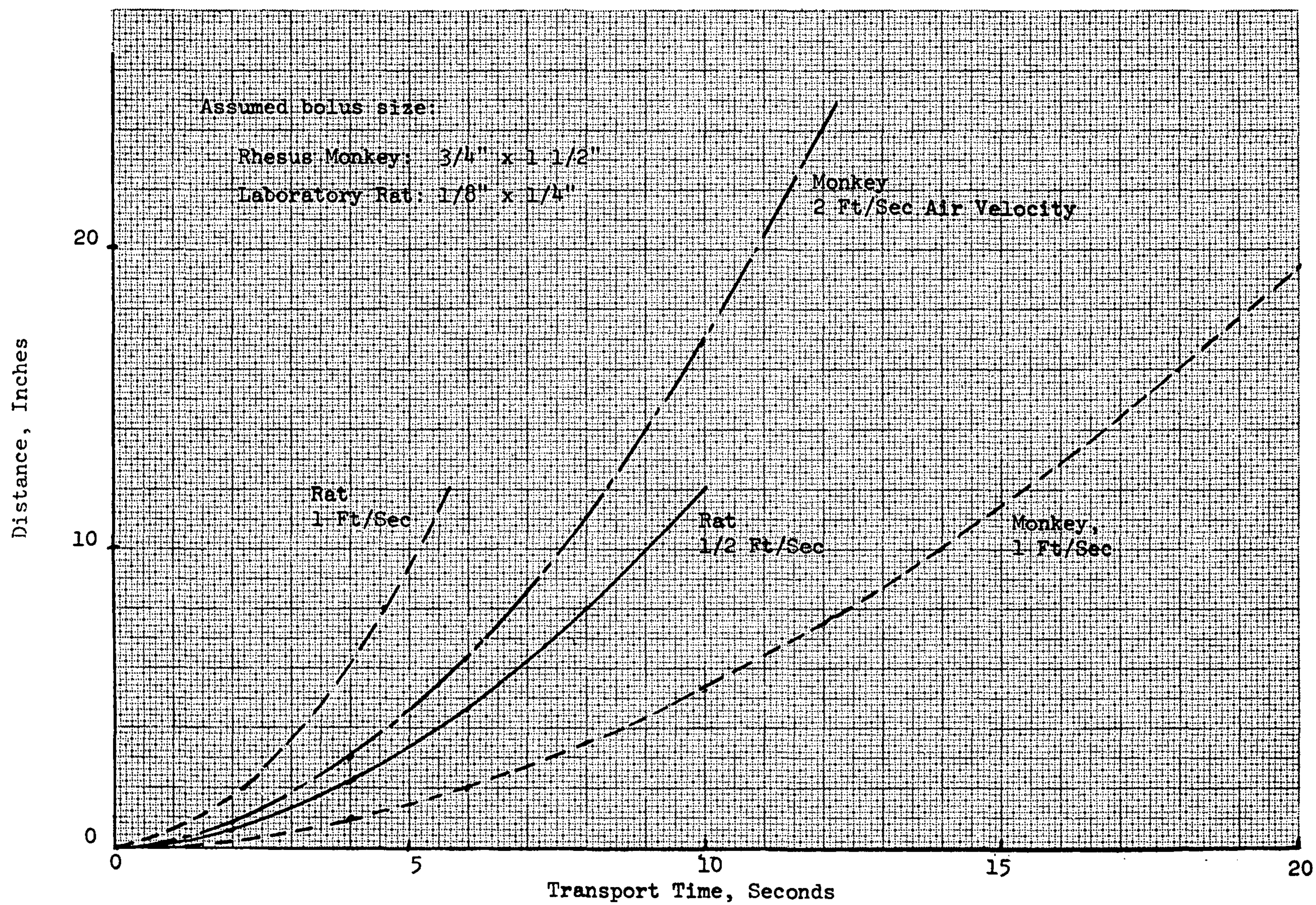


Figure 4-14. Specimen Fecal Bolus Transport Times by Air Flow

ECS air velocity - 0.5 ft/sec

Rodent module RH - 45%

Flush water volume - 180 cc/day per unit

Urine and flush water evaporation rate - 0.323 gram/hour/unit

With an expected daily volume of 13 cc per day for urine production, the average volume per micturition will seldom exceed 2 cc. This volume should not be sufficient for the urine collection system to collect at once, resulting in a fairly continuous presence of small amounts of urine on the TFE separating filter surface. Each unit will be flushed once per day washing the remaining urine and salts into the vertices of the urine collection structure where the liquid waste will enter the collection and phase separation equipment.

The collection manifold enters each of the six sections of the urine collection surface at the vertex of each section. The manifold will typically be operated on a 3-minute cycle of which two sections will be open for 30 seconds and closed for 2 minutes and 30 seconds.

The manifold will collect the fraction of the 13 cc of urine available to the manifold prior to flushing the urine collection surface with water and then collect the 180 cc of water. It is estimated that half the urine will evaporate between flushings so that 7 cc of urine and 180 cc of water will enter the collection system daily. For eight rodent units per module this will add up to a total of about 1,500 cc of liquid waste per day, and 45 liters for a 30-day flight.

Within each rodent holding unit there is an assembly composed of three screen walls and with a floor containing two layers of screen. The upper layer of floor screen will be sized so that the specimen may stand or hold on to it and it will pass fecal boli. The lower screen will retain the boli so that they cannot pass on to the urine collection surface. This inner cage like assembly is used primarily to remove the specimen for experimental treatment and examination but serves further as a feces trap and retainer. It may be removed from the holding unit and the feces removed by vacuum periodically. It is sized so that wick material may be inserted between the walls of the holding unit and the walls of the inner cage. The wick material is treated to absorb and fix urine and hold feces particularly in situations such as prelaunch positions when a side wall is in the "bottom" position. After achieving orbit, the wick material may be removed and stored.

At an average fecal collection rate of 9 grams per day per specimen, the storage capacity for one rodent module must accommodate 2.16 kg of feces for a 30-day flight.

The estimated transport time for a rodent bolus, taken from Figure 4-14, will be 2.5 seconds from a separation height of 1 inch. The specimens will be conditioned prior to flight to orient themselves so that the waste collection surfaces will be regarded as being "down".

4.1.3 Feeding Devices

Each individual species to be flown requires a specifically designed feeding device to be integrated into the BSHF. Described herein are feeding devices for the primate and laboratory rat.

4.1.3.1 Primate Feeder

Purpose/Type of Food

The purpose of this feeder is to provide a nutritionally adequate, low residue diet to an adult rhesus monkey (14 kg) which results in feces with lower odor and a firm to semiform consistency. Such diets are commercially available from companies such as the Ralston Purina Company, St. Louis, Missouri, and may be made into durable spherical pellets for use in dispensing machines by replacing fibrous ingredients with non-nutritive cellulose (alphacel).

Description

The feeding device consists of a pellet tube and dispenser located on the front of the BSHF; an identical device is mounted on each side of the BSHF door as shown in Figure 4-15. The device is installed with the dispenser hear the top of the cage to provide a reference to the "heads-up" position.

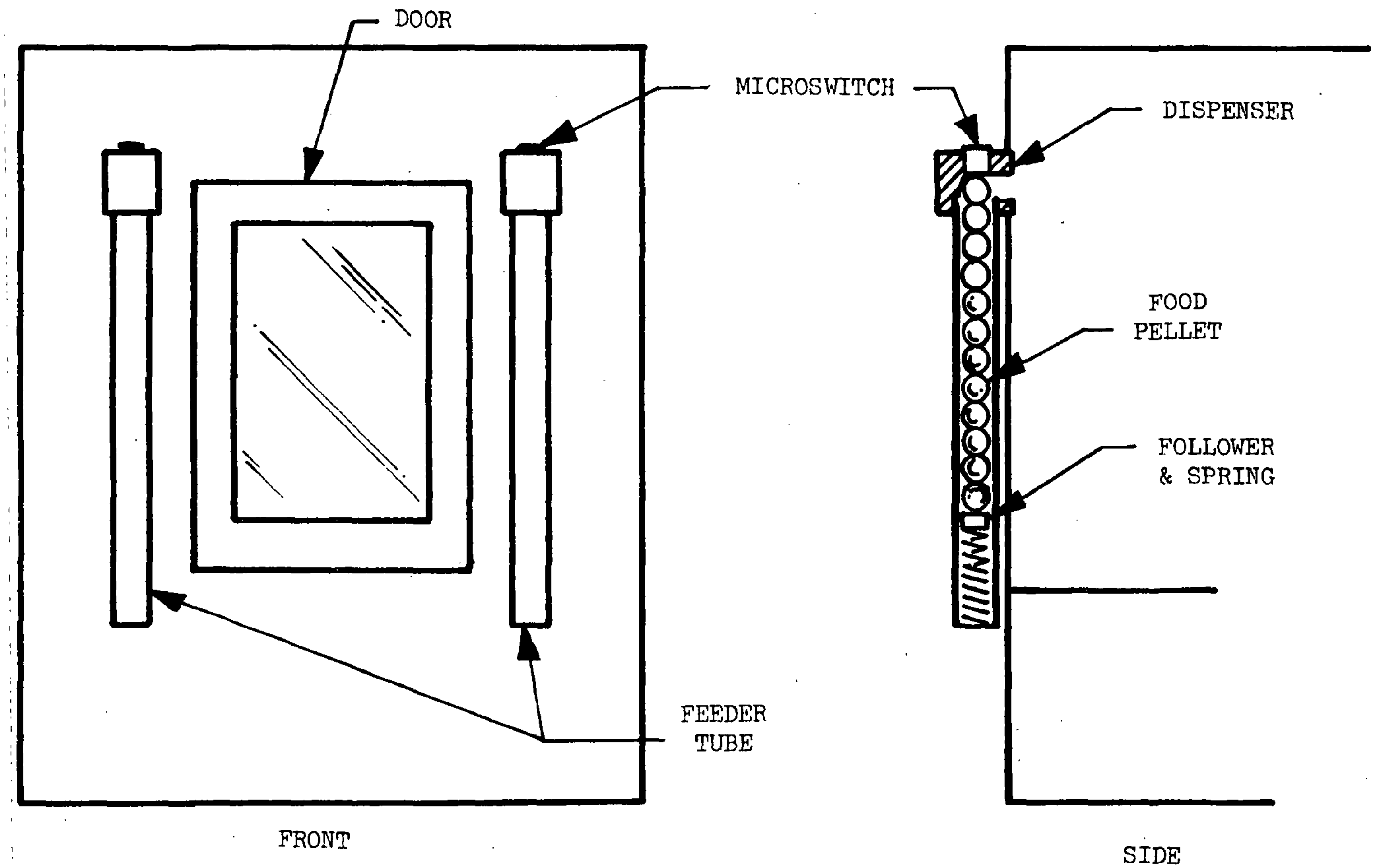


Figure 4-15. Primate Feeder

It is anticipated that the primates will make this association during ground laboratory activities for gathering baseline data or for training. The end result is expected to be primate urination and defecation in relation to a one-g environment when in the zero-g environment. The pellet tube is a cylindrical disposable container made of thin transparent acrylic material with a movable detached bottom disc as shown in Figure 4-15. Each tube contains spherical food pellets which are forced into a retaining cup in the pellet dispenser by a spring in the tube. The food pellet is retained by the dispenser cup until removed by the primate. If desired by the experimenter, a microswitch may be actuated at this time which may be used for recording the pellet removal. When a food pellet is removed, the spring forces another food pellet into the retaining cup permitting ad libitum feeding.

The pellet tube container and dispenser is 71 cm (28 in) long and 25 mm (1 inch) in diameter. With the steel spiral-wound compression spring in the compressed mode (27.5 cm, [11 in]), the tube holds 19 food pellets which are 2.8 cm (7/8 in) in diameter and contain 8 grams of food per pellets. Each pair of pellet tubes provide a 24-hour supply of food for one primate.

The food supply is replenished by using the following procedures: (1) compress the spring and place in detent lock position, (2) grasp the tube slightly above center and pull lightly away from the BSHF to release spring clip fasteners designed for expected launch loads, (3) remove the empty pellet tube from the top of the container, (4) place new pellet tube in container after removing pellet retainer cap, (5) reposition container on the BSHF by engaging spring slip fasteners, and (6) release spring from detent position.

The pellet tubes are normally replaced each day during scheduled maintenance activities. However, the transparent acrylic tube permits easy visual reference to determine if the food supply should be replenished sooner. A total of 60 food pellet tubes, each weighing 232 grams (11.6 oz), constitute the food required for one primate for a mission of 30 days duration. Considering contingency requirements, a total of 68 pellet tubes should be stored for each primate flown.

Summary

Unit Parameter	Design Value
Weight	0.790 kg (1.75 lb)
Volume	0.001 m^3 (61 in^3)
Power	2 W (intermittent)

Expendables for 30 day mission (1 primate)	
Weight	15.78 kg (34.8 lb)
Volume	0.017 m^3 (1,037 in^3)

4.1.3.2 Laboratory Rat Feeder

Purpose/Type of Food

The purpose of this feeder is to provide a nutritionally adequate paste diet for an adult laboratory rat (350 grams) which results in feces with low odor and a firm consistency. Such diets have been successfully made and utilized during laboratory tests at Ames Research Center and may be specially ordered from most commercial firms such as Ralston Purina Company, St. Louis, Missouri. The paste is made from a mixture of finely crushed standard laboratory rat chow mixed with agar medium to form a thick paste which is packaged in aluminum foil containers similar to the jelly packages served in restaurants.

Description

This feeding device consists of an aluminum foil container which contains paste food located in the door of each individual rat cage as shown in Figure 4-16. The container is located in a "feeding tunnel" with an opening into the cage into which the rat must extend its paw when it desires to obtain food from the container. Laboratory experience has shown that the rat will lick all the food from its paw thus eliminating waste food which could mix with urine and feces in the waste management collection system. The container is replaced by moving the sliding door in the front of the rat cage door and lifting the food container out of its recess. The new food container is placed in the recess and the sliding door closed. The food consumed by the rat is determined by weighing the used food container on the small mass

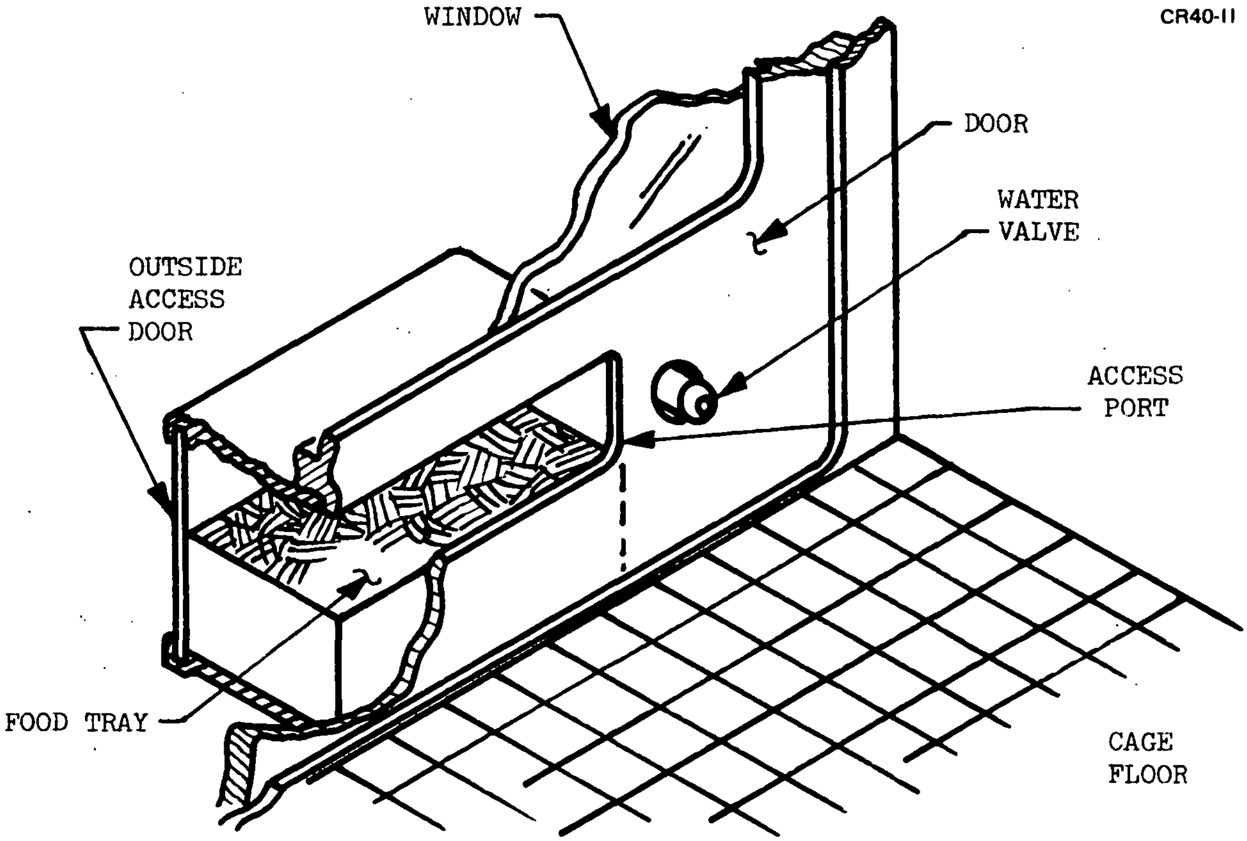


Figure 4-16. Rat Feeder and Water Dispenser

measuring device which is part of the CORE, and subtracting the value from the weight of the contractor when inserted into the cage. Used food containers are discarded as trash.

Performance and Design Summary

The paste food container is 1.59 cm deep by 4.76 cm wide by 5.72 cm long (5/8 by 1-7/8 by 2-1/4 in) with a 1/4-in flange around the top and weighs 57 grams total including paste food and container. The container is normally replaced and weighed once each 24 hours during scheduled maintenance activities. A total of 240 containers are required per rat module for a mission of 30-day duration (8 rats per module). Considering contingency requirements, a total of 272 containers must be stored for each rat module flown.

Summary

Unit Parameter	Design Value
Weight	57 grams (0.1 lb)
Volume	44.9 cm^3 (2.74 in^3)

Expendables for 30-day mission per laboratory rat module

Weight	15.50 kg (34.16 lb)
Volume	0.014 m^3 (0.5 ft^3)

4.1.4 Watering Devices

Each species to be flown requires that a specifically designed watering device be integrated into the BSHF design to provide for specimen sustenance. Described herein are watering devices for a primate and laboratory rat.

4.1.4.1 Primate Waterer

Purpose

The purpose of this watering device is to provide the primate water on an ad libitus basis but in a controlled manner so that daily consumption may be measured.

Description

This watering device consists of a pressurized water reservoir, solenoid valve, timer, and drinking tube-lip lever combination. The drinking tube lip lever is located on the cage side wall near the top. The water in the reservoir is under a continuous controlled pressure regardless of the operating environment. A sucking response by the primate on the drinking tube actuates the lip lever switch which energizes the time, counter, and solenoid valve and allows water flow through the drinking tube. The timer is set to close the solenoid valve after a predetermined amount of water is dispensed and will not actuate the solenoid valve again until the lip lever is recycled. The amount of water dispensed is computed by multiplying the counter reading by the predetermined amount of water dispensed. The dispenser supply water is replenished by closing the regulator valve, opening the bleed air valve to vent to cabin, and refilling the container through the liquid refill valve from a Skylab type water container.

Performance and Design Summary

The water supply tanks are located in the top portion of a double rack which may hold one primate cage and one rat module. Separate water tanks are required to supply specimens on each side of the Spacelab. This system design provides for a 24-hour supply with reserve but may be increased dependent upon availability of the orbiter fuel cell water supply. Based on a requirement of 1,277 ml/day/primate and 64 ml/day/rat (32 ml/day/rat when paste food is used), each water tank is sized for 3.35 liters which provides a 24-hour supply with a nominal 0.25-liter reserve. The water tank is made of stainless steel and weighs 2.5 kg empty. The weight of the total system, less the empty water tank, but including 96 mm (3.8 in) tubing, solenoid valve, timer and lip lever is 1.5 kg. The 189 liters of water are required for 4 primates and 16 rats for a 30-day mission. This water is probably available from the orbiter fuel cell output and is to be transferred manually by the crew to the Spacelab.

Summary

Design Parameter	Design Value
Weight (per tank)	4.0 kg (8.8 lb)
(launch water)	3.35 kg (7.4 lb)
Volume (water tank)	0.004 m^3
Power (intermittent)	15 W

4.1.4.2 Laboratory Rat Waterer

Purpose

The purpose of this watering device is to provide the laboratory rats water on an ad libitum basis, but in a controlled manner so that daily consumption may be measured.

Description

This watering device consists of a central pressurized water reservoir (described in the previous paragraph), two-way shutoff valves, a graduated spring-loaded reservoir for each cage, water supply tubing, and Lixit valves for each rat cage as shown in Figure 4-17. The graduated spring-loaded individual reservoirs are located on the control panel in the single rack adjacent to the primate and rat cages or in the overhead portion of a double rack. The graduated reservoirs provide a means of determining the daily consumption of water for each rat cage and are refilled by manually

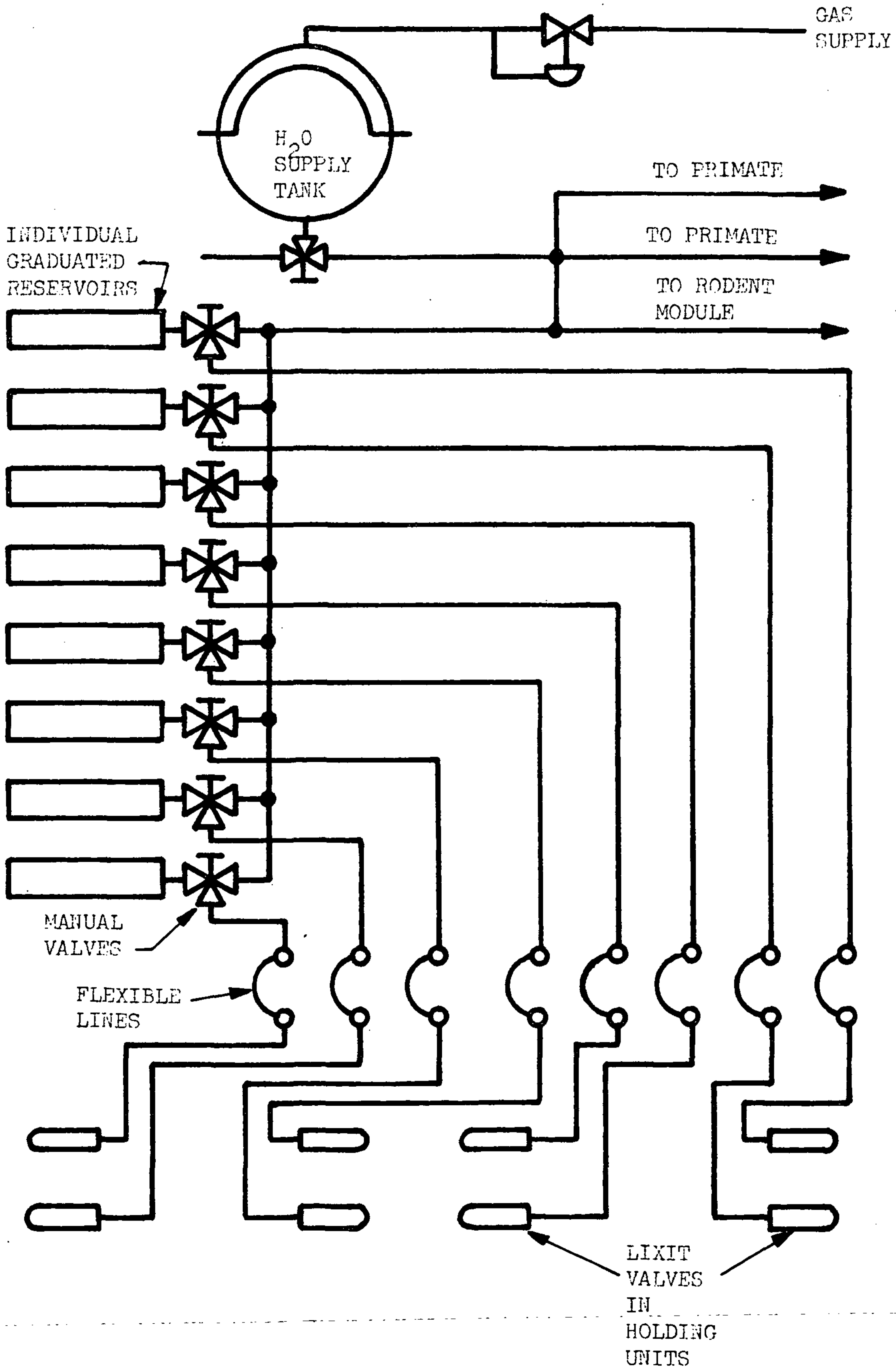


Figure 4-17. Rodent Module Drinking Water Supply Schematic

actuating the two-way valve on the control panel adjacent to the reservoir to direct the flow of pressurized water from the central reservoir into the graduated reservoirs. This resupply and recording activity is normally performed at the same time each day during scheduled maintenance activities. Any licking activity by the rat actuates the Lixit valve and a small amount of water is forced through the Lixit valve by the spring action in the graduated reservoir. The graduation of the reservoir provides an accurate measurement of the liquid which flows through the Lixit valve.

Performance and Design Summary

The water supply tank is located in the top portion of the double rack and is supplied as described in Section 4.1.4.1. Tubing is made of 36 mm (1.4 in) stainless steel and the graduated spring-actuated individual cage reservoir is made from acrylic plastic and holds 30 ml of water when completely full. The weight of the total system for one rat module, less the central water supply but including the tubing, eight two-way valves, and graduated reservoirs is 3.5 kg.

4.1.5 Data Acquisition and Monitoring

The data acquisition and management subsystem for the BSHF provides sensors or interfaces with PI-provided sensors, performs signal amplification and conditioning, and transfers conditioned data to the Spacelab command and data management system (CDMS) for display to the crew, transmission to the ground, or storage for later analysis. The BSHF instrumentation and monitoring requirements and the monitoring and signal conditioning equipment descriptions are presented in the following paragraphs.

4.1.5.1 Instrumentation and Monitoring Requirements

Habitats

The primary habitat monitoring requirements are listed in Table 4-3. The table also includes the measurement range, sensor type, its location, the type of signal conditioning, and data acquisition/display requirements. It is seen that although some sensor and signal conditioner response times are small, no need exists to sample the measurements at a correspondingly fast rate and sampling is standardized at 0.1 sample per second.

Table 4-3

HABITAT MONITORING REQUIREMENTS
ENVIRONMENTAL MONITORING

Measurement	Measurement Range	Sensor Type	Location	Coupler/Device
Differential cage to cabin pressure	0 to 5 psid	Pressure transducer	Inlet duct/cabin	None
O_2 partial pressure	150 to 170 mm Hg	Polarographic	Cage wall	Differential amplifier
CO_2 partial pressure	0 to 8 mm Hg	Infrared	Cage wall	Differential amplifier
Air temperature	18° to 27°C (70° to 78°F)	Thermister	Inlet duct	Thermister amplifier
% relative humidity	40 to 65%	Impedance	Cage wall	Humidity meter
Sound level	32 to 140 dB	Microphone	Laboratory	Audio amplifier

Signal Conditioner Requirement	Location	Output	Response	Sample Rate	Channels/Habitat
Differential pressure	Adjacent signal conditioning rack	5 V	1 msec	0.1 S/sec	1
O_2 partial pressure	Adjacent signal conditioning rack	5V	100 msec	0.1 S/sec	1
CO_2 partial pressure	Adjacent signal conditioning rack	5V	15 sec	0.1 S/sec	1
Air temperature	Adjacent signal conditioning rack	5V	20 sec	1 S/Sec	2
% relative humidity	Adjacent signal conditioning rack	100 mV	1 msec	1 S/sec	1
Sound level	External to habitat	5 vp-p	200 msec	1 S/sec	N/A*

*Only one required/laboratory in vicinity of habitats.

Additional habitat monitoring requirements, including animal behavioral and food/water consumption monitoring, are shown in Table 4-4. Nine measurements are provided on each monkey habitat and 14 on each rodent module. The disparity results from the manner in which food and water consumption is monitored for the two specimen types (rat intake data are not automatically collected), and the use of one photocell per rat for actively monitoring versus the integration of four photocells into one measurement for primates.

Specimens

Specimen/experimental monitoring requirements are shown in Table 4-5. The first category, specimen condition monitoring, includes an electrocardiogram (EKG), a heart rate derived from EKG and a deep body temperature on all specimens. During experimentation, monitoring channel assignments will be determined by the principal investigator. A maximum of 9 channels per specimen are provided for telemetered experimental measurements. Using implanted electrodes, four measurements are identified for cardiovascular research on primates. Also, four channels per rat and seven channels per primate are included for physiological measurements. Many of these measurements are seen to require sampling rates larger than those obtainable on a single Spacelab remote access unit (RAU) channel; RAU's are specified to require a minimum time between samples of 10 milliseconds corresponding to a 100 sps rate. It is thus required to parallel-wire five spaced channels for each of the measurements which are to be handled in digital form. Digitizing these signals will permit the exclusive use of a digital tape recorder for data storage and eliminates a subcarrier multiplex unit which would be needed to place the signals in analog format on the down link transmitters.

All transducers shown in Table 4-5 will be implanted in the specimen or attached when data are required. In any event, they will be provided as experiment-peculiar equipment and not a part of the BSHF. The facility will be required to provide excitation to and receive signals from these transducers.

Table 4-4

ADDITIONAL DATA COLLECTION REQUIREMENTS

Measurement	Measurement Range	Sensor Type	Location	Sample Rate (S/S)	Channels/Animal M	Channels/Animal Rat
BEHAVIORAL MONITORING						
Activity cycle Body temperature	33° to 41°C	Thermister	Implant	0.1	1	1
Activity cycle		Food/water switch closures	Water dispenser (Cage front)	0.1	Not applicable*	
Activity cycle	0 to 60 ppm/ses/sec	Photocell matrix	Cage wall	0.1	1	1
Motion	Not applicable	TV/photo camera mount	Cage front	0.1	Not applicable**	
FOOD/WATER						
Food consumption	0 to 6 ppm	Microswitch	Pellet feeder (Cage front)	0.01	1	Manual Paste Feeder
Water consumption	100 to 2,000 cc/hr	Microswitch	Water dispenser (Cage front)	0.1	1	Manual

*No additional instrumentation required (see food/water).
**Cameras mounted as required for behavioral monitoring.

Table 4-5

SPECIMEN PHYSIOLOGICAL DATA

Measurement	Measurement Range	Sensor Type	Location	Sample Rate (S/S)	Channels/Animal M	Channels/Animal Rat
SPECIMEN MONITORING REQUIREMENTS						
Electrocardiogram (EKG)	0 to 3 mv; 0.5 to 100 Hz	Electrodes	Surface or implanted	500 and analog	1	1
Heart rate	0 to 3 mv; 30 to 400 BPMIN	--	--	--	Derived from EKG	
Deep body temperature	33 to 41 C; 0 to 0.05 Hz	thermistor/	Surface or implanted	1 and analog	1	1
EXPERIMENT DATA COLLECTION (CARDIOVASCULAR)*						
Arterial blood pressure	20 to 300 mm Hg; 0 to 100 Hz	Pressure sensor	Implanted	500 and analog	1	0
Venous blood pressure	-5 to 60 mm Hg; 0 to 100 Hz	Pressure sensor	Implanted	500 and analog	1	0
Blood flow	0 to 1,000 cc/min: 0 to 100 Hz	Flow meter	Implanted	500 and analog	1	0
Heart sounds	0.1 to 10,000 Hz	Crystal microphone	Implanted	Analog	1	0
EXPERIMENTAL DATA COLLECTION (NEUROPHYSIOLOGY/ELECTROPHYSIOLOGY)*						
Electroencephalogram (EEG)	10 to 500 uv; 0.2 to 100 Hz	Electrodes	Implanted	500 and analog	4	0
Electromyogram	0.01 to 5 mv: 0.5 to 1,000 Hz	Electrodes	Implanted	500 and analog	1	0
Electrooculogram (EOG)	10 uv to 1 mv; 0.1 to 100 Hz	Electrodes	Implanted	500 and analog	1	0
Vestibular nerve activity	10 to 500 uv; 0.2 to 100 Hz	Nerve electrode	Implanted	500 and analog	1	0

*Not combined except on restrainted primates: a maximum of 9 channels provided for telemetered measurements.

4.1.5.2 Equipment Descriptions

The manner in which habitat measurements will be integrated with the Spacelab control and data management system (CDMS) is illustrated schematically by Figures 4-18 and 4-19. The signal conditioners are designed to accept 28 Vdc and can also be supplied their requisite circuit voltages by the use of small dc converters within each rack adapter.

Figure 4-20 illustrates the equipment connections for acquiring telemetered data from unrestrained rats and primates. FM rather than AM transmission and reception equipment has been selected due to the better performance of FM in a noisy environment. Due to the potentially large number of rats to be carried, a single tunable receiver for each rodent module (containing 8 rats) is used.

This requires sequential selection of each rat to be monitored, a function which will be programmed automatically in the computer. Also, since the number of primates probably will not exceed four on any given mission, an additional tunable receiver is provided for the primates.

Two egg-crate-type signal conditioner rack adapters, each with a capacity of 24 circuit cards will be used to package all the signal conditioning required for a BSHF including 4 primates and 2 rodent modules. The egg-crate-type rack adapter is shown in Figure 4-21 compared to a standard type adapter to illustrate the weight and volume savings obtained from this packaging technique. The use of MSI or LSI techniques was not attempted for this application since the small number of units to be provided for habitat signal conditioning does not allow the cost effective use of this technology. Each of the two racks provided is 24 by 19 in 3.5 in and is designed to fit into a standard 19-in Spacelab rack.

4.1.5.3 BSHF Instrumentation System Summary

A summary of the BSHF instrumentation for the typical LSL installation is presented below. As evidenced by the figure of six signal conditioners per rodent module, some measurement signals such as those output by the photocells have been grouped for conditioning on one card. It was found possible to provide all signal conditioning in two 3.5-inch-high rack adapters.

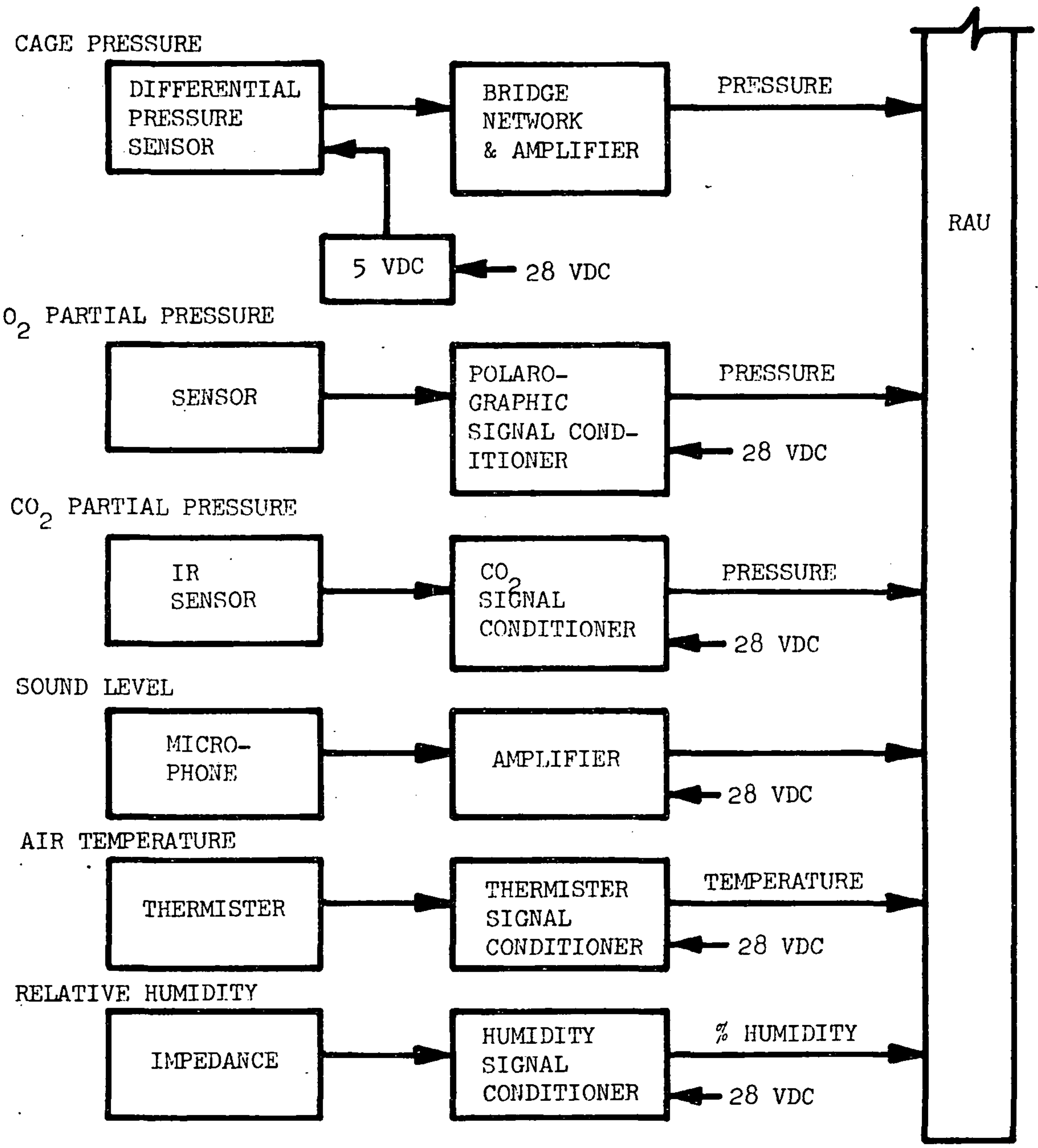


Figure 4-18. Data System Schematic, Habitat Monitoring

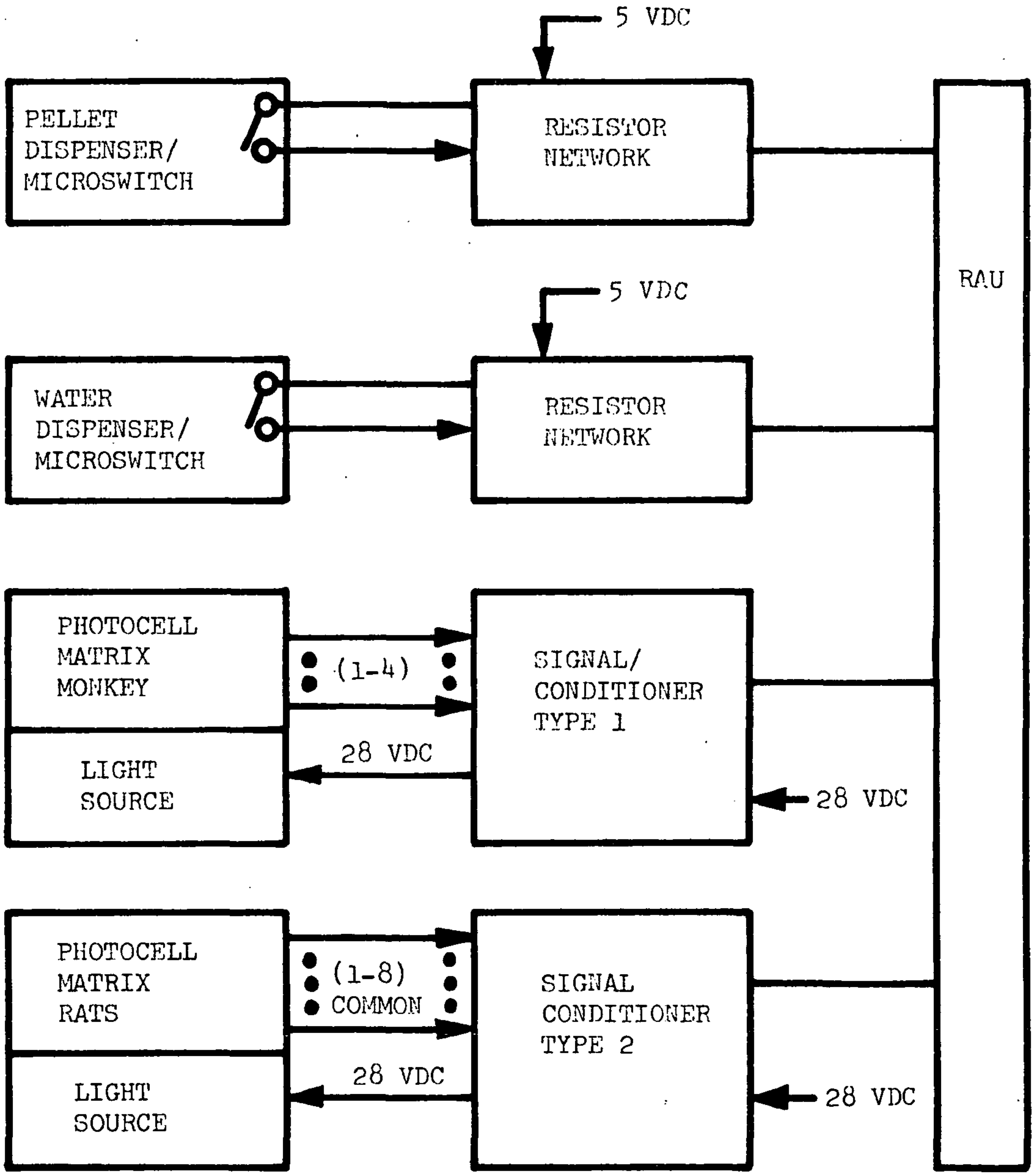


Figure 4-19. Additional BSHF Measurements

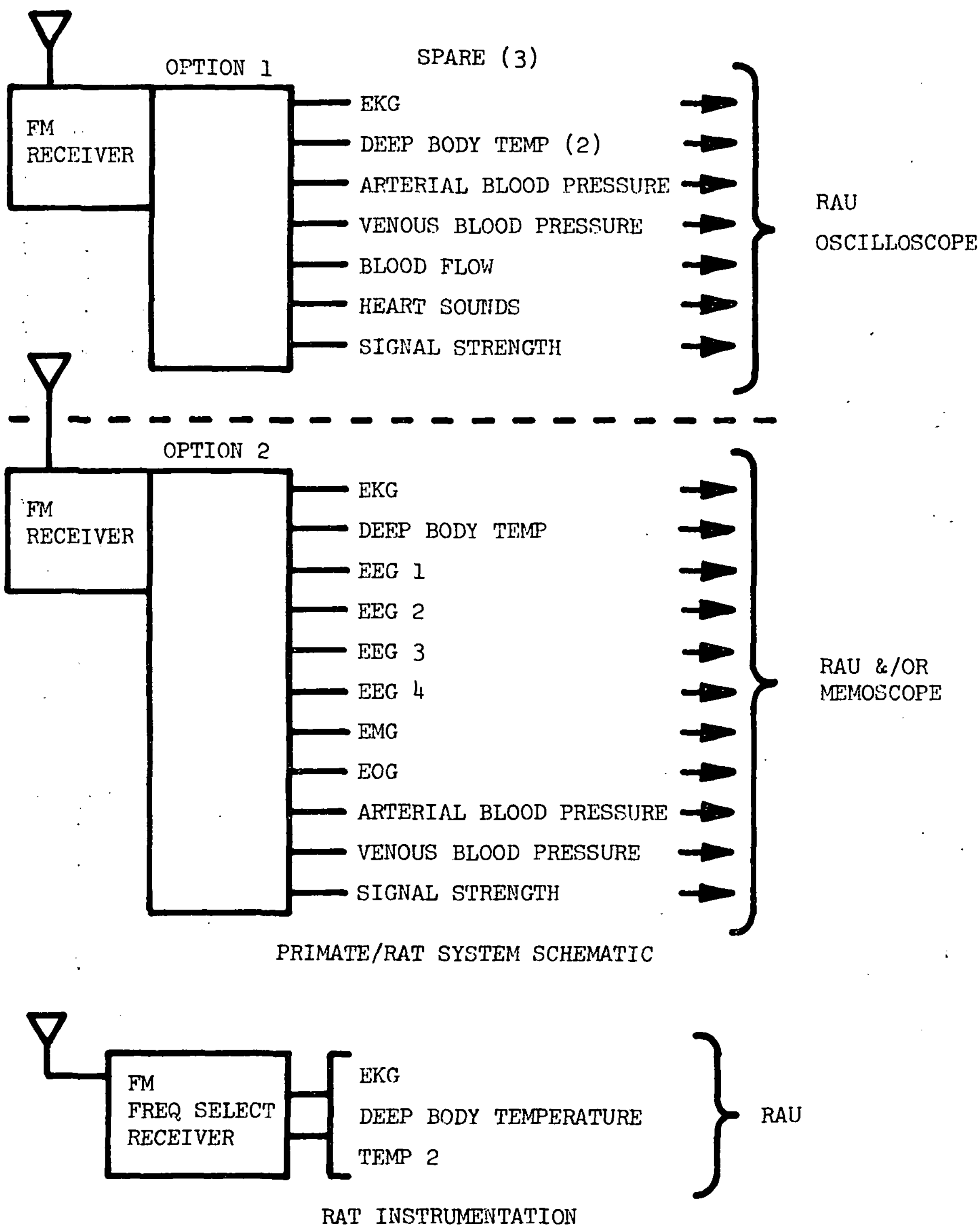
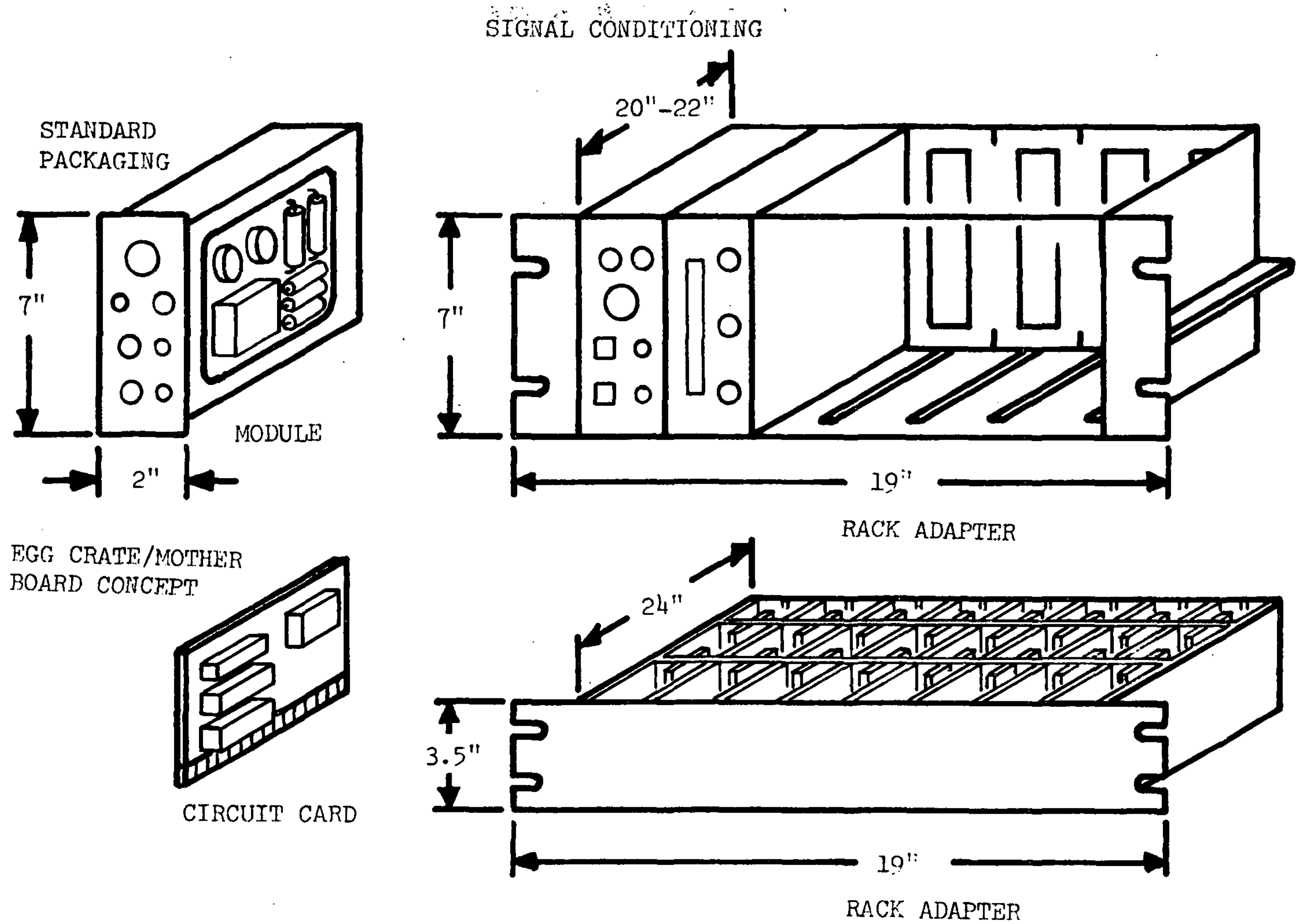


Figure 4-20. Data Obtained from Implanted Sensors by FM Link



TYPE	CAPACITY	CONTROLS	WEIGHT
STANDARD	8 MODULES	FRONT PANEL	~ 58#
EGG CRATE	24 BOARDS	KEYBOARD	~ 24#

Figure 4-21. Alternate Packaging of Signal Conditioners by Standard or Egg Crate Methods

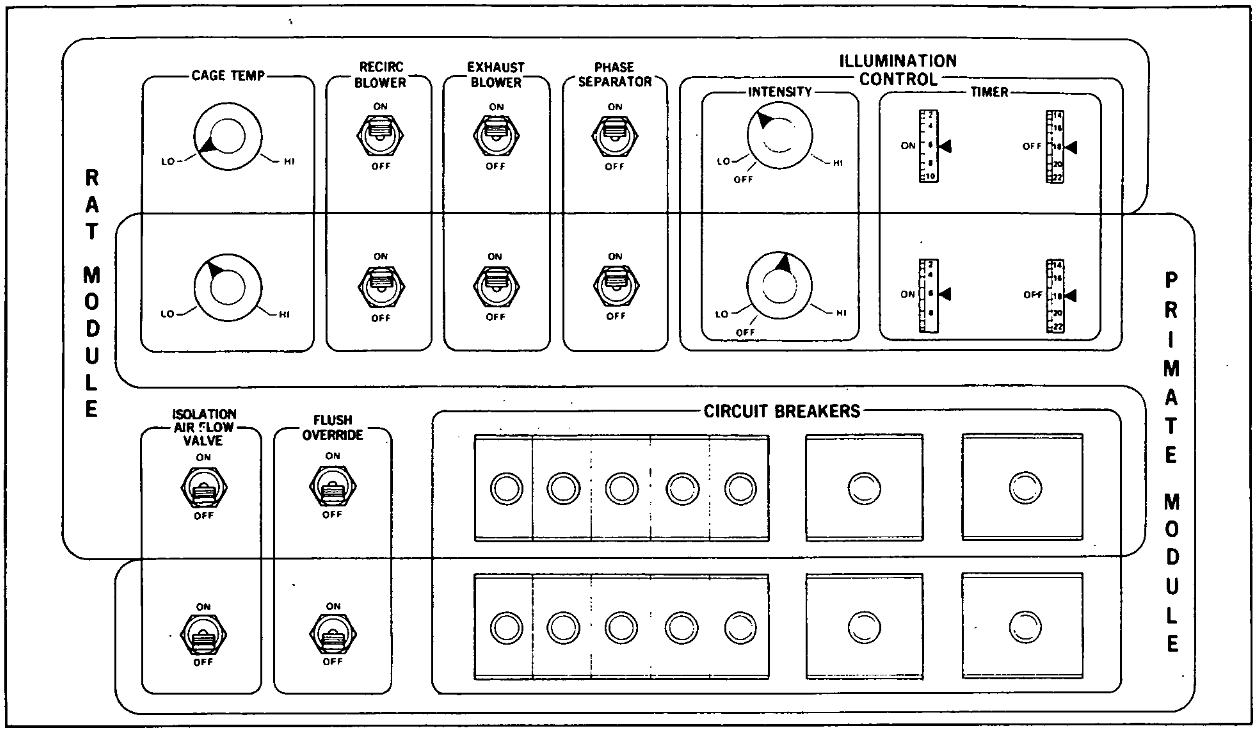
Signal conditioners/monkey habitat	8
Signal conditioners/rodent module	6
Total signal conditioner/monkey habitats	32
Total signal conditioners/rodent modules	12
Total signal conditioner rack adapters	2
Total FM receivers (4 monkeys)	1
Total FM receivers (rodent module)	1
Number of channels/receiver (monkey)	11
Number of channels/rat	2
Total receivers for BSHF	3

4.1.6 Control and Display

Controls for the BSHF may be installed in a panel of Spacelab double rack width and mounted in the rack above the rodent module, although other mounting arrangements may be selected if desired. Controls are limited to those that affect the basic environmental control functions of the BSHF: air flow, light intensity and duration, temperature, waste management, and rodent water supply. Circuit breakers and caution and warning lights for both rodent and primate modules are also provided. The panel is color-coded to differentiate rodent and primate controls where they are grouped by function such as recirculation blower and cage temperature control switches, as shown in Figure 4-22.

One half of the panel includes individual rodent water reservoirs. The reservoirs have transparent walls with a scale and colored float so that rodent water use may be read directly. The control valve is mounted next to each reservoir. The other half of the panel contains the circuit breakers, the recirculation and exhaust blower and air isolation valve switches, the cage temperature controls, the light intensity and duration controls, and the waste management water control switches consisting of phase separator and flush override switches.

The balance of the controls not directly related to the above environmental functions are generally not manually set. In order to save time and since flight personnel will be well-trained in CDMS operation, semi-automated signal conditioner controls have been selected for the BSHF application.



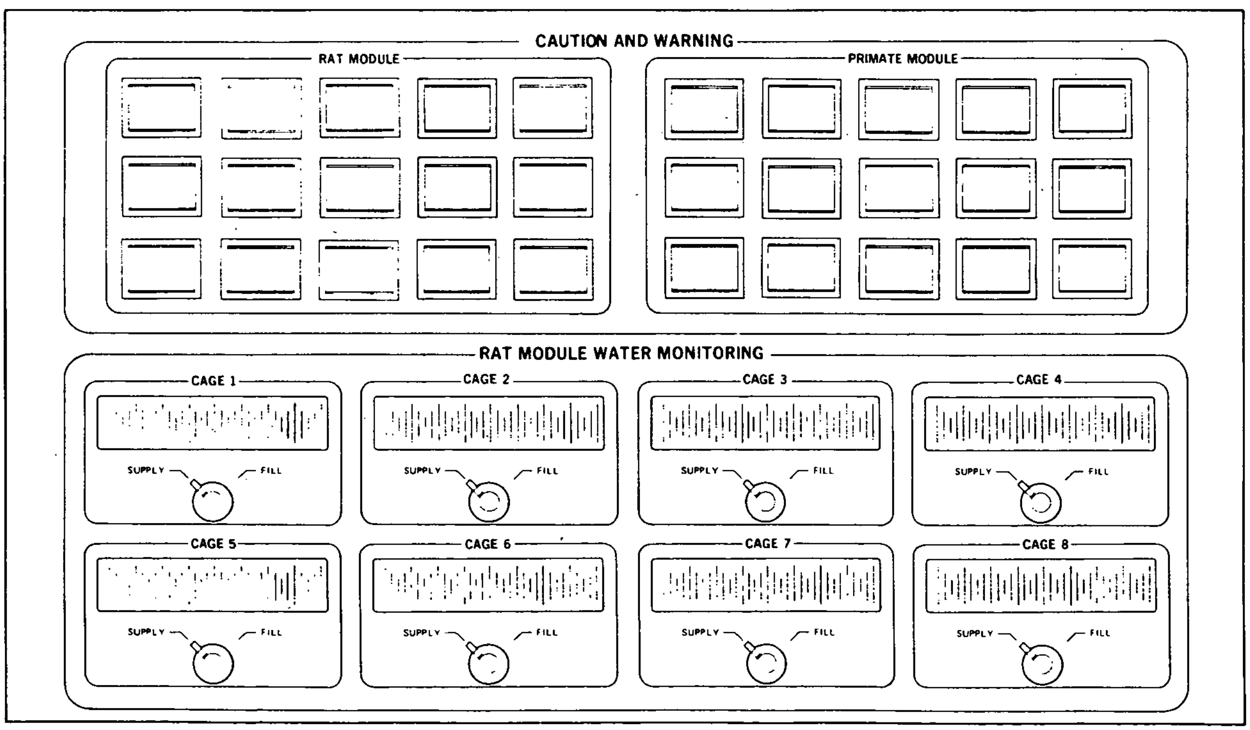


Figure 4-22. Control and Display Panel for Primate and Rat Module

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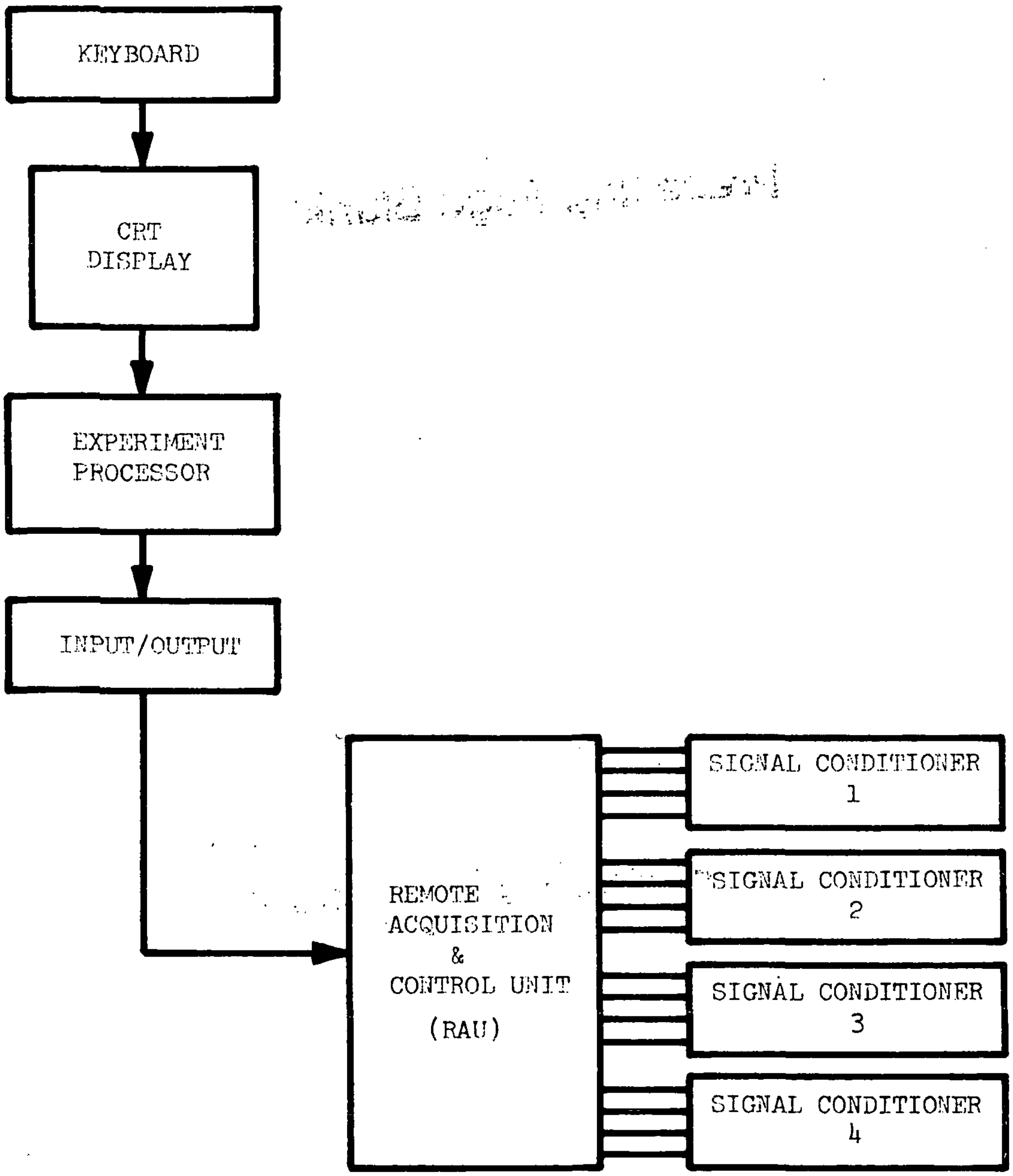

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Figure 4-23. Controlled Inputs to Signal Conditioners Via Spacelab CDMS provide protection against fluorescent tube breakage and escape of mercury and also provide for an acceptable surface touch temperature.

Each of the primate cages and rodent modules has two independent electrical circuits. Lighting reliability is provided by powering half the lights in each holding unit from each circuit.

Light is transmitted into the cage and is controllable within the range of 0 to 860 lm/m^2. All power and control circuit wiring is incorporated into the cage wiring harness. Light controls are on the control and display panel that may be located directly above the rat module in the double rack.

Performance Summary

Parameter	Design	
	Primate	Rat
Lights per module	4	4
Weight	0.7 kg	0.45 kg
Power per module	12W, 28 vdc	12W, 28 vdc
Illumination level per light	140 lm	140 lm
Weight, spare tube	100 g	100 g
Volume, spare tube	21.6 cm^3	21.6 cm^3
Life cycle	4,500-hour service life and 800 short cycles	
Cool white light specification	MIL-M-25050	MIL-M-25050

4.2 SYSTEM CHARACTERISTICS

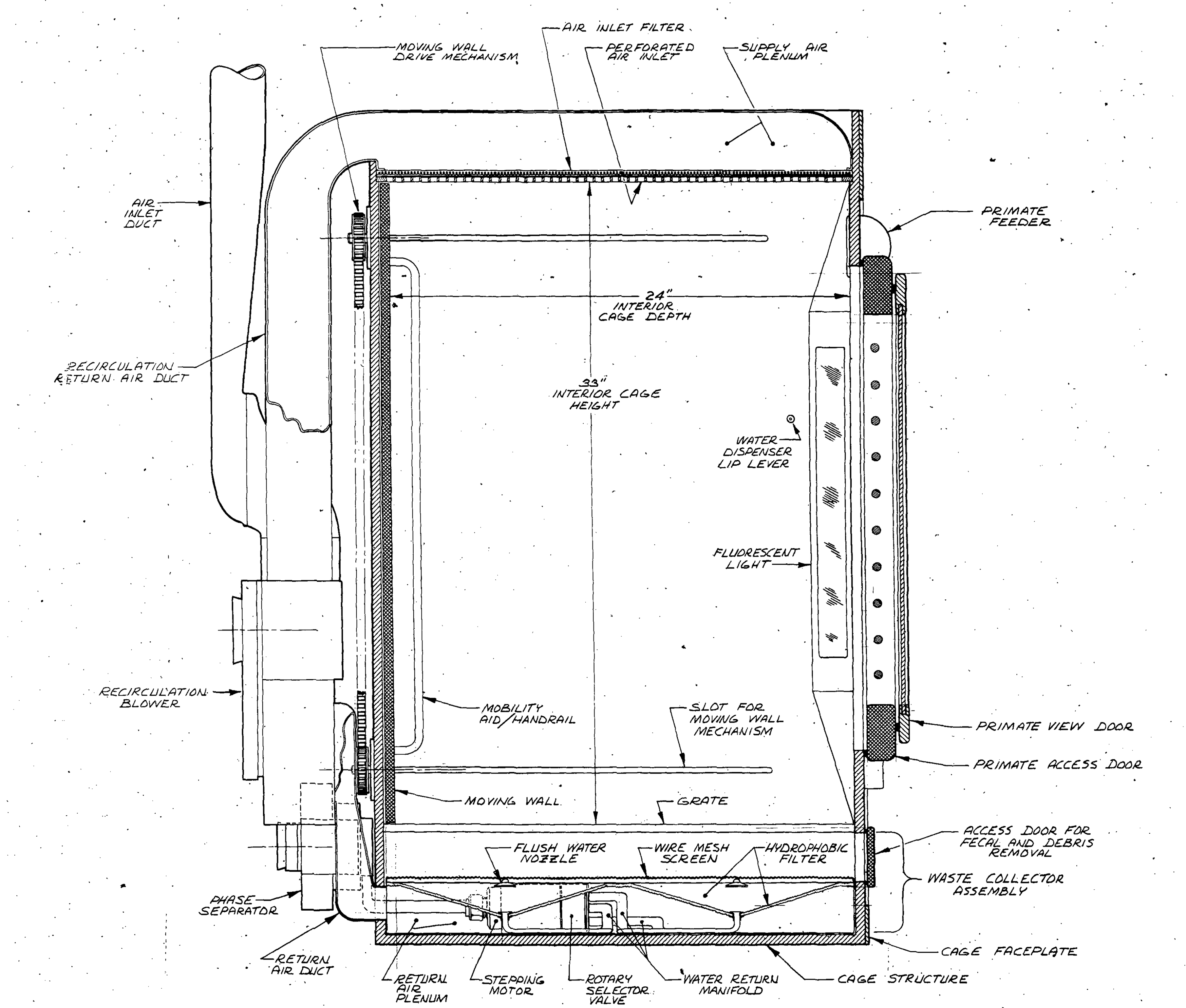
The primate and rodent cages will provide specimen support under conditions similar to those encountered in a conventional research laboratory. They will provide habitats for prelaunch, launch, orbit, experiment, observation, reentry, landing and postlanding containment of the unrestrained animals. In addition, the rhesus cage will be capable of conversion into a restrained cage configuration for two rhesus monkeys. This cage will be designed and structured to permit this conversion to be accomplished by "bolt-on conversion" assemblies, without structural alterations to the basic cage structure.

Each of the cage structures (rhesus and rodent) are required to withstand launch and reentry loads, provide access for subsystem maintenance and cleaning of interior, and prevent contamination of cabin atmosphere by cage atmosphere. The sealed environment also aids in the attenuation of harmful acoustical levels. A lightweight structure is required to maintain a minimum overall weight goal for the entire holding facility system.

4. 2. 1 Structural Design

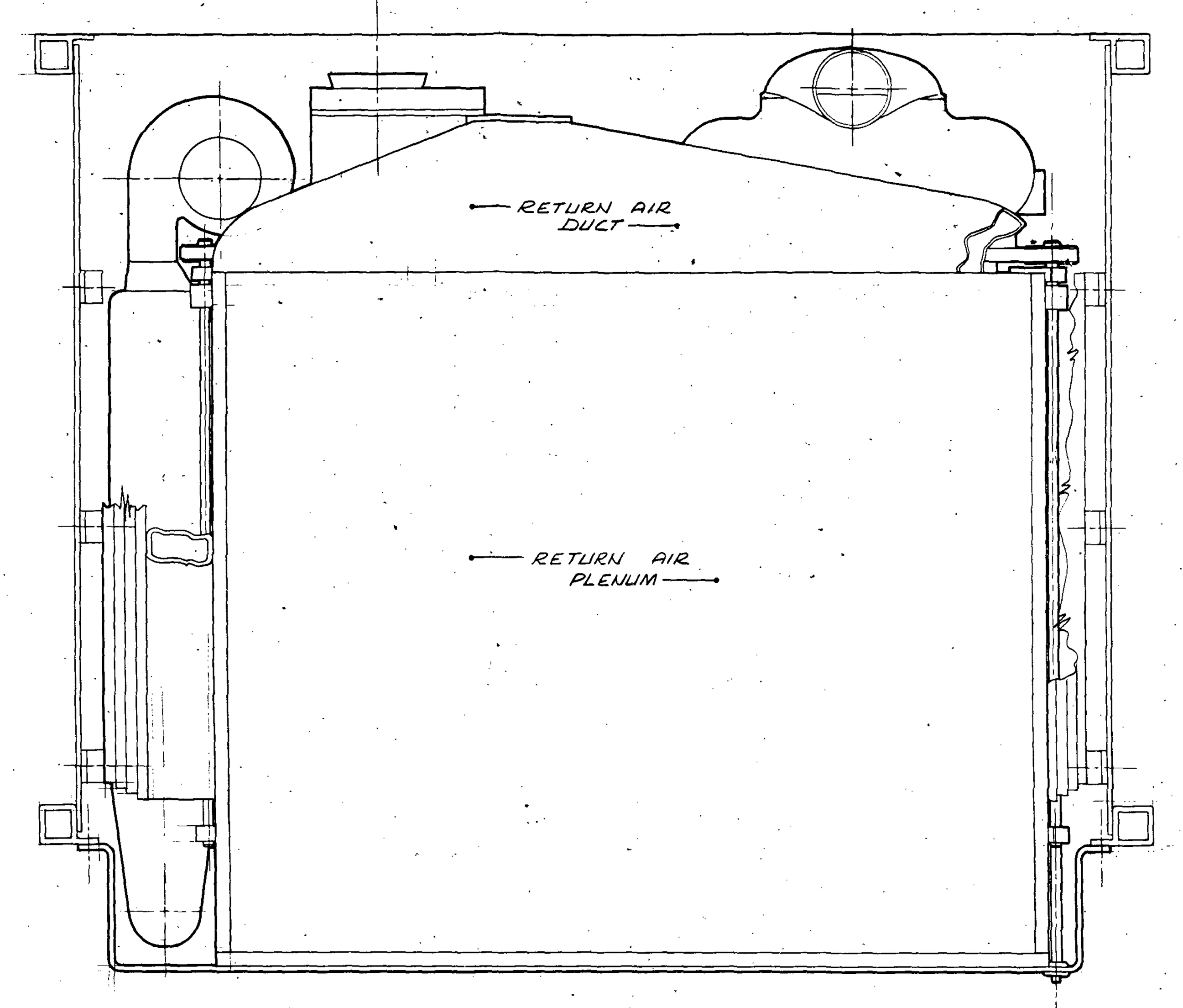
4. 2. 1. 1 Primate Holding Unit

Layouts of the primate holding unit showing details of the cage structure are presented in Figure 4-24. The basic shell of the primate cage consists of sides, back, bottom, and top. The front consists of the panel that contains the door, feeders, lights, and feces/debris removal access panel. The basic shell will be 0.020-in corrosion-resistant steel with 0.75-in radius at all flat plane intersections. All corners will be ball insert weldments. The open face portion of the cage will have reverse minimum bend radius flanges bent to the outside of the cage to provide an attach lip for the front face panel. The stainless steel liner described above will contain all of the equipment required to interface directly with the primate. All penetrations into the shell will be sealed for air flow, moisture, and sound attenuation. The bottom of the shell will accept the feces/urine/debris separator. The rear of the shell will accept the ducting for the bottom-mounted urine/air separator, as well as electrical and other penetrations, as required. The top of the shell will be perforated with 3/8-in-diameter holes located in a pattern to provide 59% open area. The recirculating 300 cfm air flow will be directed downward through this panel. The side walls will be slotted to accommodate the four extension arms (two on each side) of the primate squeeze panel. Each arm contains a drive nut that is engaged to a lead screw. The four lead screws are synchronized by a driving belt or chain. One lead screw is driven by a hand crank mounted at the front of the cage which is manually actuated by a crewmember. This powered lead screw drives the other three lead screws forcing the squeeze panel forward to restrain the primate against the bars of the cage door. The squeeze panel is returned to the rear of the cage by reversing the direction of rotation of the hand crank. The slots in the sidewall which provide for penetration of the

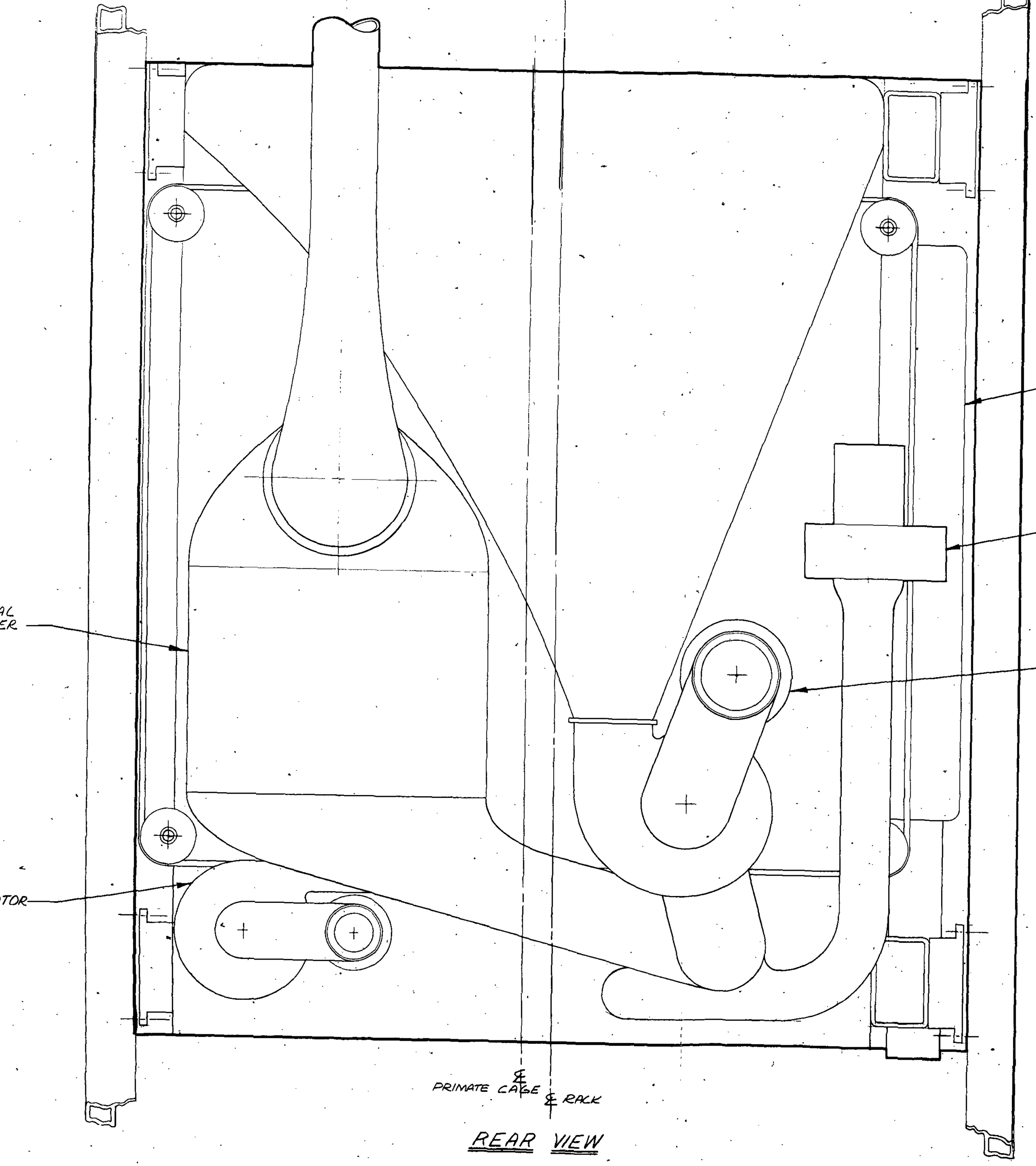


SECTION A-A

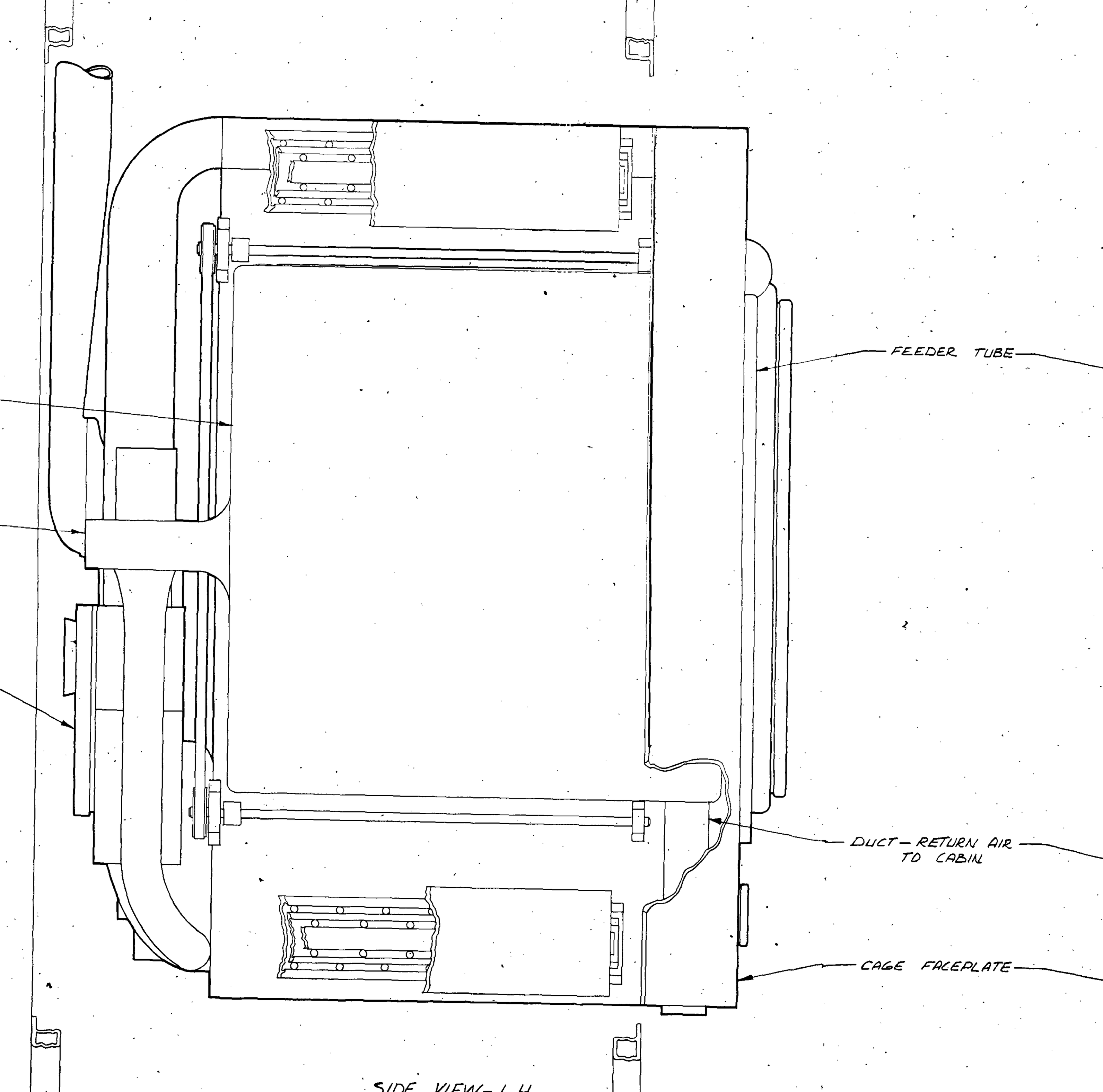
MCDONNELL DOUGLAS



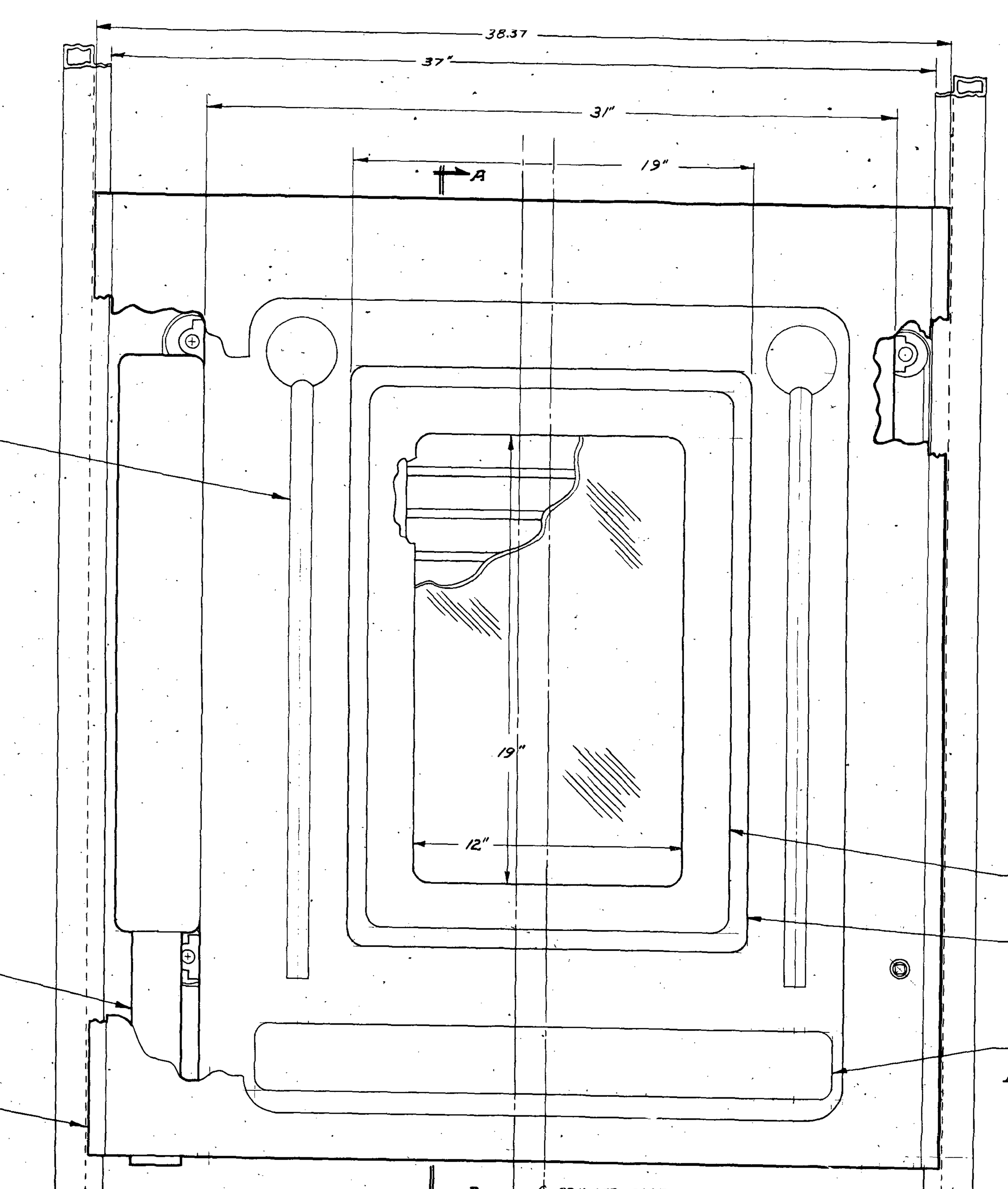
TOP VIEW



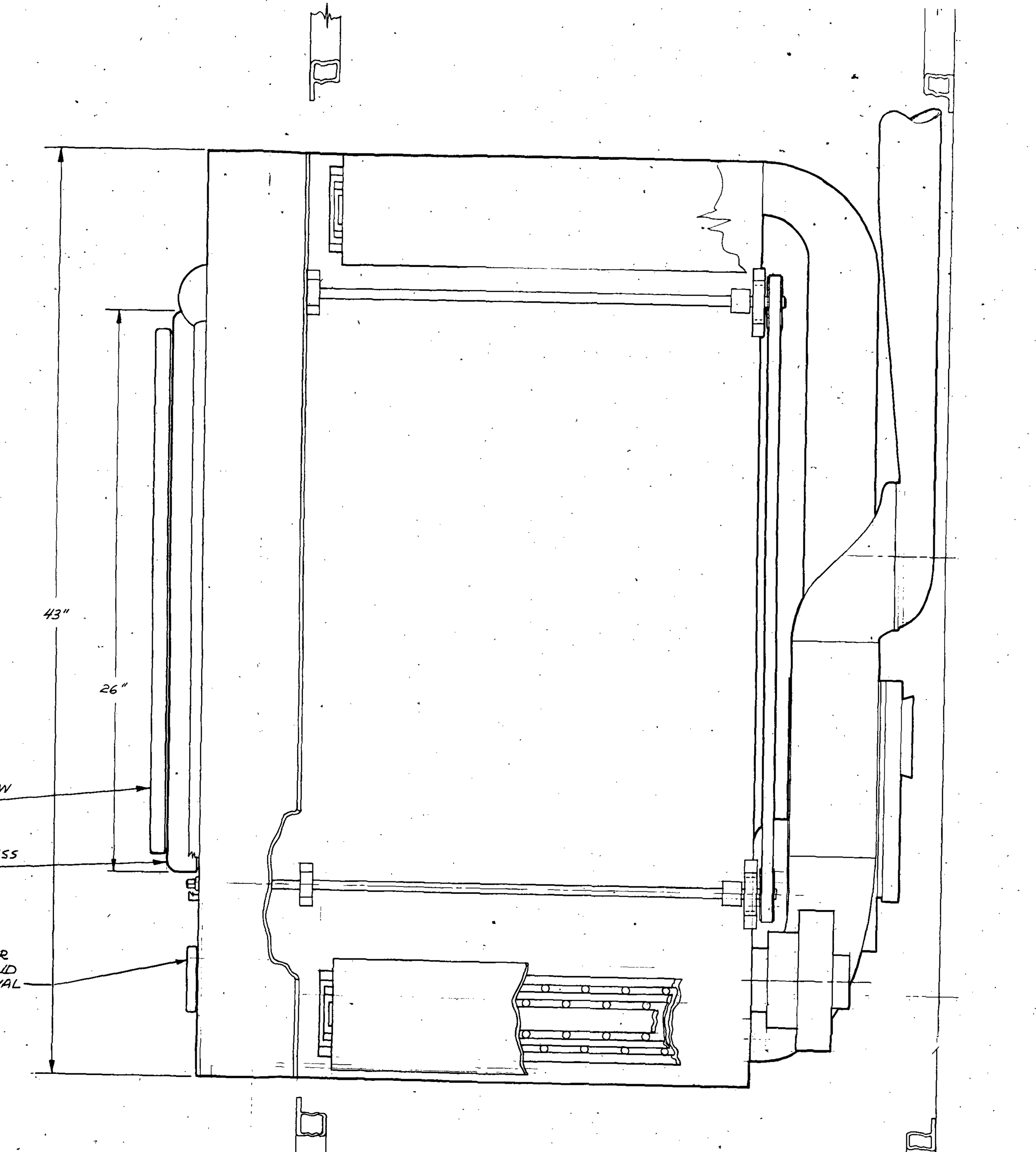
REAR VIEW



SIDE VIEW – L.H.



FRONT VIEW



SIDE VIEW – R.H.

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driving extensions of the squeeze wall will be sealed by a traveling negator spring attached to the extension which rides in a nylon track attached to the outer surface of the shell. All interior surfaces of the holding unit will be TFE-coated for ease in cleanliness.

A minimum of 1/2-in-thick insulating polyurethane foam will be attached to the exterior bottom, sides and back of the stainless steel shell. The foam will insulate against sound and thermal extremes. The foam will be contained by an outer skin of 0.020-in aluminum sheet stock that will seal the insulating foam from the Spacelab environment. The outer shell of aluminum will be fabricated by standard aircraft structure practice. Joining of the inner shell to the outer shell will be by standoff stud and nut and nutplate and screw attachment technique.

The area above the top of the perforated stainless steel cage top will contain an air filter material that is approximately 0.25-in thick, in the return air plenum that attaches to the top of the inner shell. The air plenum and associated air duct is made of 0.020-in aluminum that is formed, beaded, and welded into a subassembly structure. This subassembly is attached to the top of the cage by attach bolts and appropriate sealing gasket material. The beads in the subassembly are to provide strength and prevent an oil canning effect that would generate unwanted noise and vibration.

The front panel structure containing the door is made of the same sandwich technique as the major cage structure described above. The front panel is attached to the shell structure by screw fasteners that thread into captive nutplates attached to the flange surface of the cage front. An airtight seal joint will be made between the front panel and the cage front face flanges. The access opening in the front panel is 18-in wide and 25-in high.

The access door attaches to the front panel by use of a piano-type hinge. The access door has an open area 12-in wide and 19-in high. Bars made of stainless steel tubing (1/2-in O.D.) are set horizontally in the opening. The bars are spaced 2-in apart on centers. Attached to the access door is a view door. The view door contains a high impact strength glass window 12-in wide and 19-in high. Both doors have soft seals and positive latching catches. The view door hinge is attached to the access door and is on the same side as the access door hinge. Each door is equipped with a friction stop to permit clear opening of at least 90°.

All attached components such as blowers, filters, ducting, separators, and slides are mounted by welded studs, attach plates, or riveted nutplates. Consideration will be given to the possible need for inflight replacement of failed components.

The cage is secured to the Spacelab rack by two slides on each side. The slides will be capable of a minimum extension of 30-in. This extension will permit the cage to be extended into the Spacelab free area to allow maintenance and replacement of parts during on-orbit operations. After extension, the cage can be lifted off the slides if better access to rear-mounted components is required.

The cage is positioned and held in the rack by a front cover mask that extends approximately 4.5 in beyond the forward edge of the rack. This mask is secured to the cage front panel by attach screws that thread into the prepositioned nutplates. In turn, the mask is fastened to the rack by standard rack fasteners.

All interfaces between the cage and the rack are accomplished by solid attach points on both the rack and the cage. Electrical and water lines will be attached to the cage and rack with a service loop in between the hard points. The service loops will incorporate manual quick disconnects for unit removal or servicing. Interfaces such as bleed air duct and electronic cooling air ducts will have a simple mating surface that is similar to the cork in the bottle concept. Blower fans associated with the above ducts will be manually switched to the off mode prior to duct demating and manually reactivated after mating is completed.

4.2.1.2 Rodent Module

The rodent module, comprised of eight rat cages, is illustrated in Figure 4-25. The rodent module will consist of a corrosion-resistant steel

Figure 4-25. Biological Specimen Holding Facility Rodent Module

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structure divided into eight compartments, each sized to hold one 350-gram rat. The compartments, or cages, are arranged in two rows of four, one above the other, with an integral and symmetrical set of ducts. The ducts from the top rear of each cage are joined to a common inlet duct and the ducts from the bottom rear of each cage are joined to a common exhaust duct. Each pair of cages has a common wall assembly that contains the light fixture, photocell assembly, and all water piping and wiring required by the two cages.

The rodent module structure is fabricated from sheet metal riveted throughout the compartment sections and welded at the seams of the ducts to form a completely airtight structure. The outer walls and rear walls are lined on the interior with 1/4-in insulating foam which is faced with 0.020-in-thick aluminum sheet stock. All interior surfaces of the cages will be TFE coated.

The forward edges of all partitions and perimeter sheets will be flanged and equipped with nutplates to attach the front plate to the module. The front plate will be made of 1/8-in aluminum sheet with the interior surface TFE coated. The eight door assemblies are all mounted on the front plate.

The recirculating air flow (20 cfm per cage) is supplied to an inlet plenum at the top of each cage. An inlet filter separates the inlet plenum from the rodent space. The filter is composed of a 1/8-in sheet rayon viscose felt and corrosion-resistant steel screen. This assembly is removable for replacement and cleaning. There is one filter for each cage.

The waste collection subassembly fits into the bottom of each cage and separates the rodent living space from the exhaust duct. It consists of a flush water supply manifold and a urine collection manifold, both integral with a filter surface composed of Zitex, a felted TFE material. The water and urine lines enter the cages from the access ducts between each pair of the units, as seen in Figure 4-25.

The light fixture for each pair of cages is mounted in the upper duct common to the pair. The walls of the light duct are slotted to admit light to each cage and the slots are covered with a clear plastic sheet which seals off the duct. The light ducts are completely enclosed and sealed to contain all light bulb material in the event of breakage.

The front plate has eight access cutouts in it matching the locations of the cages. The individual doors for each cage are mounted on the front plate. The complete door assembly is bolted to the module assembly.

The drinking water supply lines run through the access ducts and attach to fittings mounted in the front plate. These fittings serve as hinge pins for the doors and allow the Lixit valves to be mounted in the door next to the food chamber.

The water system valves, meters, and controls are mounted on the ducting at the rear of the cages. The water systems, both drinking and flush water supplies, and the urine systems are run from the rodent module with flexible lines allowing the module to be slide-mounted for ease of maintenance. The module is mounted in a Spacelab double rack on one pair of slides. The slides are capable of being extended 30 in which will allow maintenance and replacement of all components. If better accessibility is desired, the cage can be lifted off the slides after extension, disengagement, and disconnecting basic utilities.

The door to each cage contains a high-strength window, the feeding compartment, and the watering valve. The feeding compartment contains a sliding door on the outside for the insertion of the food containers and an opening to the cage through which the specimen may take food. The Lixit drinking valve is mounted next to the food compartment. The door contains a seal around its entire periphery making it airtight.

The wire cage assembly that fits into each rodent cage is constructed of flat woven stainless steel screen. The floor consists of two layers of screen, the lower one of a weave fine enough to prevent the passage of rodent fecal material; the upper, which serves as the floor, is an open-weave which will permit the fecal boli to pass through it. The walls of the wire cage will be made of a weave similar to the lower screen primarily to inhibit the experimental specimen from holding on to its surface and thereby keeping the specimen on the floor screen most of the time. The wire cage will function as a retainer for rodent feces and as a transport device to install and remove the specimen from the cage.

4.2.2 Acoustic Control

The estimated acoustic spectrum inside the orbiter cargo bay during launch was found to produce an effective overall sound pressure level of 145 db. The maximum acoustic level occurs at time of lift-off and then decreases very rapidly with time. The Spacelab module shell and insulation will attenuate the acoustic vibration by approximately 7 db overall, the attenuation being frequency-dependent.

The live specimens launched inside the BSHF require a substantial decrease in acoustic levels from the 138 db prevailing inside the Spacelab shell. A mandatory requirement is made for a maximum level of 120 db inside the specimen holding units. Additional reductions to 90 to 80 db are more desirable. However, further studies are required to establish the precise maximum acoustic levels and frequencies that can be tolerated by each of the species considered.

Preliminary analyses were made to assess methods of BSHF sound attenuation. A NASA study indicated that overall Spacelab sound attenuation by increasing the shell thickness or by adding a layer of sound absorbing foam results in excessive weight penalties of up to 2,830 lb for 9 to 10 db attenuation.

The alternate and more favorable approach is by local attenuation of the individual holding units. Analyses were conducted in this study and by NASA which show the feasibility of this approach. Preliminary analyses indicate that approximately a 2- to 3-in-thick acoustic insulation would reduce the sound level to lessl than the required 120 db. However, considering the rack dimensions, this insulation would considerably reduce the dimensions of the living area available for the primate. Additional studies are required to assess the feasibility and effects of placing the acoustic insulation in the rack structure surrounding the holding units rather than in the units themselves. It is recommended that such studies be conducted during the following phase of the program, prior to the commencement of detailed system design.

4.2.3 Mockups

Full-size soft mockups of the specimen holding units installed in a mockup of a Spacelab rack were constructed to provide a study tool for the evaluation of the engineering design concepts developed during the study. The major objectives of the mockup effort included the evaluation of volume, floor area, lighting, feeding, observation techniques, accessibility for maintenance, adequacy of control and displays, and man/system interfaces.

The mockups were constructed to represent the BSHF volume and man/system interfaces as installed in the Spacelab. The FOME-COR technique was used in the construction of the soft mockups. This approach to full-size mockup effort was found to be cost effective and showed all the fidelity of detail and accuracy of construction required at this stage of the design. Both the primate cage and the 8-cage rodent module were mocked up from the FOME-COR material as shown in full view in Figure 4-26. The figure also shows the control and displays panel depicting switches, dials, and other monitoring equipment in two-dimensional graphic art work. ECS ducting, blowers, filters, and support equipment were also duplicated to illustrate typical construction and routing of components. Figure 4-27 illustrates the mockup used to study accessibility to the primate cages microbial filter and other ECS components. The mockups were also used to study the operational procedures used in removing the primate and the rat from their cages, as depicted in Figures 4-28 and 4-29, respectively.

Another major advantage realized through the utilization of the mockups is that design discrepancies not readily discernible on two-dimensional drawings were discovered while constructing the mockup. Revisions made to the mockups were then reflected in the master layout drawings. These revisions were found to be mainly in the area of ducting, clearances between components and racks, as well as rearrangement for maintenance and accessibility.

Figure 4-26. Mockups of Primate Cage and Rodent Module in Dual Rack

Figure 4-27. Accessibility to Rear of Primate Cage

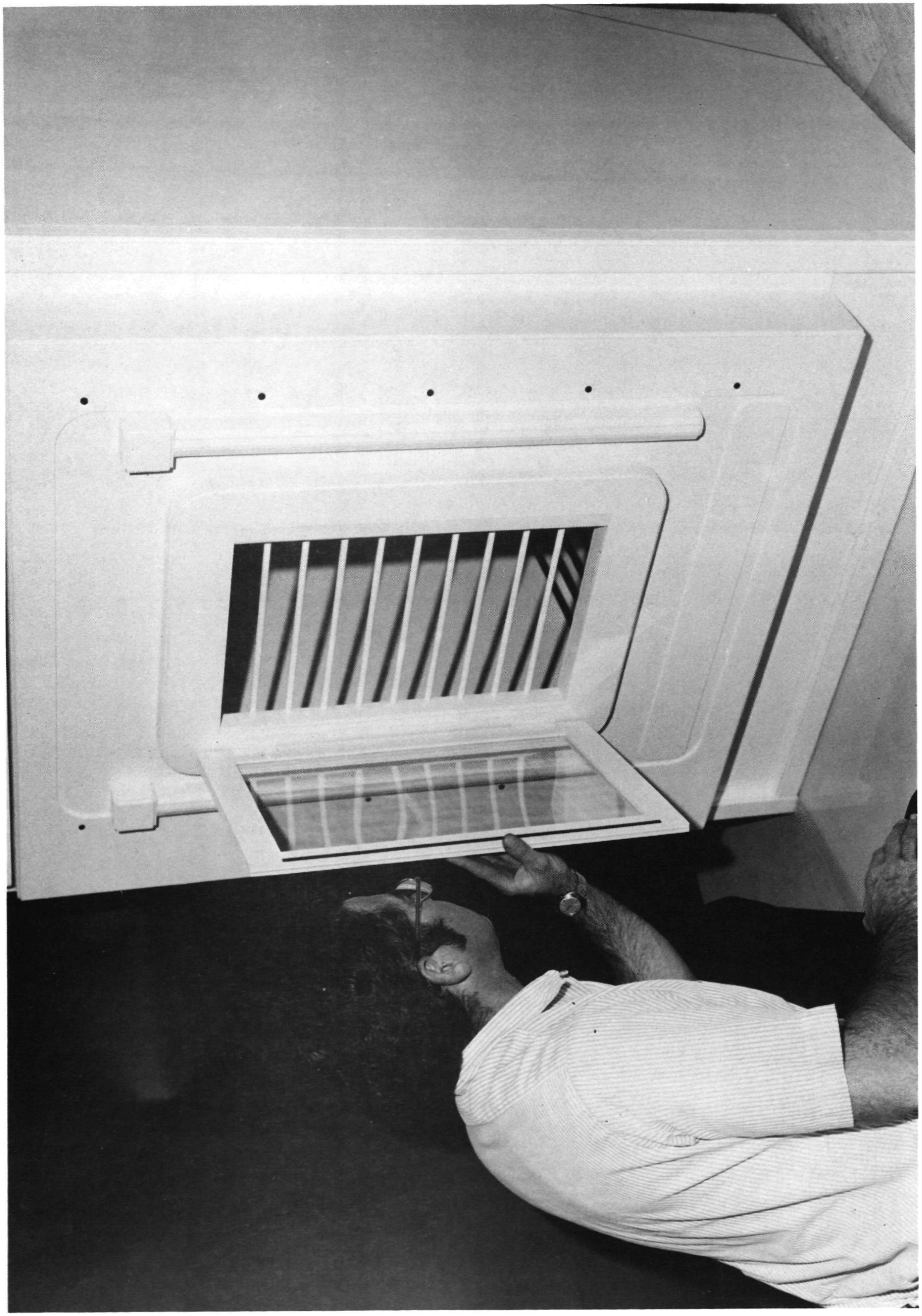

Figure 4-28. Access to Primate Cage Interior

Figure 4-29. Liner of Rodent Cage

4.2.4 Accessibility

A study of holding unit accessibility for repair and maintenance was performed to assess both the feasibility and crew times required for such tasks as malfunction diagnosis and component removal and replacement. The requirement for zero-g accessibility for the holding units was incorporated in unit design. The mockup photographs (Figures 4-27 through 4-29) show both the primate and rodent holding units mounted with side rails secured to the Spacelab racks. Rails with a 76 cm (20-in) extension were used. At full extension of the rails, accessibility is possible to all serviceable components. Through the construction and utilization of a full-size mockup of a Spacelab double rack that contains the holding units, it was found that additional accessibility could be attained by employing pivoting rack slides. Illustrations showing the added accessibility gained through the use of pivoting slides are presented in Figures 4-30 through 4-32. Rear access is provided by the use of slide rails incorporating a pivot that permits unit rotation of up to 90°.

Figure 4-30 illustrates the primate cage extended 76 cm (30-in); the two upper slide rails are disengaged to permit the cage to pivot down a full 90°. This rotation exposes the rear of the cage for total access. Figure 4-31 illustrates the rodent unit extended 76 cm (30-in); both side rails then pivot up a full 90°. This rotation exposes the rear of the unit for total access. In Figures 4-30 and 4-31, the rotation could be reversed but the directions illustrated are considered the most advantageous for zero-g access. Figure 4-32 illustrates two primate cages each having two slides mounted on the top and bottom of the cage. Each cage has a right- and left-hand breakaway slide and a pivot slide that permits either left or right 90° rotation. The direction of rotation would be dependent upon the Spacelab configuration and the location of the cage within that configuration. Adequate rear access is possible with all three figures with the greatest degree of access obtained from the top and bottom-mounted slides. The rotation access concept requires additional length to all electrical, water, and other identified interfaces that are required to remain intact when the units are extended from the racks.

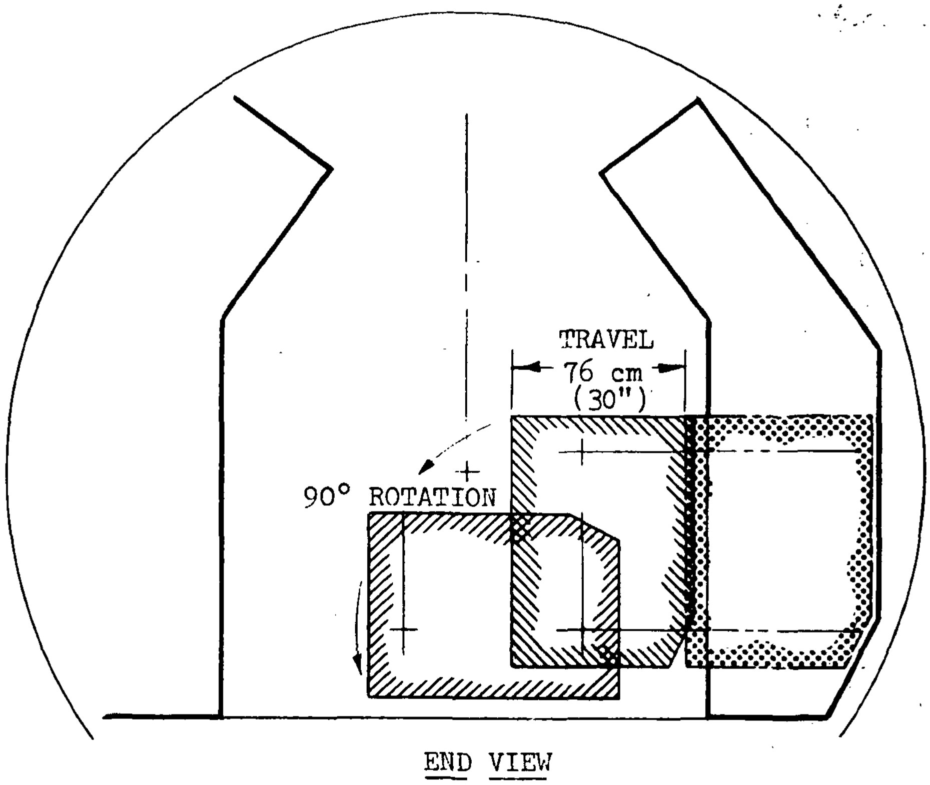

Figure 4-30. Primate Cage Accessibility Obtained by 90° Rotation from Bottom of Side-Mounted Slides

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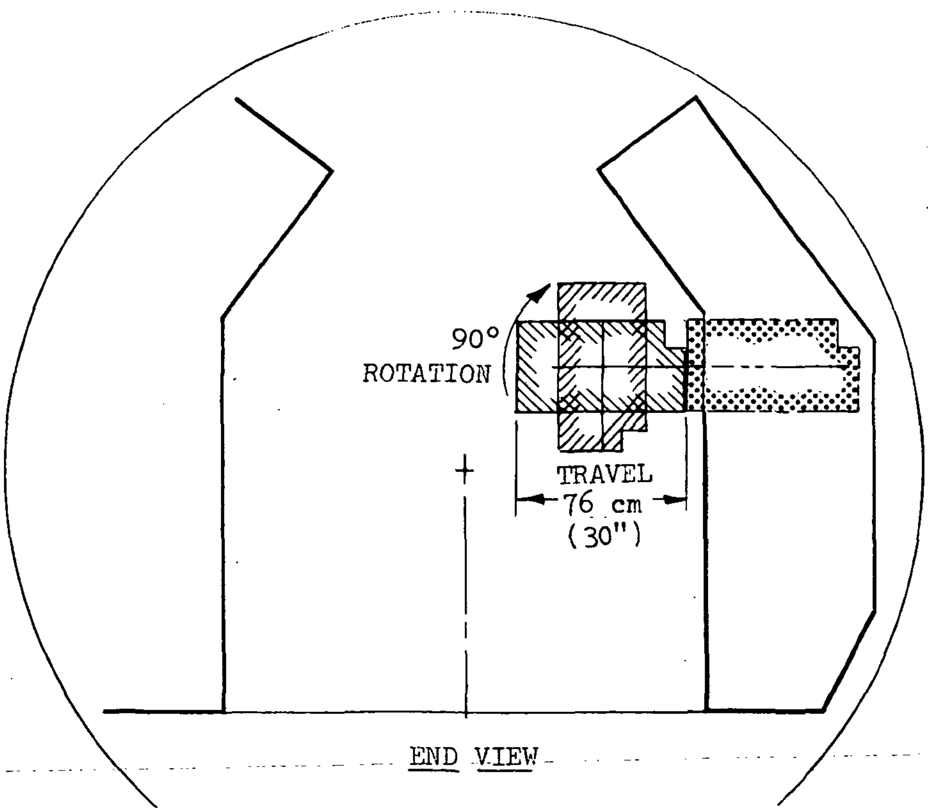

Figure 4-31. Rodent Module Accessibility Obtained by 90° Rotation from Side-Mounted Slides

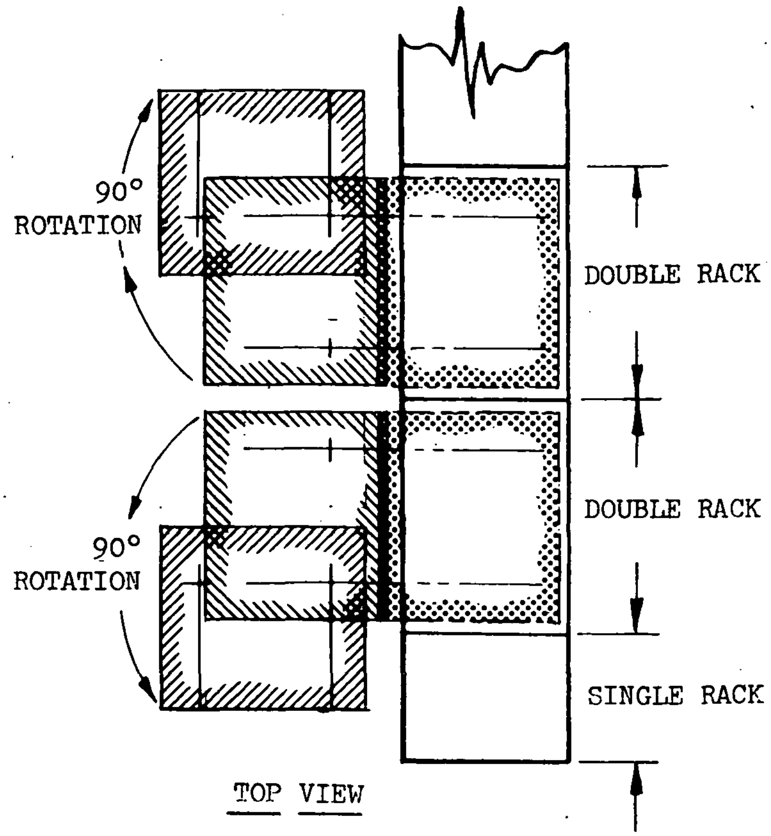

Figure 4-32. Primate Cage Accessibility Obtained by 90° RH and LH Rotation from Top and Bottom Mounted Slides

4.3 INSTALLATION AND INTERFACES

The installation and interface data provided in this section include BSHF packaging, supporting flight equipment, Spacelab/orbiter interfaces and ground support equipment.

4.3.1 Packaging

The BSHF is comprised of a number of packages dependent on the number of specimens and experiments desired. Basically, the following packages are included.

A. The specimen holding units — which consist of unrestrained primate cages, primate cages modified to support two restrained primates, and rodent modules. Also, the same units may be modified to support other biological specimens such as plants, invertebrates, cells and tissues, as well as other species of vertebrates.

B. Potable water supplies – These include potable water and flush water tanks and supporting distribution assemblies. Each potable water tank is sized to supply the water required by specimens in one double rack for 24 hours plus 12 hour contingency. The tanks are refilled daily from a central Spacelab water reservior or from the orbiter fuel cell water storage, utilizing a portable refill tank.

C. Flush water supply tanks – Provided in pairs, one on each side of the laboratory aisle so as not to have distribution lines traversing the aisle. Each flush tank is sized for ten gallons and is used for all cages on one side of the aisle.

D. Waste water tanks – These tanks will be provided for the general collection of urine and flush water. One will be installed on each side of the center aisle. The size of tanks is dependent both on mission duration and on the possibility of dumping waste water overboard. Two-gallon tanks will be used if overboard dumping is allowed. Otherwise, the tanks are sized for the duration of the mission.

E. Control and display panels – Individual control and display panels are provided for holding units in each Spacelab double rack. A design has been prepared in which panels each support one primate cage and one rodent module. However, they may be modified to support other combinations. Each panel is 99 cm (39-in) wide by 28.9 cm (11-in) high by 12.7 cm (5-in) deep.

F. Signal conditioner adapters – Signal conditioning equipment will be supplied either in one or two adapters, to support the needs of any BSHF size. Each signal conditioner adapter is 48 cm (19-in) wide by 8.9 cm (3.5-in) high by 61 cm (24-in) deep.

The BSHF equipment described above does not include interface equipment such as transfer cages and waste storage and food storage compartments. The latter are described in the following paragraphs.

4.3.2 Supporting Flight Equipment

The following equipment items will interface with and support the BSHF.

4.3.2.1 Inflight Specimen Transfer Units

Specimen transfer units are used during flight to transfer specimens between the holding units and the surgical table or other laboratory locations. The transfer units will have a simple hinged door and will require no environmental control or special support equipment due to the short duration of occupancy. The primate transfer unit, used to transfer an anesthetized primate, will be 38 cm (15-in) wide by 76 cm (30-in) long by 30.5 cm (12-in) high and will be made of collapsible construction for easy storage. A collapsible rat transfer unit, 19 cm (7.5-in) wide by 30.5 cm (12-in) long by 15.2 cm (6-in) high, will be used for the transfer of one to three rats at a time. The rats will not usually be anesthetized during transfer. Normally, a life science laboratory will be supplied with only one primate transfer unit and one rat transfer unit.

4.3.2.2 Launch Phase Waste Management

Before launch, the specimen holding units will be oriented such that their floors are vertical. For this reason, the cage design must provide for a temporary launch phase waste collection tray. This tray will be located on the lower wall of the cage that will serve as a floor for the launch position. Solid and urine wastes, unaffected by cage recirculation air flow, will be deposited on the waste pad during prelaunch and launch phases of the flight. The primate cage launch waste pad is 57.2 cm (22-1/2-in) wide by 83.8 cm (33-in) long by 2.5 cm (1-in) deep and is made of two outer layers of 100 x 100 mesh stainless steel screen with spring memory and three inner absorbent wick layers impregnated with H_3PO_4 for contaminant and odor control. The build-up pad will be stable in the 22-1/2-in width dimension. The stainless steel wire mesh screen will be capable of being expanded from 29 to 33-in length. The top and bottom of the expanded 33-in pad will be secured to the primate cage side by a pull rod that slides through mating rings attached to the pad and to the wall of the cage. The pad is removed by removing the top rod first and then the bottom rod, thus retracting the pad to the 29-in length. The two longitudinal sides of the pad are retained by short lengths of crimped tubing that are made to slide in two slide tubes. The slide tubes are slotted lengthwise and secured to the sides and under floor areas of the cage. Upon release of the top and bottom rods the pad will be pulled under the bar floor of the cage, using a double cable and pulley arrangement, and removed through the feces and debris removal door. The collapsed pad is then placed in a disposal bag and stored in the life science laboratory waste processing and storage unit. For the rat cage, the launch phase waste tray will be made of two adsorbent wick layers sandwiched between two 1/8 by 1/8 in stainless steel screens. This tray is 15.2 cm (6 in) wide by 30.5 cm (12 in) long by 1.8 cm (0.7 in) deep and will be placed in the launch position floor of the cage between the cage wall and the basket cage screen wall. When orbit is attained the basket cage, with the rat inside it, is removed from the cage. The waste tray is then removed through the cage door, placed in a disposal bag and stored in the waste processing and storage unit. The rat, in its basket cage, is then returned to the cage and the waste management subsystem allowed to revert to its normal mode of operation.

4.3.2.3 Waste Storage

Specimen solid wastes may be collected periodically as required in individual vacuum bags. The primate bags will be 5.1 cm (2 in) diameter by 10.2 cm (4 in) long. The rodent bags will be 5.1 cm (2 in) diameter by 5.1 cm (2 in) long. One bag will be used at each collection from the primate cage or rodent module. The bags will have to be stored either in the LSL refrigerator or in the LSL waste processor/storage compartment.

4.3.2.4 Water Storage

Potable and flush water requirements for the BSHF will be provided from a LSL water storage tank, utilizing a small portable tank for refilling the individual BSHF tanks. The amount of water supplied is mission and specimen dependent, based on the following daily requirements.

Primate water consumption	=	1,277 ml/day
Rat water consumption (exclusive of water in food)	=	32 ml/day
Primate cage flush water requirements	=	720 ml/day
Rodent module flush water requirements	=	1,440 ml/day

For example, a 4 primate/16 rat BSHF will require 341 liters (90.2 gallons) for a 30-day mission. Some or all of this may be available from the orbiter potable water system; the balance must be stored on board the Spacelab.

4.3.2.5 Food Storage

Storage space is required in the Spacelab to store the food required for the mission. For the baseline system the types of food recommended for both the primates and the rodents may be stored without refrigeration. The amount of food depends on the number of specimens and the length of the mission, and may be determined from the following daily requirements.

	Primate	Rat
Food weight	304 g/day	57 g/day
Food packaging allowance,		
weight	160 g/day	8 g/day
volume	5×10^{-4} m^3/day	5×10^{-5} m^3/day

As an example, a 4 primate/16 rat BSHF will require a storage space of 0.096 m^3 (3.4 ft^3) for the storage of 98.5 kg (217 lb) for a 30-day mission.

4.3.2.6 Surgical Bench

An evaluation of specimen research requirements indicated that the transfer of animals between the holding units and the surgical bench does not necessitate complete isolation of the specimen from the cabin atmosphere during the short transfer time. Only a physical isolation, in the transfer unit, is needed to prevent inadvertent excretional contamination of the cabin. For these reasons, it was concluded that no physical interfaces that include the use of airtight seals are required on the surgical bench. Rather, the transfer unit will be secured by attach points to the surgical bench and the specimens transferred manually into the surgical bench.

4.3.3 Orbiter/Spacelab Interfaces

This section presents the BSHF interfaces and support provisions of the orbiter and Spacelab. Table 4-6 presents the orbiter/Spacelab support

Table 4-6

SPACELAB PAYLOAD SUPPORT CAPABILITY

Interface	Capability
Cabin Atmosphere	1 Atmosphere Nominal
Habitable Volume Temperature	65° to 80°F (18-27°C) Selectable
Humidity	48°F (6°C) DP to 75% Relative Humidity
CO_2 Partial Pressure	5 mm Hg nominal
Thermoconditioning	
Cabin loop in orbit	1 kW nominal at 67°F (19.5°C) design point
Avionics loop in orbit	3 kW nominal based on 120°F (49°C) outlet
Ascent/descent cooling	1 kW average
Electrical Power	
Orbital power	4 kW average; 9 kW peak for 15 minutes
Ascent/descent power	1 kW average; 1.5 kW peak for 2 minutes
Data Management	
Data Rate	500 KBPS
Storage	30 Mbits/30 min
Racks for Equipment	
Double Racks (6 of 8)	41.42 in (1.05 m) width
Single Racks (4)	22.18 in (0.563 m) width

capabilities available to the LSL and the BSHF. A review of the more pertinent interfaces applicable to the BSHF is presented as follows:

- Mechanical/structural interfaces
- Electrical power support
- Data Management capability

Interfaces with the orbiter/Spacelab environmental control and life support system are presented in Section 4.1.

4.3.3.1 Mechanical/Structural Interfaces

The equipment mechanical/structural interfaces are directly dependent on location, rack configuration, and attachment type. Figure 4-33 presents the rack dimensions and configurations that were used to establish BSHF accommodations and interface support. The stay-out areas and proposed baseline location of power and data management interface hardware for the LSL are also shown. The primary trunk line routing of pneumatic, hydraulic, and vacuum lines throughout the Spacelab was considered to be contained within a conduit and located in the floor as shown in Figure 4-34. Figure 4-35 presented the standard avionics cooling loop duct location in the standard Spacelab racks.

4.3.3.2 Electrical Power Support

The Spacelab receives its primary power from a dedicated fuel cell in the orbiter. The primary power delivered from the orbiter during orbital operations to the Spacelab is 7 kW average and 12 kW peak for 15 minutes every 3 hours at a nominal voltage of 28 VDC. The supply of peak power is directly related to the orbiter heat rejection capabilities, which are attitude dependent because of radiator orientation requirements.

In case of failure of the dedicated power source, the degraded power available is 5 kW average and 8 kW peak from the backup source in the orbiter. The normal power available to the payload is approximately 4 kW average and 9 kW peak. Analysis has shown that the Life Science Laboratory can perform a 7-day mission on this available energy. Longer missions require the addition of kits to increase the mission duration. The power services that can be provided to Spacelab experiments are listed in Table 4-7. The primary power available to the payload during ascent and descent is 1 kW average and 1.5 kW peak for up to 2 minutes. In the present operational concept, Spacelab will be inactive during launch, ascent, and descent (except for monitoring of caution and warning signals) and hence the BSHF would not be provided with power, heat rejection, and other support. However, the provision of the required resources and services to specimens during these phases is presently under investigation. The recommended support for the LSL program during ascent and descent are presented in Reference 3-1.

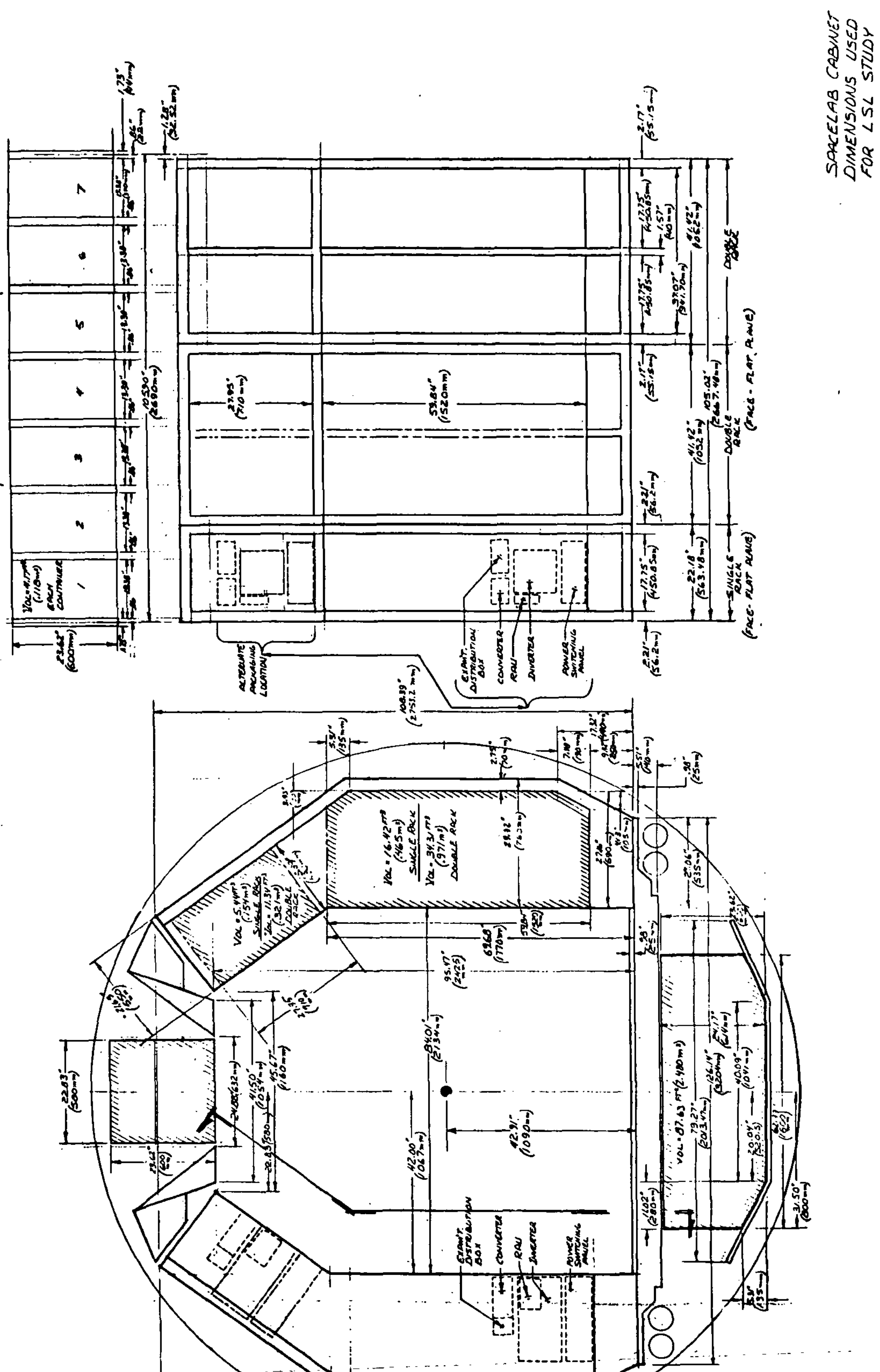

Figure 4-33. Rack and Storage Arrangement in Spacelab

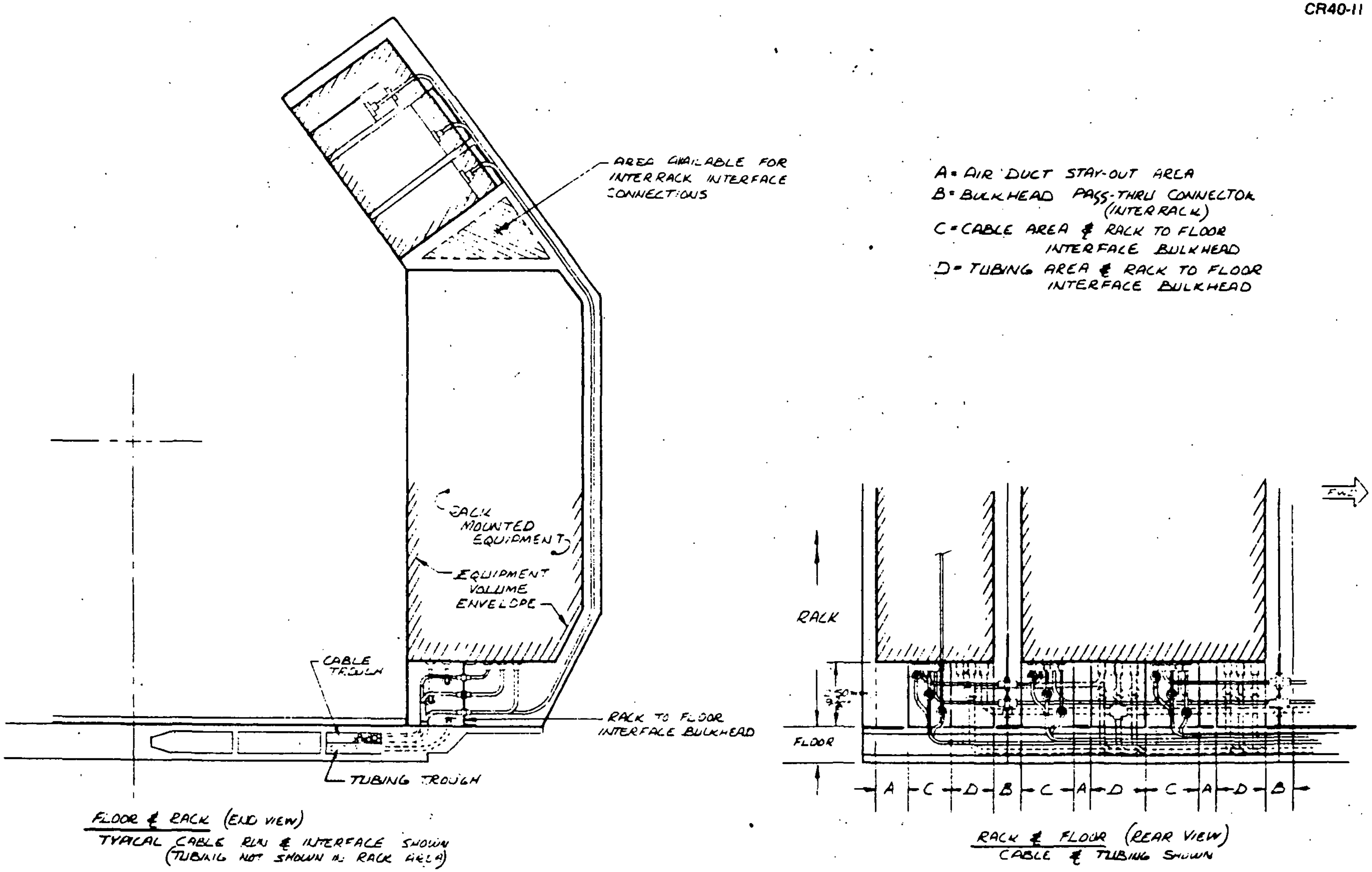

Figure 4-34. Cable and Tubing Interface for LSL Study

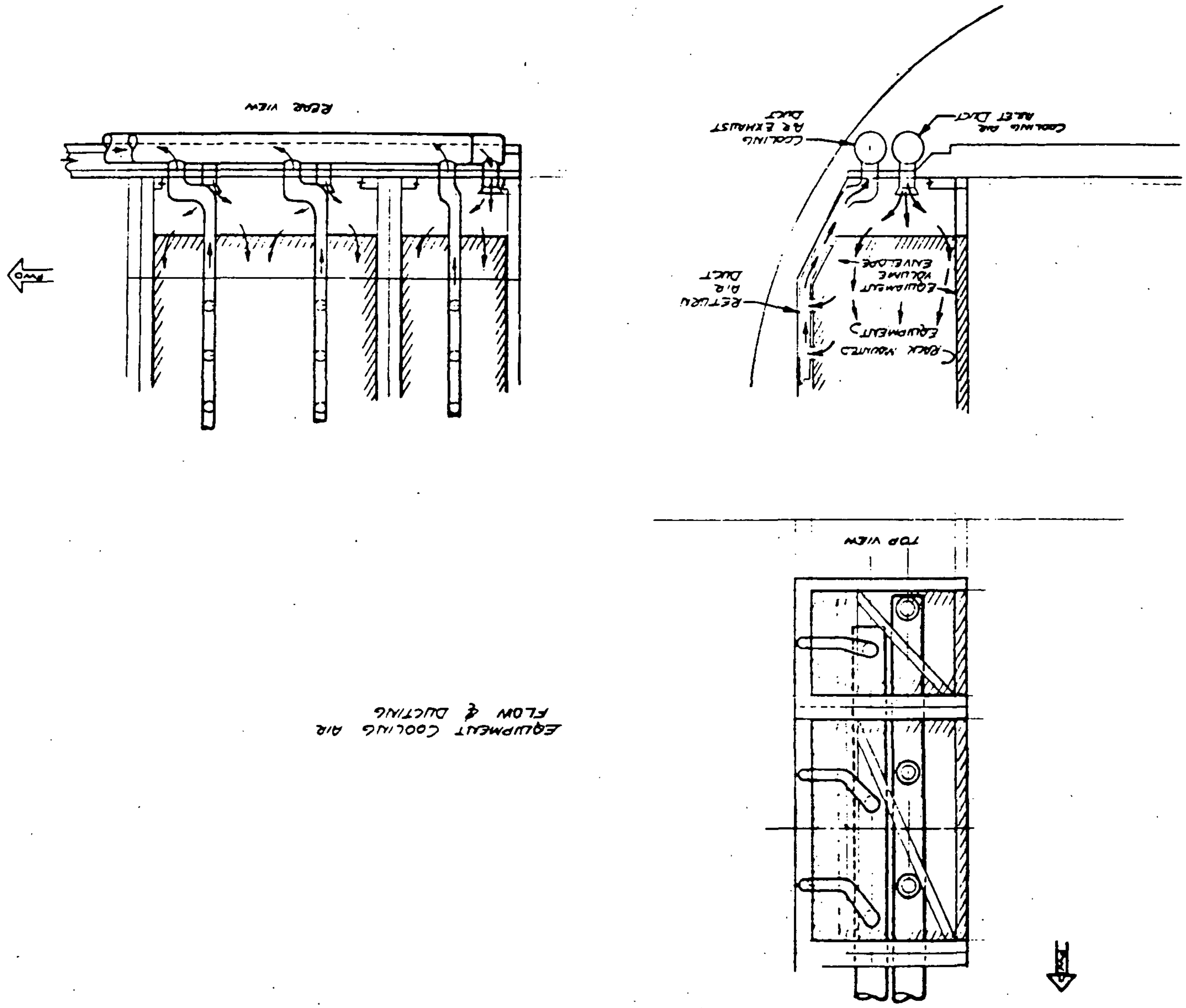

Figure 4-35. Avionics Cooling Duct Interface for LSL Study

Table 4-7

SPACELAB POWER SYSTEM INTERFACES

Experiment Input Power	Equipment Interface	Power Origin
28 vdc unregulated	Power switching panel Experiment distribution box	power control box
28 vdc regulated	Power switching panel	DC/DC converter
115 vac, 400 Hz, single and three phase	Power switching panel	Power distribution box (DC/AC inverter)
115 vac, 50 Hz	Power switching panel	DC/AC inverter
115 vac, 60 Hz	Power switching panel	DC/AC inverter

The electrical power is distributed from the power buses via experiment power distribution boxes. Within the module, the buses are routed from the distribution boxes to experiment power switching panels located in the positions shown in Figure 4-36. The power switching panels provide connectors for rack internal access and power outlets in front of the panel for external access. Each output is protected against overload and switched manually from the front side. The unregulated dc, the dc/dc converter(s), and the 60-Hz inverter(s) are installed in the locations shown in the figure.

The power is received from the distribution box or experiment power switching panel in the module via payload supplied cables. Each of the primate cages and the rodent modules will require two circuits for servicing. The bleed air fan and the water separator will be on one circuit and the recirculation blower to the second. The use of two circuits per cage or module will ensure that at least one fan or blower is operating in each unit when the other one is disconnected for service or replacement.

4.3.3.3 Data Management Capability

The Spacelab CDMS provides the means to transfer data between the Spacelab support facilities and the payload (laboratory). The CDMS provides for storage or display of the data on-orbit and/or its transfer between experiment facilities and the ground. Data interfaces consist of those for the acquisition

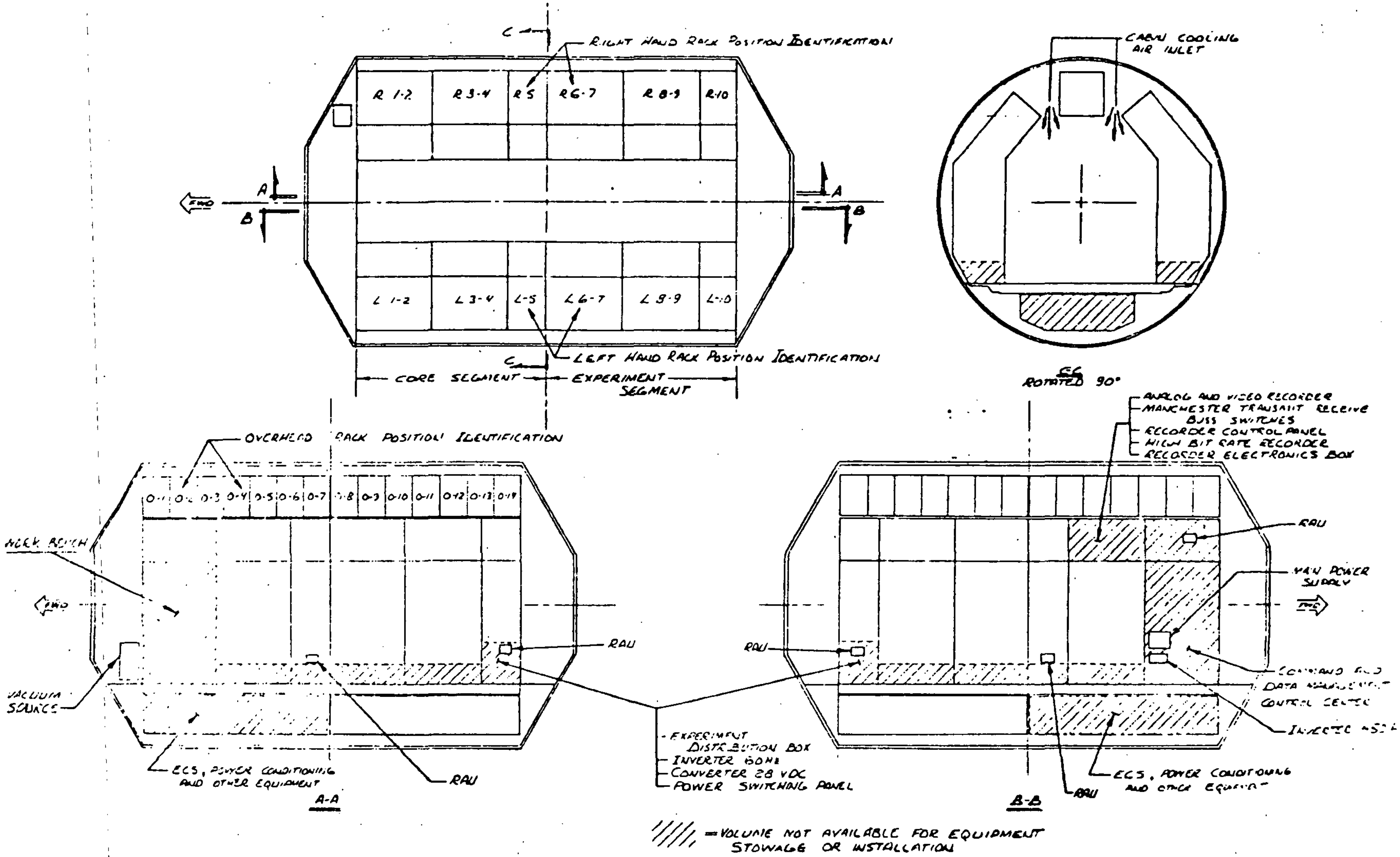

Figure 4-36. Baseline Rack Configuration, Stay-out Areas, and Locations of Power and Data Management Interface Support Hardware

of digital, analog, video, and voice signals and for the issuance of digital and analog control signals in a variety of forms. These include timing or synchronization signals and safing commands in addition to those required for the conduct of the experiments.

The CDMS capability and interfaces are shown in Figure 4-37. The diagram layout is subdivided on the right by the particular category of payload data requirement supported. The left side of the diagram represents facilities provided at the orbiter's aft flight deck.

The transfer of command, low rate data, and timing signals is provided by the remote acquisition units (RAU's) which allow access to the data bus and experiment computer for commands and data and the time display unit for timing signals.

The video interface for closed-circuit TV monitoring of experiments is primarily with the video switching network located within the orbiter cabin which handles the distribution of video and camera synchronization signals. High rate serial digital data interfaces with a digital multiplexer located within the CDMS consoles.

The signal types, the equipment with which they interface, and the immediate equipment origin or destination of signals from the interfacing equipment are summarized in the CDMS subsection of Reference 3-2. The interfaces for high rate digital data, emergency, caution and warning, status and safing commands, and the timing are included in the CDMS data presentation.

Figure 4-38 presents additional detail of the CDMS supplied by Spacelab for experiment accommodation. It was extracted from "Spacelab Electrical System Interface Block Diagram," drawing number SK 15090, dated June 12, 1975. The equipment provided for data processing consists of the experiment computer, mass memory, and input/output unit which perform the functions of checkout, sequencing and control, data reduction and the computation of data for display on the 12-inch color CRT. The data management has a storage capability of 30 Mbits/30 minutes and a data rate of approximately

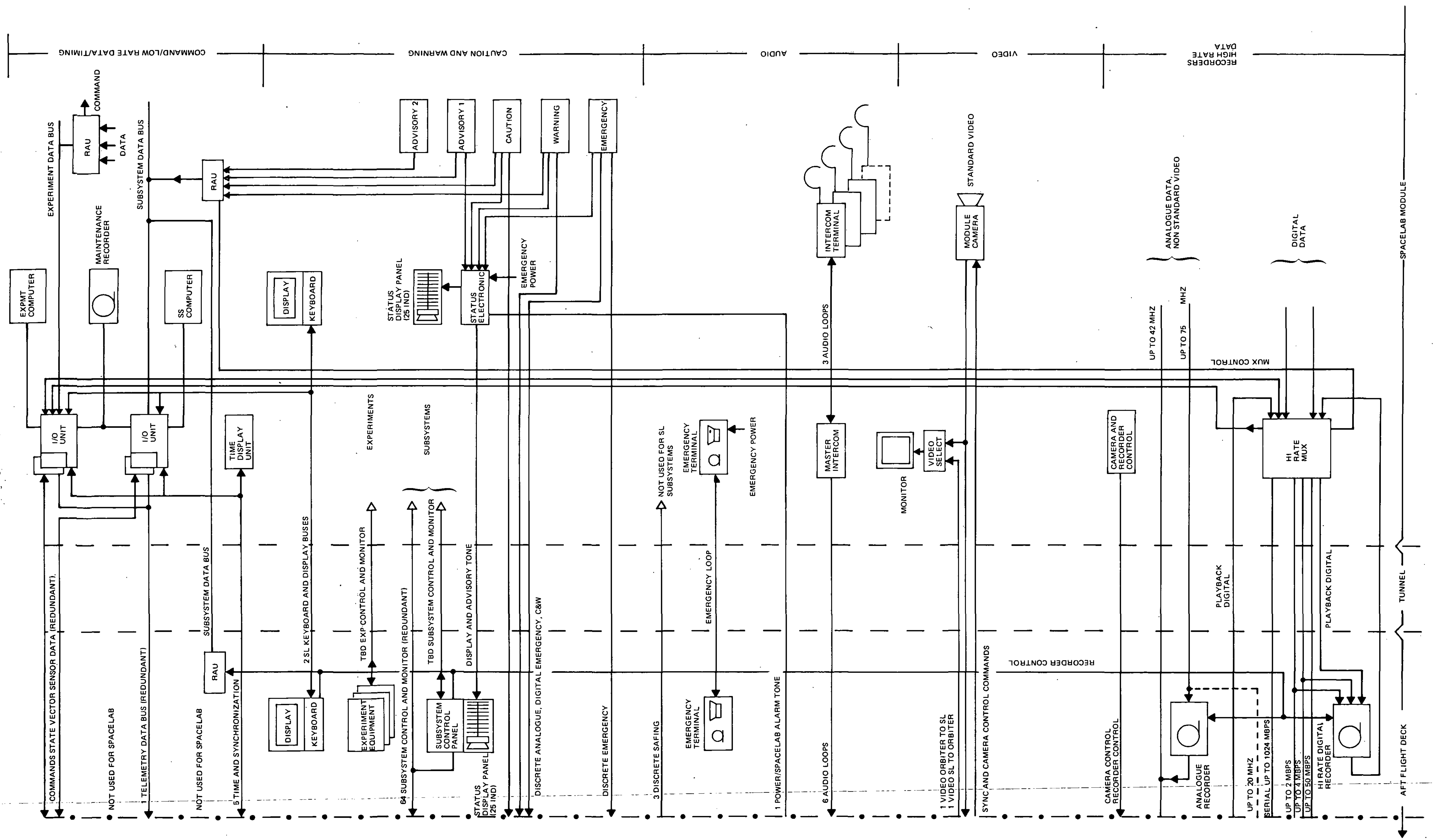

Figure 4-37. Spacelab Experiment Equipment/CDMS Interfaces

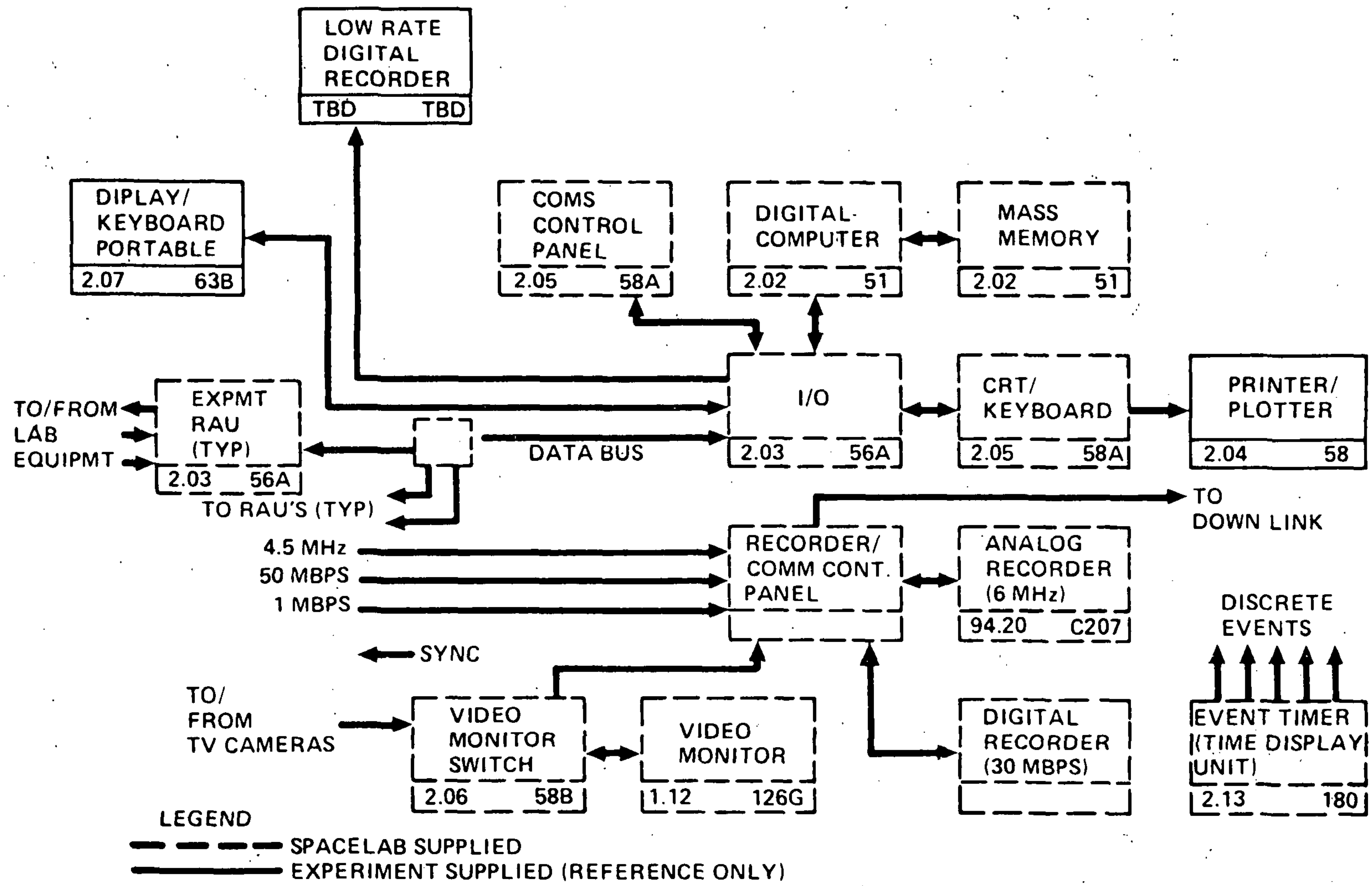

Figure 4-38. Primary Control and Data Management System

500 KBPS. The CRT unit contains an alphanumeric keyboard for processing control. The primary devices for experiment data inputs are the RAU's. These units, interfaced with the data bus via bus couplers, are controlled by the I/O. They allow data to be entered into the computer for processing, to be transmitted to the ground at 64 kbps and 2 Mbps rates on separate lines or stored on a digital recorder; this latter unit is not supplied. A control panel is provided for such purposes as equipment calibration and power control. Additional equipment for high rate or large bandwidth signal storage or transmission via orbiter subsystems originally included a recorder control panel, a single channel 30 Mbps digital recorder and a two-channel (6 MHz each) analog recorder. The analog recorder was deleted per the Subsystem Requirements Review (SRR) at Bremen on June 16, 1965. A video monitor switch for camera or input selection and monitor for television viewing is also available with synchronization for the closed-circuit TV system supplied by the orbiter's video switching network. A time display unit completes the list of Spacelab CDMS equipment interfacing with the experiments. In addition to displaying Greewich and vehicle elapsed time, it also produces discrete event signals for experiment sequencing. Figure 4-28 also shows several units that may be provided by the LSL CORE for experiment support. One is a portable remote display/keyboard assembly. Another is a printer/plotter which allows a display on the CRT to be produced in hard copy.

Typical requirements for the dedicated LSL as determined during the LSL definition study was a data rate of 15 kbps (average), 40 kbps (peak) with a total of 1.54×10^9 bits/day. The minilab ML 2G/2H had a data rate of 46 bps (average) and 12 kbps (peak) and generated a total of 4.7×10^6 bits/day. The Spacelab capability exceeded all of the data requirements of the LSL concepts studied.

4.3.4 Ground Support Equipment and Facilities

The following discussion of BSHF ground support equipment provides early program visibility of the types, complexity, and quantity of GSE that will be required to support the BSHF. The GSE was determined by an analysis of the ground operations to be performed in the processing and checkout of the BSHF. In addition to GSE, a discussion of some related support facilities such as the ground holding laboratories and the loading/unloading training fixture are also presented.

The following ground rules and assumptions, relating to Spacelab operations, were used as the basis in final determination of required GSE for the BSHF.

A. Loading of specimens into the Spacelab will take place on the launch pad in a vertical position through the scientific airlock.

B. Removal of specimens from the Spacelab will be from the horizontal position after landing through the access tunnel and orbiter mid-deck.

C. The Spacelab internal vertical access kit will be installed while on the pad as noted in the Spacelab Payload Accommodations Handbook, May 1975.

D. The tunnel access kit will be available for installation after landing for access to the Spacelab.

In addition to the above ground rules, the effects of ground handling of the specimens on GSE selection are based on the following assumptions.

A. Specimen data collection is not required during transfer times between laboratory and Spacelab.

B. Maximum planned duration of transfer time between laboratory and Spacelab is 4 hours.

C. Temperature and humidity control is required while specimens are in ground transfer units.

D. Primates will be restrained while in transfer units.

E. During transfer of specimens from ground holding units to flight cages, primates will be tranquilized and manually transferred.

F. Food is not required in ground transfer units; however, water will be provided.

G. Ground transfer units will be manually handled when not installed in a ground cart.

4.3.4.1 Ground Holding Laboratories

The ground holding laboratory will be used by experiment PI's to provide the specimens with housing, final training and/or preparation for flight. The laboratory should be provided with ground-type holding cages that duplicate the interior environment of the BSHF so as to accustom the specimens to the surroundings to be encountered in flight. The holding cages will be located in the ground holding laboratory facility for use as required by the PI. Air flow inside the cage, as well as the dispensing portions of the inflight feeder and waterer, will also be duplicated. The ground holding cages will be used to orient the specimens to the "up-down" characteristics of the cage in order to aid the normal operation of the waste collection units. Training requirements for both specimens and specimen handlers will also be provided.

The specimens, in transfer units, will be delivered from the ground laboratories to the transfer van for transportation to the launch pad. Also, after mission completion, the specimens, samples and pertinent flight data will be returned to the ground laboratories for data reduction and further evaluations. During the mission, control specimens will probably be maintained in the ground holding laboratory in order to provide data comparable with the flight specimens.

4.3.4.2 Transfer Van

A van compatible with the physical characteristics of the transfer units will be required to transfer the specimens from the ground holding laboratory to the launch pad. The transfer units will be provided with self-contained air conditioners and will require no special environmental control or other support equipment.

4.3.4.3 Specimen Ground Transfer Unit

Ground transfer units will be provided to contain the specimens while they are moved between the ground laboratory and launch pad. The transfer units will be supplied with environmental conditioners to keep the specimens in comfortable conditions for periods up to four hours during transfer.

The primate transfer devices will include couches and restraints to ensure the safety of the specimens and the integrity of wiring attached to instrumented primates. Provisions will also be made to provide water to the primates during the transfer period. The rat transfer devices will have mesh screen floors for the specimens to cling to and will also require a supply of water for a maximum period of 4 hours.

4.3.4.4 Specimen Loading and Unloading Kits

These two kits will provide the necessary equipment, including loading hardware for installing the specimen in the Spacelab at the launch tower, scientific airlock protective cover, tunnel cart adapter, and other support equipment to provide the necessary means to load the specimens in the vertical position and unload them through the tunnel in the horizontal position.

4.3.4.5 Loading and Unloading Training Fixture

A loading and unloading training simulator will be required, preferably in the ground holding laboratory area, to provide a realistic training facility for both the specimens and the crew to practice the specimen loading operations. The loading simulator will physically simulate the access route utilized to load the specimens through the airlock hatch and unload them through the transfer tunnel and will also include the Spacelab interior, including the BSHF holding units.

4.3.4.6 GSE Summary

The recommended quantities and locations of GSE required to support the BSHF are as follows:

GSE Item	Location		
	Factory	Integration Site	Launch/Recovery Site
BSHF ground test set	1	1	
Transfer van			2
Specimen transfer units			2 sets
Loading/unloading kit			2 sets

In addition, the ground holding laboratory and the loading-unloading trainer, which are assumed to be facilities rather than GSE at this time, will be required at the launch/recovery site.

Section 5
OPERATIONAL DESCRIPTION

The operational concept described in this section was selected from the numerous study concepts analyzed because of its comparatively low cost and compliance with the requirements in Section 3. This description covers specimen flow and use of the BSHF and associated equipment as defined in Section 4 beginning with activities in the ground holding laboratory through prelaunch, on-orbit, and postlanding operation until the specimens are returned to the ground holding laboratory (see Figure 5-1). Specimens are: (1) selected and prepared for flight in the ground laboratory; (2) transported to the launch pad in transfer cages using a mobile van; (3) loaded into the Spacelab through the scientific airlock hatch from the PCR; (4) housed in the BSHF and support research activities during on-orbit operations; (5) off-loaded in transfer cages via the tunnel during OPF operations; and (6) transported to the ground laboratory in transfer cages using a mobile van where they undergo postflight examinations. A trade study comparing several methods of specimen loading and unloading is provided as Appendix A.

5.1 PRELAUNCH OPERATIONS

Prelaunch operations begin with specimen preparations in the ground holding laboratory and end with Shuttle lift-off.

5.1.1 Ground Laboratory Operations

The ground laboratory located at the launch site is used by life science personnel to house, maintain, and train specimens and collect baseline data. Depending upon specific experiment requirements, the specimens will be moved to the launch site from 7 to 30 days before launch and housed prior to launch in accordance with experiment protocols in cages whose interior design duplicates the biological specimen holding facility flight units. The ECS, water, feeder, and waste management subsystems of these units can be of low-cost design for operation in a one-g environment.

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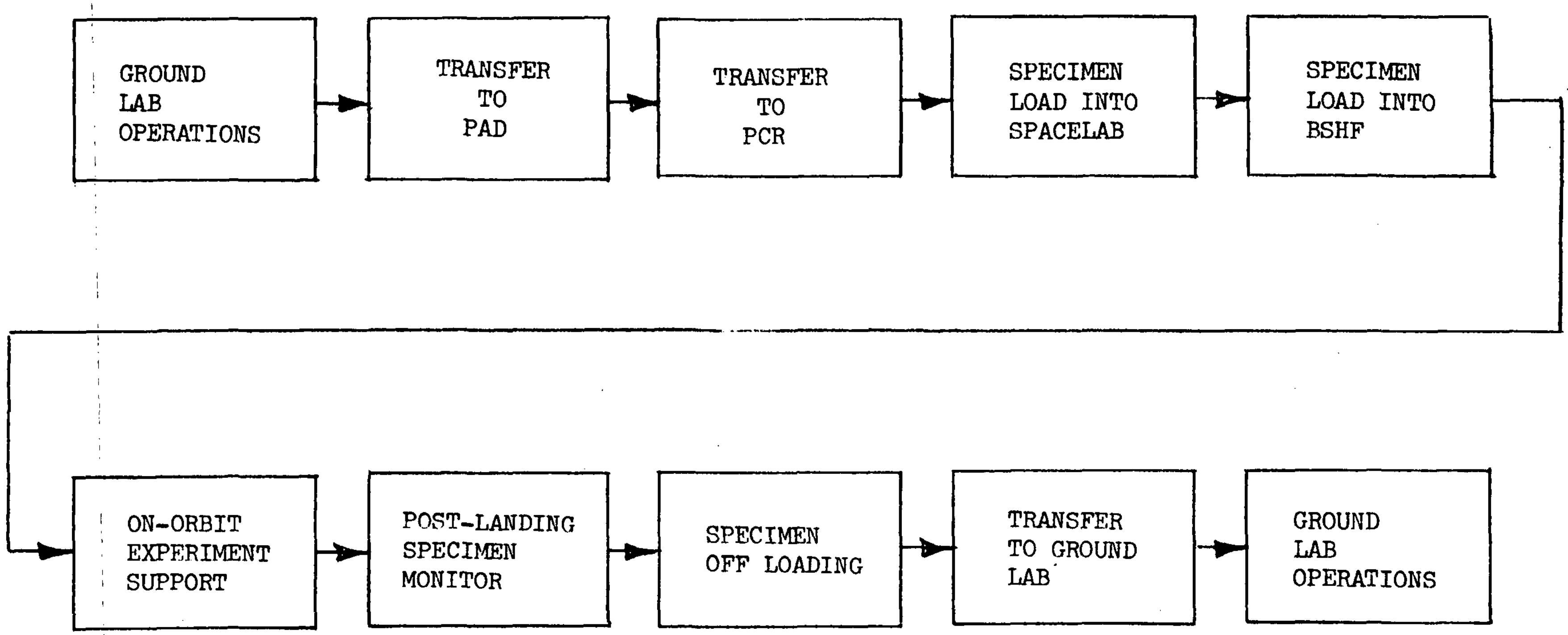


Figure 5-1. Specimen Functional Flow

Time-consuming operations concerned with preparation of specimens for flight such as a complete checkout of all specimen preparation GSE and detailed physical examination of all potential flight specimens, including clinical workups, should normally be completed the day before scheduled launch. As a minimum, these activities should include: (1) a laboratory check to ensure that all necessary specimen preparation equipment and supplies are available and in their proper location; (2) a functional check of all test equipment; (3) a check of the mobile van, including function of all equipment; (4) a functional check of all specimen physiological instrumentation; (5) initiation or verification of diet and feeding schedules as required by experiment protocol; (6) clinical studies and specimen examinations as required by experiment protocols; and (7) a functional check of specimen transfer units.

Launch day ground laboratory operations should be streamlined and specific to preparation of specimens for flight. As a minimum, these activities should include: (1) examine potential flight specimens and review previous day's physical examination and clinical workup results; (2) select flight and backup specimens in accordance with experiment protocols, if specimens are not previously selected; (3) collect specimen samples in accordance with experiment protocols; (4) prepare and load specimens into transfer cages and perform operational check of equipment; and (5) move transfer cages containing specimens to the mobile transfer van and load into the van.

5.1.2. Specimen Loading Operations

Specimen loading operations begin with transfer of specimens to the launch pad in the mobile van and end with specimens loaded in BSHF cages ready for launch with Orbiter payload bay doors closed.

The baseline loading configuration to be utilized is shown in Figure 5-2. The specimen transfer cages will be loaded into the Spacelab through the scientific airlock hatch using a loading rail assembly. In addition, the following assumptions apply which affect functional analysis and timeline activities: (1) Spacelab internal loading GSE and "temporary floor" will be installed in the Spacelab during OPF operations; (2) the scientific airlock will not be installed as there is no life science experiment requirement for its use;

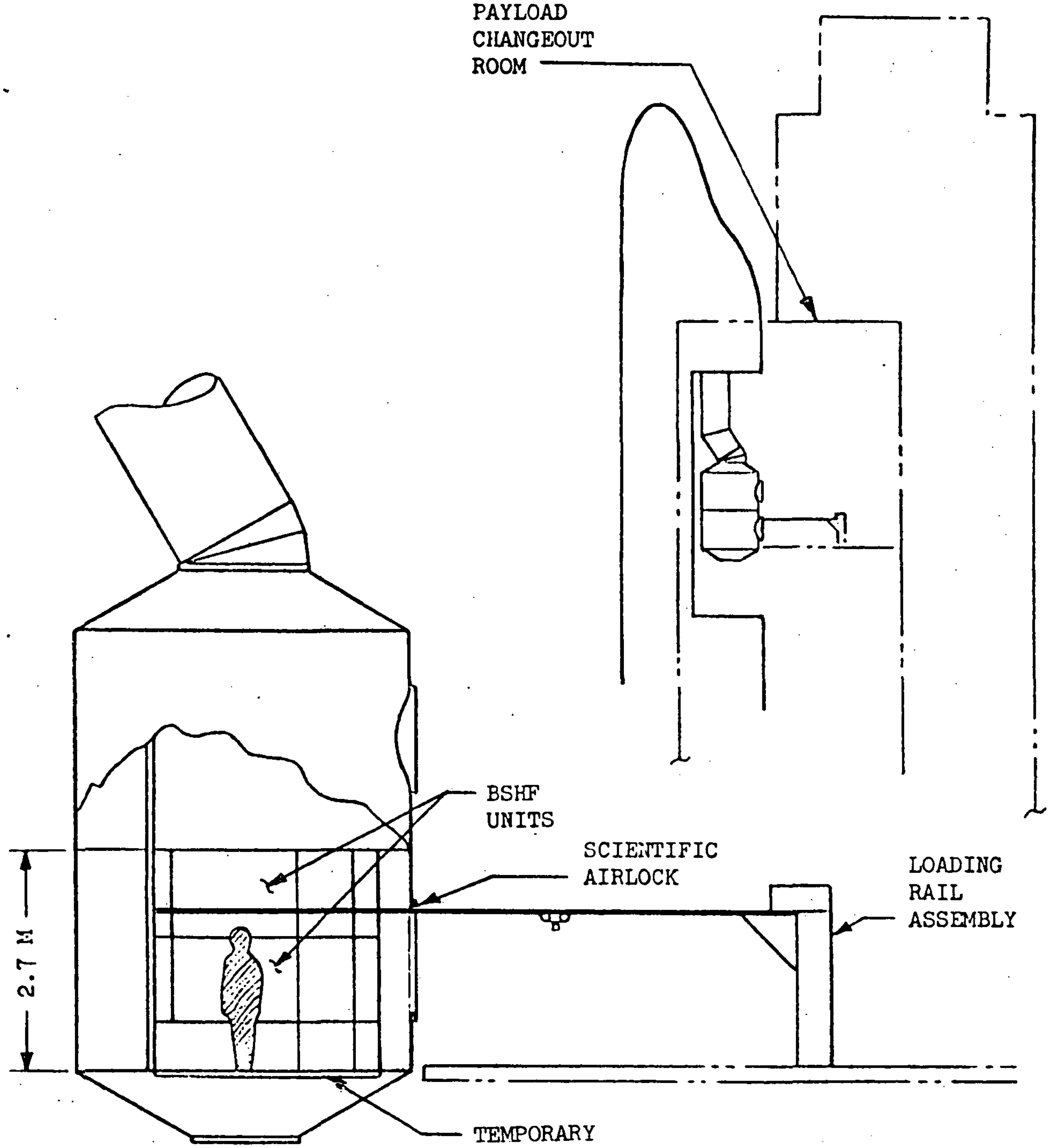


Figure 5-2. Specimen Loading Configuration

(3) the scientific airlock hatch cover will be designed to facilitate quick hatch opening, closure, and seal verification; (4) specimen loading GSE will be designed for easy and quick insertion and removal through the scientific airlock hatch opening; (5) sufficient space will be available in the PCR clean room to accommodate the loading crew, loading GSE, and specimens in transfer cages; (6) a minimum of six personnel will be available to support the loading operations; one veterinary scientist and five well-trained loading specialists, two of whom are stationed in the Spacelab; (7) primates will be tranquilized by the veterinary scientist in the PCR to facilitate their removal from transfer cages for ingress into BSHF flight cages; and (8) specimen task flow will be integrated with other PAD operations to minimize delays in loading of specimens.

The specimen loading functional flow which reflects the LSL-Mod-1A configuration of four primate units and two rat units as defined in MDC G6302 is presented in Figure 5-3. These functions, integrated with the KSC Spacelab launch pad allocation to permit specimen loading after hypergolic service during a planned 3.5-hour hold, are presented in Figure 5-4. The clear bars show the KSC launch pad turnaround allocation functions and the solid and hatched bars show the MDAC-defined specimen loading functions. It is significant to note that the functions "open payload bay doors", "position loading GSE/remove hatch," "prepare specimens for transfer," "load specimens into transfer van", and "transfer specimens to the launch pad" are performed in parallel with designated KSC Pad allocation functions and, therefore, do not impact the KSC allocation timeline. However, specimen loading task flow functions, "off-load specimens from van" through "close hatch, and verify seal," are performed on the pad and must be integrated with other pad operations to insure a smooth specimen task flow and loading operation.

Significant characteristics of this operational concept are: (1) the KSC Pad turnaround allocation is impacted a minimum of 3.5 hours; (2) specimens are in transfer cages for approximately 4 hours which permits simple and inexpensive design of the transfer units; and (3) up to 4.5 hours of prelaunch baseline specimen physiological data may be observed and recorded via the Spacelab/Orbiter data management system, after specimens are loaded for launch in the BSHF cages.

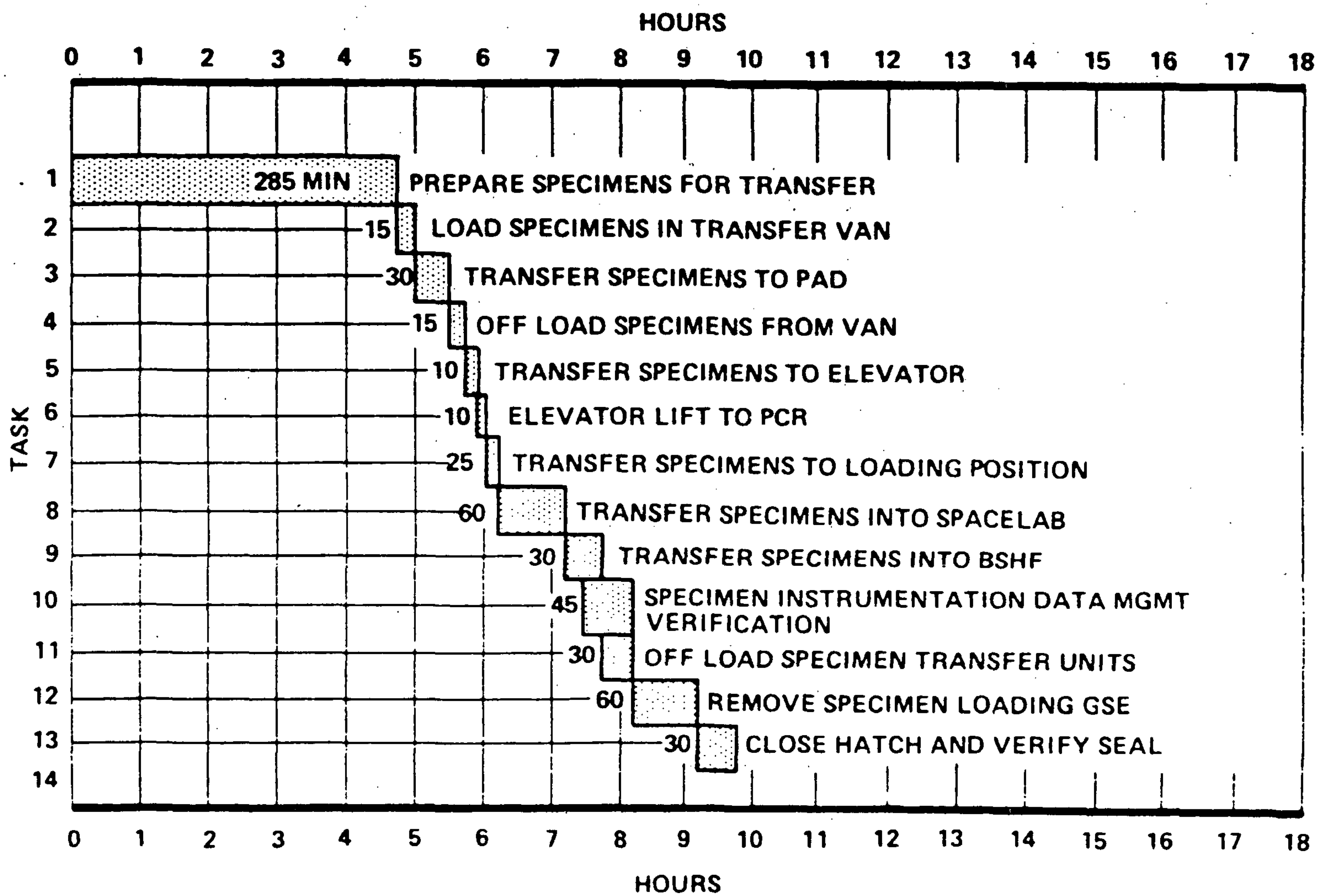


Figure 5-3. Specimen Loading Task Flow

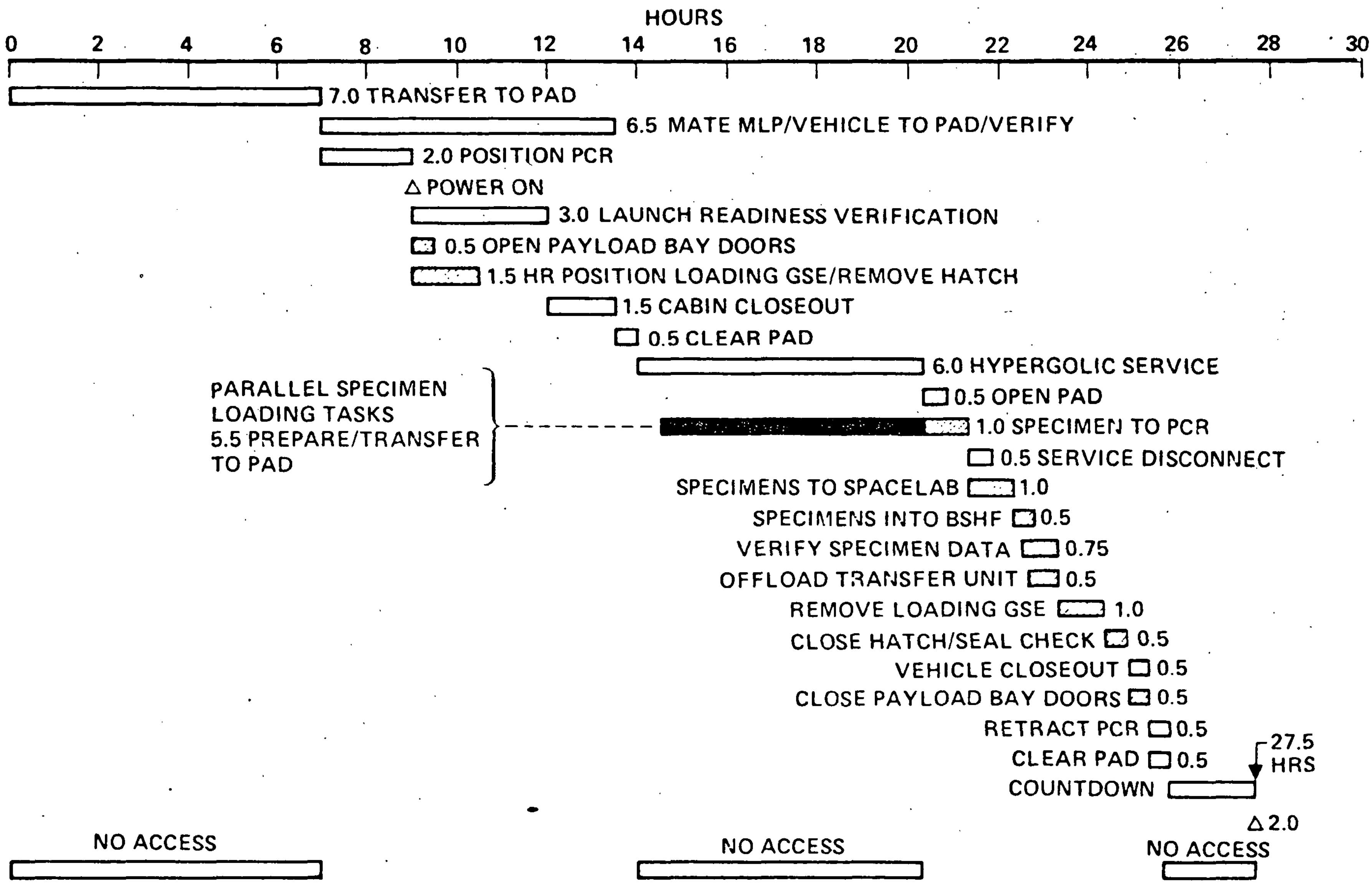


Figure 5-4. Pad Specimen Load Timeline

5.2 ON-ORBIT OPERATIONS

On-orbit operations begin with Shuttle lift-off and end with the Orbiter stopped on the landing strip. This period of time will be from 7 days to 30 days as required for completion of mission objectives. The experimental and operational use of the primate and rat BSHF as described herein are based on those activities required to complete a typical dedicated life sciences medical emphasis mission (Mod-1A) as defined in Reference 3-1.

5.2.1 Mission Description

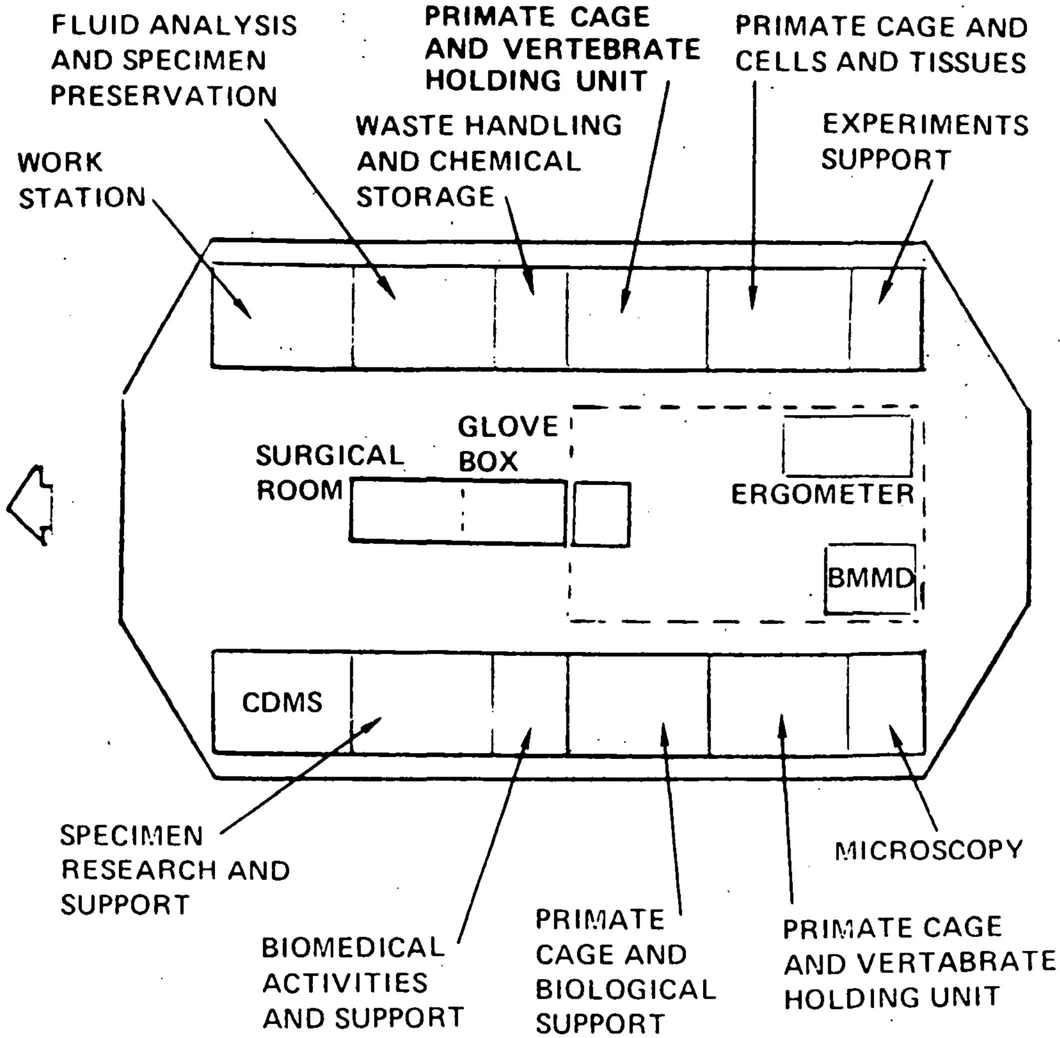
The Mod-1A mission is a medical emphasis mission designated to be flown on a dedicated life sciences Spacelab in the early 1980's. A crew of four consisting of a Commander, Pilot, Mission Specialist, and a Medical Payload Specialist will perform life sciences research over a 7-day period in the Spacelab configuration shown in Figure 5-5.

Nominally, 10 hours per day in the Spacelab will be devoted to research activities and experiment support functions in the following areas:

A. Blood volume and body fluid balance
B. Cardiovascular activities
C. Bone density and calcium balance
D. Primate physiology
E. Small vertebrate physiology
F. Cell, tissue growth morphogenesis
G. Pulmonary function
H. Muscle size/strength/nitrogen balance
I. Maximum oxygen consumption
J. Blood cell morphology
K. Clotting mechanisms
L. Patterns in alertness
M. Blood gas transportation

5.2.2 Crew Activities

Research and supporting activities required to complete the mission protocols and provide maintenance support for the specimens during a 7-day Spacelab mission are shown in Table 5-1.



- RESEARCH CAPABILITY

MAN-FLUID AND ELECTROLYTE BALANCE
- CARDIOVASCULAR
- RESPIRATION/ENERGY METABOLISM

PRIMATES AND SMALL MAMMALS
- MAINTENANCE AND OBSERVATION
- MANIPULATION AND EXAMINATION
- ELECTROPHYSIOLOGICAL
- DISSECTION AND SAMPLE ACQUISITION
- SAMPLE PREPARATION/PRESERVATION

CELLS AND TISSUES

- CHARACTERISTICS

MASS

TOTAL LAUNCH	23,000 LBM
TOTAL LANDING	21,800 LBM

POWER
- PEAK – 3.8 KW
- AVERAGE – 2.4 KW

DATA
- BIT RATE AVERAGE 16 KBS
- BIT RATE PEAK 40 KBS
- TOTAL BITS/DAY 1.54 X 10^9

Figure 5-5. MOD-1A Life Science Laboratory: Medical Emphasis

Table 5-1

CREW TIME FOR SPECIMEN HANDLING

Activity	Frequency	No. of Crewmen	Task Duration (min)	Crew Time (min)	Total Crew Time per Mission (min)
Primate BSHF Maintenance	1/day	1	15/unit	60	360
Rat BSHF Maintenance	1/day	1	30/unit	60	360
Primate Monitor	2/day	1	15	30	180
Primate Experimentation	1/mission	2	45	90	90
Rat Experimentation	3/mission	2	60	120	360

Primate BSHF maintenance is performed at the same time each day and consists of: (1) reading and recording the number of food pellets and amount of water consumed; (2) removing the pellet holder tubes and replenishing the food supply by replacing new tubes on the cage front; (3) obtaining an aliquot from the urine collection reservoir and placing in the refrigerator; (4) collecting feces by using a hand-held vacuum; and (5) wiping cage interior with wet biocide wipes as required to remove urine salts and feces.

Rat BSHF maintenance is performed at the same time each day and consists of: (1) reading and recording the amount of water consumed per cage; (2) refilling individual cage water reservoirs; (3) replacing paste food container, weighing removed container and recording amount of food consumed per cage; (4) obtaining urine aliquot from reservoir; and (5) partially removing wire-mesh cage interior and hand vacuuming feces from the bottom of the cage.

Primate monitoring is performed twice per day, in the morning and afternoon, and consists of monitoring primate activity and implanted sensor data displayed on the CRT at the experiment work station.

Primate experimentation is performed on each primate once during the mission and consists of: (1) actuating the squeeze cage capability by use of the manual hand crank; (2) opening the outer cage door and anesthetizing the primate by injection; (3) opening the inner cage door, removing primate and transporting him to the surgical table in the primate transfer unit; (4) performing physiological measurements and collecting samples in accordance with the experiment protocol; and (5) returning the primate to the cage by reversing steps one through four.

Rat experimentation is performed three times during the mission and consists of: (1) opening the individual cage doors and removing two specimens; (2) transporting specimens to surgical table and restraining for surgery; (3) exsanguinating the specimen, taking samples and performing dissection and tissue fixing procedures in accordance with experiment protocols; and (5) washing down surgical table and stowing waste.

Inherent to the above operations is the recording of selected activities by TV, movie, and still camera.

5.3 POSTLANDING OPERATIONS

Postlanding operations begin with ingress of experimenter(s) to monitor and evaluate specimens and end with specimens detailed postflight physical examinations and observations as specified by experiment protocols in the ground holding laboratory.

5.3.1 Off-Loading Operations

Off-loading operations begin with experimenter(s) ingress to the Spacelab via the tunnel and end with specimen delivery to the ground holding laboratory.

The baseline off-loading configuration is shown in Figure 5-6. The specimens will be off-loaded via the transfer tunnel using transfer cages with the orbiter located in the OPF. In addition, the following assumptions apply which affect functional analysis and timeline activity: (1) the tunnel design will, at a minimum, permit one-g access between the orbiter and Spacelab

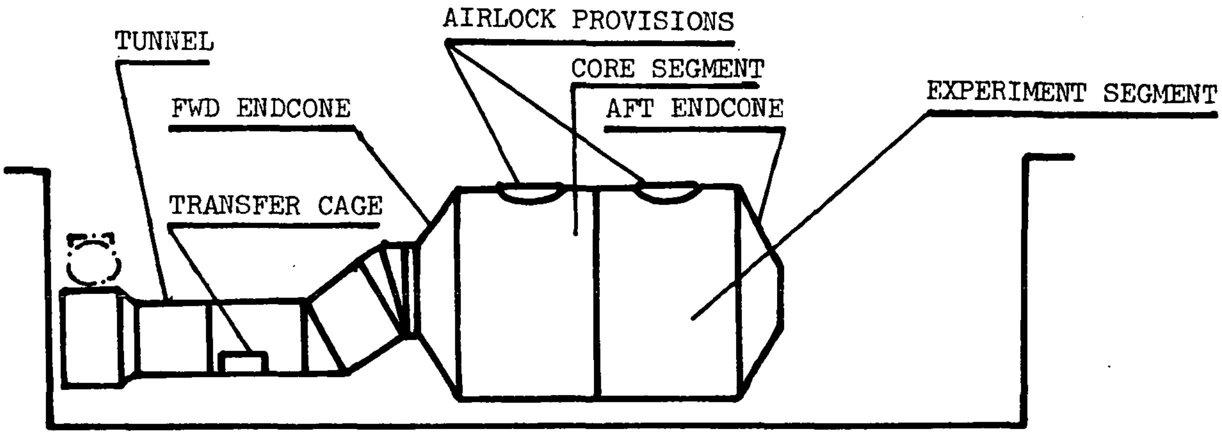


Figure 5-6. Spacelab/Tunnel Off-Loading Configuration

for one man at a time without installation of access GSE, or permit access after installation of specially designed lightweight GSE which is positioned by an off-loading specialist during the period within landing plus 1 hour; (2) safety requirements will be waived to permit experimenter(s) access to Spacelab during tow and initial OPF operations; (3) specimen off-loading GSE will be designed for easy insertion into the tunnel and to facilitate timely specimen movement through the tunnel; (4) a minimum of seven trained off-loading specialists will be available to support the off-loading (three in the Spacelab and four operating between the orbiter and mobile transfer van); and (5) primates will be anesthetized by the experimenter(s) prior to their egress from the Spacelab.

A typical specimen off-loading task flow is presented in Figure 5-7. These functions integrated with the KSC turaround allocation to permit off-loading of specimens in the OPF starting at landing plus 3 hours are presented in Figure 5-8. The clear bars show the KSC turnaround allocation and the hatched bars show the MDAC-defined off-loading functions.

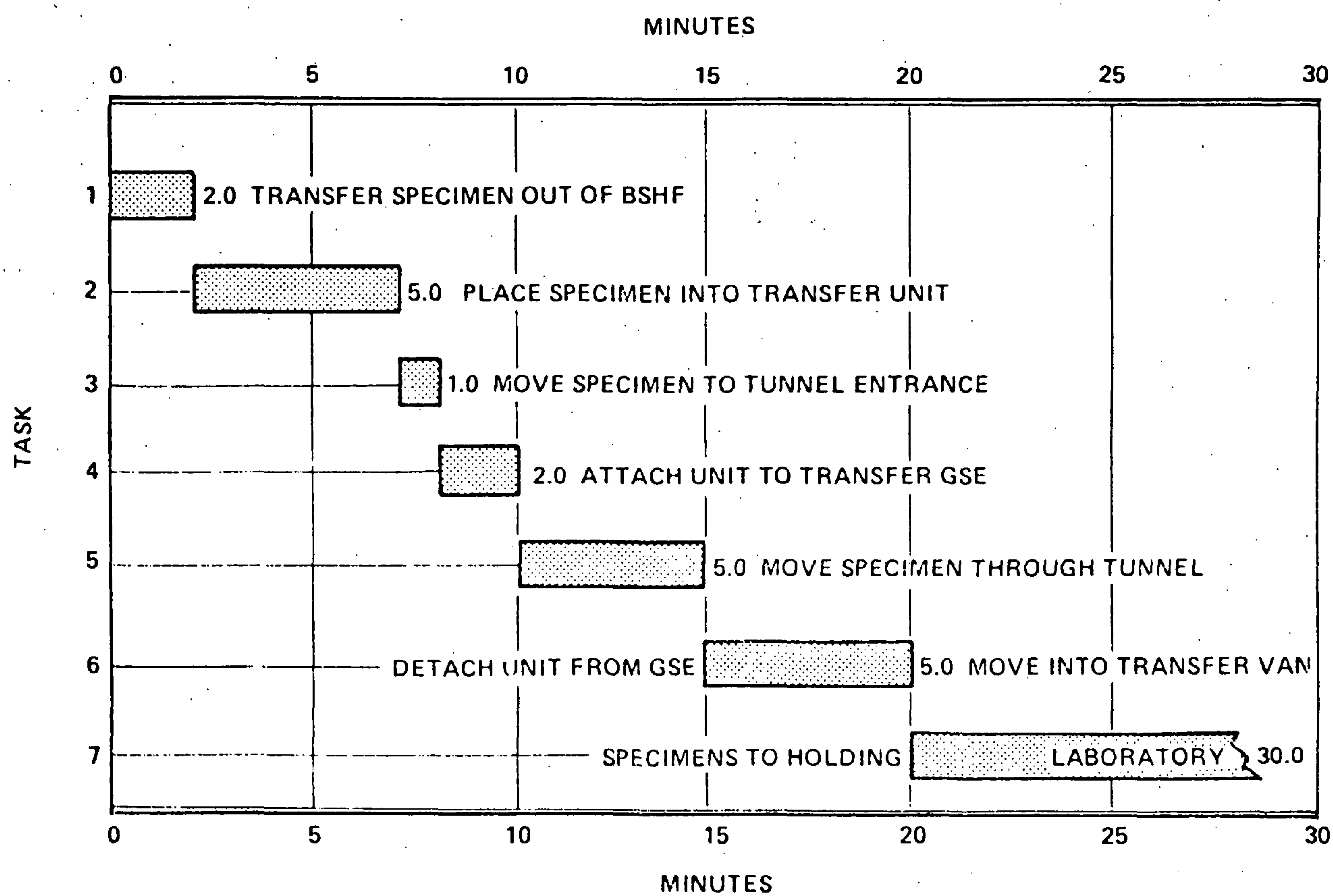


Figure 5-7. Specimen Off-Loading Task Flow

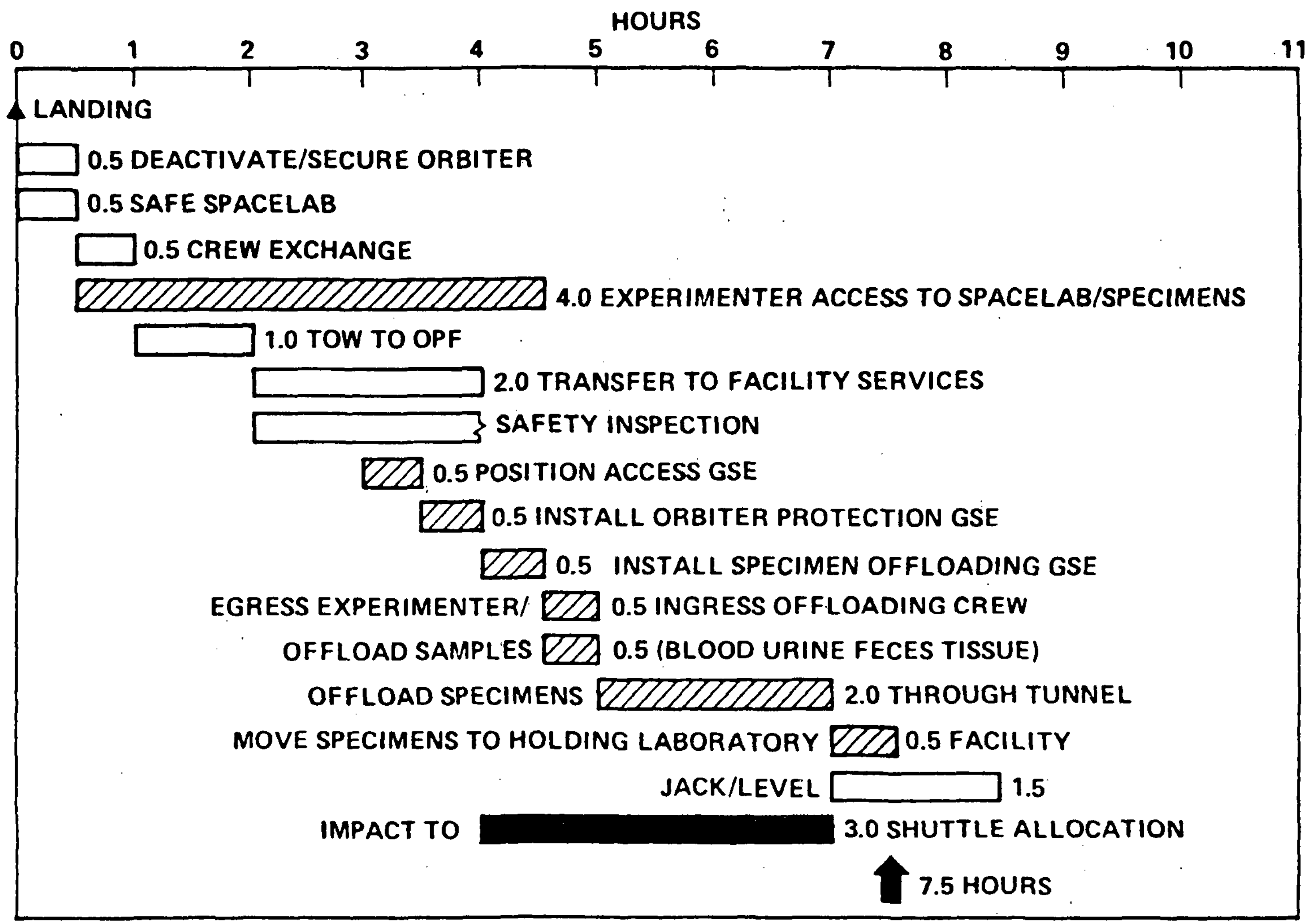


Figure 5-8. Specimen Off-Load at OPF prior to Jack and Level

This method of operation permits access to specimens well within the requirement of landing plus 2 hours and in addition provides ample time, 4 hours, for experimenter(s) evaluation of specimen response to reentry, landing and readaptation to the one-g environment. In addition, specimens are transferred to the ground holding facility within 7.5 hours after landing without major impact to the Spacelab turnaround allocation.

5.3.2 Postflight Specimen Evaluation Operations

Postflight specimen evaluation operations begin with arrival of specimens at the ground holding laboratory and ends with disposition of specimens as designated by experiment protocol.

Section 6
TECHNICAL REQUIREMENTS SPECIFICATION

This section describes, in specification format, the technical requirements for the BSHF. This will provide habitats and support for the living specimens which will be carried on-board the Spacelab in the Space Shuttle and used for research in the Life Science Laboratory. The major emphasis has been placed upon the design of a facility for the rhesus monkey (macaca mulatta) and the laboratory rat (Rattus norvegicus) and where it is necessary to refer to specific species, these are the specimens considered in the following discussion.

6.1 GENERAL REQUIREMENTS

The BSHF shall be designed to meet the following general requirements:

The facility shall be designed to minimize physiological changes and stress in the specimens at a level comparable with normal terrestrial specimen habitats.

Transfer of specimens to and from the cages shall be accommodated during prelaunch and postlanding operations and on-orbit when required to perform research procedures at a specimen examining unit.

The design operating time shall be consistent with a 30-day Spacelab mission.

The BSHF shall include, as a minimum, the structure, environmental control, food and watering subsystems, waste management, lighting, and specimen data collection.

The elements of the BSHF shall be compatible with the Spacelab rack design, and shall operate at the various gravity levels and directions that will be encountered by the Spacelab before launch, during flight, and after landing.

Modular design features shall be incorporated to allow BSHF element usage in minilabs as well as dedicated labs.

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Availability of space-qualified components must be considered in design studies.

Commonality of component usage and selection of available low-cost hardware shall be a major design consideration.

Air entering and leaving the specimen holding facility from the Spacelab cabin must be filtered to prevent microbial exchange between the crew and the specimens.

Air returned to the cabin from the holding facility must be treated to remove odors, other objectionable trace contaminants, and particulate matter.

Special restraints for specimens are not required during launch and reentry phases of the mission.

6.2 DETAIL REQUIREMENTS

6.2.1 System Performance

The Biological Specimen Holding Facility shall be designed to meet the requirements defined in Volume III of this report. This BSHF shall include the following subsystems: environmental control, feeding, watering, waste management, lighting, and data acquisition. In addition to the elements of the the habitats themselves there is a supporting equipment group including potable water supply, flush water supply, waste water storage, a control and display panel, signal receivers, and a signal conditioner unit.

The actual makeup of a BSHF is dependent upon the research requirements of the specific mission. A typical dedicated Life Science Laboratory installation, according to the results of the Definition Study, might include habitats and supporting equipment for 4 unrestrained rhesus monkeys and 16 laboratory rats housed in two modules. The weight, volume, and power requirement of such a laboratory are shown in Table 6-1.

6.2.1.1 Primate Cage, Unrestrained

The unrestrained primate cage shall provide a habitat for prelaunch, launch, orbit, experiment operations, reentry, landing, and postlanding containment. In addition, the cage structure provides the interface for attachment of the food, water, lighting, ECS and waste management subsystems, and the

Table 6-1

SUMMARY OF BIOLOGICAL SPECIMEN HOLDING FACILITY FOR A TYPICAL DEDICATED LIFE SCIENCE LABORATORY*

Item Number	Name	Quantity*	Weight (kg)	Volume (m^3)	Power (watts)
1000	Habitat Assembly, Primate	4	544.0	3.676	824 + 104 (I)**
2000	Habitat Assembly, Rodent	2	134.4	0.574	262 + 52 (I)
3000	Signal Conditioning Assembly	2	42.0	0.0523	160
4000	Receiver, Telemetered Signal	3	5.4	0.0048	48
5000	Supporting Equipment Group	2	203.18	0.8331	16 + 24 (I)
	Subtotals		928.98	5.104	1,310 + 180 (I)
	Allowance for brackets, structure, misc (20%)		185.80	1.021	262 + 36 (I)
	TOTAL		1114.78	6.125	1,572 + 216 (I)

*Typical laboratory includes 4 primate and 2 rat modules.

**(I) denotes intermittent, for short periods only.

design provides for easy conversion to a restrained primate cage configuration without major structural alterations to the basic lightweight cage structure.

Performance Summary

Overall dimensions (outside): 94.3 cm wide x 109.2 cm high x 86.4 cm deep (37-1/8 in wide x 43 in high x 34 in deep)

Overall dimensions (inside): 76.2 cm wide x 83.8 cm high x 61 cm deep (30 in wide x 33 in high x 24 in deep)

Cage weight: 136 kg (300 lb)

Fabrication material: 0.05 cm (0.020 in) corrosion-resistant steel

Interior surfaces: TFE coated

Insulation: 1.27 cm (1/2 in) minimum for acoustic and thermal isolation

Front panel access: 45.7 cm wide x 63.5 cm high (18 in wide x 25 in high)

Access door open area: 30.48 cm wide x 48.3 cm high (12 in wide x 19 in high)

Access door bars: 1.27 cm (1/2 in) O.D. stainless steel tubing at 5.1 cm (2 in) centers

View door glass area: 30.48 cm wide x 48.3 cm high (12 in wide x 19 in high)

Door latches: positive latch, soft seals

Spacelab rack attachment: 4 slides with minimum extension of 76 cm (30 in)

Service loop interface: manual quick disconnects

6.2.1.2 Primate Cage, Restrained

The restrained primate cage shall provide a habitat for prelaunch, launch, orbit, experiment operations, reentry, landing and postlanding containment. In addition, the cage structure provides the interface for attachment of the food, water, lighting, ECS, and waste management subsystems. The same basic structure is utilized as for the unrestrained cage. It is modified by replacement of the cage front containing the access and view door with a cage front containing a view door only which opens to provide access to either of the two primates contained in the cage in contoured restraint couches. In addition, the food and water subsystems are modified to provide for two primates; a simple bag type waste management system is incorporated into the couch design, and a barrier containing a social window separates the two primates.

Performance Summary

Overall dimensions: Same as unrestrained primate cage

Cage weight: 150 kg (330 lb)

Material: 0.05 cm (0.020 in) corrosion-resistant steel

Interior surfaces: TFE coated

Insulation: 1.27 cm (1/2 in) minimum sound and thermal

Door latches: positive latch, soft seals

Spacelab rack attachment: 4 slides with minimum extension of 76 cm (30 in)

Service load interface: manual quick disconnects

6.2.1.3 Rodent Module

The rodent module shall provide a habitat for prelaunch, launch, orbit, experiment operations, reentry, landing, and postlanding containment. In addition, the cage structure provides the interface for attachment of the food, water, lighting, ECS, and waste management subsystems. Each module shall be comprised of eight cages sized to hold one 350-gram rat each. Each pair of cages has a common wall assembly that contains the light fixture, photocell assembly, and all water piping and wiring required by the two cages. There are four such pairs of cages in the rodent module. The door to each cage contains a high-strength window, the feeding compartment, and the watering valve mounted next to the food compartment. A wire cage assembly fits into each rodent cage and functions as a retainer for feces, a transport device to remove the specimen from the cage, and a means for rat restraint within the cage.

Performance Summary

Overall outside dimensions: 94.3 cm wide x 38.6 cm high x 76 cm deep
(37-1/8 in wide x 17 in high x 30 in deep)

Cage dimensions (inside): 19.1 cm wide x 15.2 cm high x 30.48 cm deep
(7.5 in wide x 6 in high x 12 in deep)

Module weight: 67.2 kg (148 lb)

Fabrication material: 0.05 cm (0.020 in) aluminum sheet stock

Interior surfaces: TFE coated

Insulation: 0.64 cm (1/4 in) foam

Front panel access: 15.2 cm wide x 14 cm high (6 in wide x 5-1/2 in high)
Door view glass: 12.7 cm wide x 6.35 cm high (5 in wide x 2-1/2 in high)
Spacelab rack attachment: 2 slides with minimum extension of 76 cm (30 in)
Service loop interface: manual quick disconnects

6.2.2 Subsystem Performance

An indented parts lists of the subsystems, assemblies and units and major components of the BSHF is presented in Table 6-2. Also included in this table are weight, volume, and power estimates for these elements.

The major elements of the facility include a primate habitat and a rodent habitat. Each of these include environmental control, feeding, watering, waste collection, lighting, and data acquisition. There is also a requirement for various equipment items mounted external to the habitats. These include signal conditioning units, control and display panels, and storage facilities for food, potable water, waste water and flush water. The various subsystems of the BSHF usually include elements of the habitats as well as elements of the peripheral equipment. A cross reference showing the assemblies and units that comprise each subsystem of the BSHF is shown in Table 6-3. The following discussion of the BSHF requirements is presented on a subsystem basis.

6.2.2.1 Environmental Control Subsystem

The environmental control subsystem (ECS) shall maintain the cage internal environment within habitable limits for the specimens and provide safe interfaces for the Spacelab experimenters by performing the following functions:

A. Control cage air temperature within the range of 20 to 26°C (68-79°F)

B. Remove particulate and microbial contaminants from the air entering and leaving the cages.

C. Remove odors and trace contaminants from the air leaving the cages.

D. Provide air recirculation which introduces a uniform downward air velocity of 8.5 m^3/min (300 cfm) for the primate cage or 0.5 m^3/min (20 cfm) for each rat cage to facilitate the collection of solid and liquid wastes.

Table 6-2

EQUIPMENT LIST AND WEIGHT, VOLUME, AND POWER DATA (Page 1 of 5)

Item Number	Nomenclature	Quantity Per Module	Quantity Per Side**	Quantity Per Laboratory	Per Unit Weight (kg)	Per Unit Volume (cm^3)	Per Unit Power (watts)	Remarks
1000	Habitat Assembly, Primate	1	(2)	(4)	136	919,000	206 + 26 (I)*	Quantities show requirements for typical Life Science Laboratory
1100	Environmental Control Subsystems	(1)			(43.42)	(77,461)	[150 + 21 (I)]	
1101	Blower, Bleed Air	1			3.18	6,125	50	
1102	Blower, Air Recirculation	1			14.09	21,400	95	
1103	Valve, Air Inlet	1			1.09	1,268	21 (I)	
1104	Valve, Air Isolation	1			0.90	330	0	
1105	Control, Temperature	1			1.32	2,030	5	
1106	Screen, Protective, Blower	2			0.15	32	0	(each, for 2 units, per assembly)
1107	Filter, Microbial, Inlet	1			2.18	6,550	0	
1108	Filter, Microbial, Outlet	1			4.36	13,100	0	
1109	Filter, Odor Control, Outlet	1			8.76	7,374	0	
1110	Ducting, etc	1			7.24	19,220	0	
1200	Waste Collection Unit	(1)			(34.28)	(62,044)	[44 + 5 (I)]	
1201	Waste Collector, Cage	1			23.0	50,120	0	
1202	Valve, Rotating Selector	1			2.27	1,810	5 (I)	
1203	Phase Separator	1			2.05	2,474	40	
1204	Valve, Solenoid, 3-way, liquid	1			1.25	2,000	4	Energize only to obtain sample
1205	Piping, etc.	1			5.71	5,640	0	
1300	Feeding Unit	(1)			(1.32)	(1,470)	0	
1301	Feeder	2			0.40	500	0	
1302	Switch, Feeder	2			0.15	175	0	
1303	Brackets, holding	2			0.11	60	0	

*(I) means intermittent, for short periods only.

**On each side of the Spacelab central aisle.

Table 6-2

EQUIPMENT LIST AND WEIGHT, VOLUME, AND POWER DATA (Page 2 of 5)

Item Number	Nomenclature	Quantity Per Module	Per Side**	Per Laboratory	Per unit Weight (kg)	Volume (cm^3)	Power (watts)	Remarks
1000	Habitat Assembly, Primate (continued)							
1400	Watering Unit	(1)			(0.90)	(925)	0	
1401	Waterer and Piping	1			0.75	750	0	
1402	Waterer Switch Assembly	1			0.15	175	0	
1500	Lighting Subsystem	(1)			(0.92)	(1,148)	(12)	
1501	Bulbs, Fluorescent	4			0.12	18	3	
1502	Housing, Lights	2			0.22	574	0	
1600	Data Acquisition Unit	(1)			(9.43)	(9,170)	0	Power supplied from Signal Conditioner Assembly
1601	Transducer, Pressure	1			0.38	400		
1602	Sensor, Polarographic O_2	1			0.05	80		
1603	Sensor, Infrared CO_2	1			1.20	1,400		
1604	Thermister	2			0.025	80		
1605	Sensor, Humidity	1			0.05	60		
1606	Acoustimeter	-	-	1	1.20	1,700		
1607	Photocell group	1			2.50	2,900		
1608	Antenna, Signal Receiver	1			1.30	900		
1609	Wiring Harness	1			1.35	1,200		
1610	Bracket Set	1			1.35	450		
2000	Habitat Assembly, Rodent	1	(1)	(2)	67.20	287,000	131 + 26 (I)*	Quantities show requirements for typical Life Science Laboratory
2100	Environmental Control Subsystem	(1)			(17.94)	(38,522)	[75 + 21 (I)]	
2101	Blower, Bleed Air	1			0.77	972	25	
2102	Blower, Air Recirculation	1			3.14	8,620	45	
2103	Valve, Air Inlet	1			1.09	1,268	21 (I)	

*(I) means intermittent, for short periods only.

**On each side of the Spacelab central aisle.

Table 6-2

EQUIPMENT LIST AND WEIGHT, VOLUME, AND POWER DATA (Page 3 of 5)

Item Number	Nomenclature	Quantity Per Module	Quantity Per Side**	Quantity Per Laboratory	Per Unit Weight (kg)	Per Unit Volume (cm^3)	Per Unit Power (watts)	Remarks
2000	Habitat Assembly, Rodent (continued)							
2104	Valve, Air Isolation	1			0.90	330	0	
2105	Control, Temperature	1			1.32	2,030	5	
2106	Screen, Protective, Blower	2			0.15	32	0	(each, for 2 units/assy)
2107	Filter, Microbial, Inlet	1			2.18	6,550	0	
2108	Filter, Microbial, Outlet	1			2.18	6,550	0	
2109	Filter, Odor Control, Outlet	1			3.07	2,580	0	
2110	Ducting, etc.	1			2.99	9,558	0	
2200	Waste Collection Unit	(1)			(17.24)	(26,360)	[44 + 5 (I)]*	
2201	Waste Collector, Cage	8			1.10	2,210	0	
2202	Valve, Rotating Selector	1			2.27	1,810	5 (I)	
2203	Phase Separator	1			2.05	2,474	40	
2204	Valve, Solenoid, 3-way, liquid	1			1.25	2,000	4	Energize only to obtain sample.
2205	Piping, etc.				2.87	396	0	
2300	Feeding Unit				(0.52)	(360)	0	
2301	Feeder	8			0.065	45	0	
2400	Watering Unit	(1)			(2.25)	(2,250)	0	
2401	Waterer	1			2.25	2,250	0	
2500	Lighting Subsystem	(1)			(0.96)	(2,424)	(12)	
2501	Bulbs, Fluorescent	4			0.12	18	3	
2502	Housing, Lights	4			0.12	606	0	
2600	Data Acquisition Unit	(1)			(5.70)	(4,720)	0	Power supplied from Signal Conditioner Assembly
2601	Transducer, Pressure	1			0.38	400		
2602	Sensor, Polarographic O_2	1			0.05	80		
2603	Sensor, Infrared CO_2	1			1.20	1,400		

*(I) means intermittent, for short periods only.

**On each side of the Spacelab central aisle.

Table 6-2

EQUIPMENT LIST AND WEIGHT, VOLUME, AND POWER DATA (Page 4 of 5)

Item Number	Nomenclature	Quantity Per Module	Quantity Per Side*	Quantity Per Laboratory	Per Unit Weight (kg)	Per Unit Volume (cm^3)	Per Unit Power (watts)	Remarks
2000	Habitat Assembly, Rodent (continued)							
2604	Thermister	2			0.025	80		
2605	Sensor, Humidity	1			0.05	60		
2607	Photocell Group	1			1.07	900		
2608	Antenna, Signal Receiver	1			1.30	900		
2609	Wiring Harness				.80	650		
2610	Bracket Set				.80	250		
3000	Signal Conditioning Assembly		1	(2)	21.00	26,140	80	Each Signal Conditioning assembly panel, as shown, herein, will support two primates and one rat module.
3X01	Bridge Network and Amplifier (Pressure Transducer)	1						
3X02	Signal Conditioner, Polarographic O_2	1						
3X03	Signal Conditioner, CO_2	1						
3X04	Signal Conditioner, Thermister	2						
3X05	Signal Conditioner, Humidity	1						
3X06	Amplifier, Acoustimeter	1						
3X07	Signal Conditioner, Photocell	1						
3X08	Network, Resistor, Feeder Switch	1						For primate module only.
3X09	Network, Resistor, Waterer Switch	1						For primate module only.
4000	Receiver, Telemetered Signal	-	-	3	1.80	1,600	16	Each receiver will support four primates or one rodent module.
4001	Receiver, Tuneable	-	-	3	0.40	400	8	
4002	Demodulator and Amplifier, Signal	-	-	3	0.80	800	8	
4003	Wiring Harness	-	-	3	0.60	400	0	

* On each side of the Spacelab central aisle.

Table 6-2

EQUIPMENT LIST AND WEIGHT, VOLUME, AND POWER DATA (Page 5 of 5)

Item Number	Nomenclature	Quantity Per Module	Quantity Per Side**	Quantity Per Laboratory	Per Unit Weight (kg)	Per Unit Volume (cm^3)	Per Unit Power (watts)	Remarks
5000	Supporting Equipment Group	-	(1)	(2)	101.59	416,540	8 + 12 (I)*	
5100	Control/Display Panel	-	(2)	(4)	(8.00)	(34,200)	(4)	NOTE: Each Control/Display Panel will support one primate and one rodent module, installed in a double rack.
5200	Flush Water Unit	-	(1)	(2)	(22.74)	(63,870)	[(4) (I)]	
5201	Tank, Flush Water		1	-	15.90	56,780	0	
5202	Regulator, Pressure, N_2		1	-	1.60	1,250	0	
5203	Valve, Solenoid, 2-way		1	-	1.05	1,230	4 (I)	
5204	Valve, Relief		1	-	0.40	820	0	
5205	Piping		1	-	3.79	3,790	0	
5300	Waste Water Collection Unit	-	(1)	(2)	(46.8)	(218,560)	0	
5301	Tank, Waste Water		1	-	44.5	216,200	0	
5302	Valve, Check, Liquid		1	-	0.05	110	0	
5303	Piping		1	-	2.25	2,250	0	
5400	Potable Water Supply Unit	-	(2)	(4)	(16.05)	(15,710)	[8 (I)]	In this row, "per unit" values are given per side (2 primates and 1 rodent module).
5401	Tank, Potable Water		2	-	4.00	4,000	0	
5402	Regulator, Pressure, N_2		2	-	1.60	1,250	0	
5403	Water Distributor, Primate	1	2		0.75	750	0	For primate module only.
5404	Valve, Solenoid, 2-way, liquid	1	2		1.05	1,230	4 (I)	For primate module only.
5405	Water Distributor, Rodent Module	1	1		1.25	1,250	0	For rodent module only.

*(I) means intermittent, for short periods only.

**On each side of the Spacelab central aisle.

Table 6-3

RELATIONSHIP OF ASSEMBLIES AND SUBSYSTEMS OF THE BSHF

Assemblies \ Subsystems	Environmental Control	Food Management	Water Management	Waste Management	Lighting	Data Management
Specimen Habitat Assembly						
Environmental Control	x					
Feeding Unit		x				
Watering Unit			x			
Waste Collection Unit				x		
Lighting					x	
Data Acquisition Unit						x
Signal Conditioning Assembly						x
Telemetered Signal Receiver						x
Supporting Equipment Group						
Control/Display Panel						x
Flush Water Storage				x		
Waste Water Storage				x		
Potable Water Storage			x			
Food Storage		x				

E. Provide capability to meet off-design conditions.

F. Provide spares and remedial actions to meet failure conditions.

Blowers, temperature controllers, and air inlet valves are used to provide adequate ventilation to maintain proper carbon dioxide, humidity, and trace contaminant levels within specified limits and to maintain cage air temperature. Inlet and outlet filters are provided to remove microbes, particulates, and odors. The performance requirements of major components of the ECS are specified in the following paragraphs:

Bleed Air Blower

This blower draws in air from the Spacelab cabin, through the inlet air valve, filter and the lower air plenum. The exhaust air is returned to the cabin through the odor and microbial filters.

Performance Summary	Primate Cage	Rat Module
Design air flow, m^3/min (cfm)	1.274 (45)	0.6797 (24)
Δp at design point, torr (in H_2O)	4.20 (2.25)	(2.7)
Power input, watts	50	25
Power type	208 V, 3Ø, 60 Hz	200 V, 3Ø, 400 Hz
Weight kg (lb)	3.18 (7)	0.77 (1.7)
Volume, cm^3 (in^3)	6125 (373.5)	972 (59)

Air Recirculation Blowers

These blowers are used to draw in air from the cages, together with inlet air from the cabin and recirculate the combined air flow rate of 8.5 m^3/min (300 cfm) into the primate cage or 4.53 m^3 min (160 cfm) into the rodent module. The air is introduced through a wick/plenum located at the top of the cage, then through the cage space, down through the waste management collector and finally returned to the suction side of the blower. Before the recirculation air is returned to the blower, an amount equivalent to introduced cabin air is extracted from the main flow and returned to the Spacelab cabin for processing by the cabin ECS. The air recirculation blowers are of the centrifugal type with motors cooled by avionics air rather than the blower air flow. In this manner, the motor heat loads are rejected to the avionics cooling loop and not to the limited capacity cabin cooling loop.

Performance Summary	Primate Cage	Rodent Module
Design air flow m^3/min (cfm)	8.5 (300)	4.53 (160)
Δp at design point, torr (in H_2O)	1.68 (0.9)	0.37 (0.2)
Power input, watts	95	45
Power type	208 V, 3Ø, 60 Hz	208 V, 3Ø, 60 Hz
Weight, kg (lb)	14.09 (31)	3.14 (6.9)
Volume, cm^3 (in^3)	21,405 (1306)	8,617 (526)

Air Inlet Valve

This motor-operated electric shutoff flapper valve is used to control the amount of air bled into the cage as a function of the air temperature. The actuator positions the flapper in the flow stream in response to discreet electrical inputs from the temperature controller.

Performance Summary

Voltage: 20 to 28 VDC
Power: 21 watts
Weight: 1.09 kg (2.4 lb)
Envelope: 1268 cm^3 (77 in^3)
Operating pressure: 1.013 bar (14.7 psia)
Operating media: air

Temperature Control

The temperature control provides temperature sensing, signal conditioning, and control logic functions for the cage inlet air valve. A cage temperature signal is provided by a thermistor type of sensor which is conditioned and amplified by the control electronics. A single turn variable resistor is to be provided to enable manual selection of the desired cage temperature.

Performance Summary:

Control Electronics:

Size: 6.35 cm (2.5 in) x 6.35 cm (2.5 in) x 3.8 cm (1.5 in) exclusive of connector and mounting lugs

Weight: 0.41 kg (0.9 lb)

Operating life: 9,000 hours (continuous)
Power consumption: 0.2 amps
Temperature Sensor:
Temperature Range: 10 to 49°C (50 to 120°F)
Weight: 0.09 kg (0.2 lb)
Operating media: air
Temperature Selector
Total resistance: 10,000 ± 10% ohms
Load resistance: 2 megohms
Shaft torque: 17.3 kg-cm (15 in-lb) maximum
Operating Temperature range: 2 to 49°C (35 to 120°F)
Voltage: 10 VDC
Power: 0.01 watts
Weight: 0.3 kg (0.7 lb)

Microbial Air Filters

Microbial filters are to be used at the inlets and outlets of the primate cages and rodent modules to remove microbial contaminants and prevent transfer of organisms between the crew and the specimens.

These filters shall comprise a number of filter elements, each with 7.37 cm (2.9 in) diameter and 25.4 cm (10 in) long, enclosed in a filter housing.

Performance Summary	Primate Cage	Rat Module
Air flow, m^3/min (cfm)	1.27 (45)	0.68 (24)
Filter rating	100% removal, 0.9μ particles	100% removal, 0.9μ particles
	98% removal, 0.07μ particles	98% removal, 0.07μ particles
Pressure drop		
Inlet	1.27 torr (0.68 in H_2O)	0.36 torr (0.19 in H_2O)
Outlet	0.32 torr (0.17 in H_2O)	0.36 torr (0.19 in H_2O)

Performance Summary	Primate Cage	Rat Module
Dimensions		
Inlet cm (in)	26.04 x 33.02 x 7.62 (10-1/4 x 13 x 3)	19.05 x 34.93 x 19.05 (7-1/2 in x 13-3/4 in x 7-1/2 in)
Outlet cm (in)	25.4 x 60.96 x 7.62 (10 x 24 x 3)	19.05 x 34.93 x 19.05 (7-1/2 in x 13-3/4 in x 7-1/2 in)
Number of elements		
Inlet	4	4
Outlet	8	4
Weight (estimated)		
Inlet	2.18 kg (4.8 lb)	2.18 kg (4.8 lb)
Outlet	4.36 kg (9.6 lb)	2.18 kg (4.8 lb)
Operating lifetime	34 days	34 days

Odor Control Filter

Exhaust air from the specimen holding unit shall be passed through an activated charcoal bed for the removal of odors and trace contaminants generated by the specimens. The charcoal shall be treated with phosphoric acid for the removal of ammonia from exhaust air. The activated charcoal filter is located downstream of the bleed air blower and ahead of the microbial filter in the exhaust air stream.

Performance Summary	Primate Cage	Rat Module
Air flow m^3/min (cfm)	1.27 (45)	0.68 (24)
Pressure drop	1.31 torr (0.7 in H_2O)	0.24 torr (0.13 in H_2O)
Area	580 cm^2 (90 in^2)	203.2 cm^2 (31.5 in^2)
Depth	12.7 cm (5 in)	12.7 cm (5 in)
Volume	7374 cm^3 (450 in^3)	2581 cm^3 (157.5 in^3)
Weight	8.76 kg (19.3 lb)	3.07 kg (6.76 lb)
Operating lifetime	34 days	34 days

6.2.2.2 Waste Management Subsystem

The waste management subsystem (WMS) includes the waste collector, selector valve, phase separator, flush water tank, flush distribution assembly, waste water storage tank, and solenoid valves. The air recirculation blower of the ECS is used to impart a downward velocity to deliver waste to the waste collector. The recirculation blower has been included with the ECS as it circulates all the air in the cage and is also used as the backup blower in case of failure of the bleed air blower. Major component specifications are given in the following.

Waste Collector

The waste collector includes a wire grid which retains fecal and solid wastes and the collector structure which is comprised of a number of rectangular sections, each having a center vertex lower than the edges. The collector floors are made of a hydrophobic material which passes air but collects urine that is directed by the air stream to the vertices and collection tube manifolds. Flush water and urine are collected in the tube manifolds and routed sequentially by the rotating selection valve to flow to the phase separator and the waste collection tank.

Performance Summary	Primate Cage	Rat Cage
Cross-sectional area, m^2 (ft^2)	0.400 (4.30)	0.058 (0.625)
Hydrophobic surface area, m^2 (ft^2)	0.531 (5.71)	0.064 (0.684)
Total air flow rate, m^3/min (cfm)	8.5 (300)	0.566 (20)
Air flow to phase separator, m^3/min (cfm)	0.236 (8.33)	0.236 (8.33)
Air velocity, m/sec (ft/sec)	0.305 (1)	0.152 (1/2)
Urine flow	840 ml/day	13 ml/day
Flush water flow	720 ml/day	180 ml/day
Fecal mass	86 g/day	9 g/day
Fecal bolus pass through grid, cm (in)	3.81 x 3.81 (1.5 x 1.5)	1.27 x 1.27 (0.5 x 0.5)

Rotating Selector Valve

The rotating selector valve is used to sequentially drain the urine/flush water liquid collected in each of the troughs of the waste collector. Individual drainage of the troughs is desired to reduce the induced air flow rate and pressure rise of the phase separator. Each of the waste collector troughs will have a line connected to the valve. A single line then leads from the valve to the liquid/air phase separator. The valve is driven by a stepper motor and designed to give the desired stay time at each trough.

Performance Summary

Fluid flow, air: 0.236 m^3/min (8.33 cfm)

Fluid flow, liquid: 0 to 1.8 kg/hr (0 to 4 lb/hr)

Voltage: 115 vac, 60 Hz

Power: 5 watts

Weight: 2.27 kg (5 lb)

Envelope: 11.2 cm x 11.2 cm x 13.5 cm (4.4 in x 4.4 in x 5.7 in)

Phase Separator

The phase separator is used to separate the entraining air from the flush water/urine. The air and liquid mixture from the waste collector manifolds is drawn into the liquid separator by a pressure differential created by the unit. The separated air is returned to the recirculation air loop, upstream of the recirculation blower. The collected flush water/urine mixture is routed to the waste water storage tank or may be diverted to an experimenter-provided sampling device by means of the three way solenoid valve.

The phase separator consists of a single package containing a motor-driven centrifugal rotating drum and a centrifugal fan integrated with a rotating condensate drum. The motor used is a 115 volt, 400 Hz, 3 phase induction type unit. A rotating labyrinth seal prevents the liquid from flowing into the rotor housing. This unit is similar in characteristics to that used for separation of the humidity condensate in both the Spacelab and Orbiter cabins, but adapted to handle the more corrosive urine.

Performance Summary

Fluid flow, air: 0.236 m^3/min (8.33 cfm)

Fluid flow, water: 0 to 1.8 kg/hr (0 to 4 lb/hr)

Pressure rise, air: 3.98 torr at 0.236 m^3/min (2.13 in H_2O at 8.33 cfm)

Liquid pumping head: 1.79 bar (diff) at 1.36 kg/hr flow
(26 psid at 3.0 lbs/hr flow)

Fan/separator speed: 5,700 rpm

Voltage: 115 vac, 400 Hz

Power: 40 watts

Weight: 2.05 kg (4.5 lb)

Performance Summary

Envelope: 12.7 cm x 15.75 cm diameter (5 in x 6.2 in diameter)

Operation pressure: 0.98 to 1.014 bar (14.4 to 14.9 psia)

Operating media: urine, water, air

Waste Water and Flush Water Tanks

Bladder-type tanks shall be used for the storage of flush water and waste water for the primate and rodent holding units. The flush water tanks will supply water to the flush distribution assemblies in the waste collectors. For the typical dedicated laboratory, one tank will supply flush water to two primate cages and two rodent modules on one side of the laboratory. A separate tank will be installed on the opposite side of the laboratory to avoid the complication of liquid lines crossing the central aisle. Two other tanks will be installed for storing the waste water from the waste collectors, also installed on opposite sides of the aisle. All the tanks will be made of stainless steel and will be pressurized with nitrogen from a common laboratory source. Pressure regulators will control the nitrogen pressure to the tanks.

Performance Summary	Flush Water	Waste Water*
Number of tanks	2	2
Tank capacity, 2 primates/2 rodents	37.85 l (10 gal)	176 l (46.5 gal)
Tank capacity, 2 primates	37.8 l (10 gal)	87.1 l (23 gal)
Tank weight, 2 primates/2 rodents	15.9 kg (35 lb)	44.5 kg (98 lb)
Tank weight, 2 primates	15.9 kg (35 lb)	27.7 kg (61 lb)
Tank material	Stainless steel	Stainless steel

*NOTE: Sizes given apply if all waste water is stored for the mission duration. If waste water can be vented overboard periodically, smaller tanks can be used.

6.2.2.3 Food Management Subsystem

Primate Feeder

The primate feeder shall provide a nutritionally adequate, low residue diet for an adult monkey (14 kg) which results in a low-odor fecal bolus with a firm to semifirm consistency. The design provides for operation in a 1-g or zero-g environment, ad libitum dispensing of spherical food pellets and automatic indication of food pellets dispensed to the primate.

Performance Summary
Required per cage: 2 units
Weight per unit: 0.40 kg
Volume per unit: 500 cm^3
Weight, spare pellet tube: 232 gms
Weight, 30 day food supply for one primate: 15.78 kg
Volume, spare pellet tube: 500 cm^3
Volume, 30-day food supply for one primate: 0.017 m^3
Pellet tube material: transparent acrylic
Food pellets: 2.2 cm (7/8 in) sphere, 8 grams of food

Rodent Feeder

The rodent feeder shall provide a nutritionally adequate diet for an adult laboratory rat (350 grams) which results in low odor feces with a firm consistency. The feeding device shall consist of an aluminum foil container with paste food to be located in the door of each individual rat cage. The design provides for "no waste food in the waste management system" in that the rat must get the food by immersing its paw into the food dish and then eating by licking the food from its paw. Food containers are replaced on a daily basis with consumption computed by weighing the used food container.

Performance Summary
Weight per unit, including packaging: 65 grams
Volume per unit: 44.9 cm^3
Weight, 30-day food supply for one module: 17.68 kg
Volume, 30-day food supply for one module: 0.014 m^3
Food: paste type

6.2.2.4 Water Management Subsystem

Primate Water Unit

The primate water device shall provide the monkey with water on an ad libitum basis but in a controlled manner so that daily consumption may be measured. The dispenser is a drinking tube-lip switch combination. The lip switch will activate a solenoid valve for a predetermined time interval, thus dispensing a fixed quantity of water for each activation. The dispenser is located near the top of the cage front to facilitate conditioning the monkey to a "head-up" orientation. Water shall be provided from a water supply tank which services both primates and rodents. One potable water tank shall be provided on each side of the laboratory so that liquid lines do not require crossing the central aisle.

Performance Summary
Weight, water tank: 4.0 kg
Volume, water tank: 0.004 m^3
Dispensing piping weight/cage, 1.5 kg
Water tank material: stainless steel
Tubing: 8.4 mm stainless steel
Primate water: 1277 ml/day/primate

Rodent Water Unit
The rat water units shall provide laboratory rats with water on an ad libitum basis but in a controlled manner so that daily consumption can be measured. Water shall be provided from a water tank which services both rodents and primates. Each cage (eight per module) shall have an individual graduated spring-loaded reservoir which provides a means of determining the daily consumption of water for each cage. It shall be refilled by manually actuating a two-way valve which directs water from the pressurized water tank into the graduated reservoirs. The water dispensing valve, located in the cage door shall be a pintle-type mechanically actuated valve which is opened as the rat nuzzles the outlet.

Performance Summary
Weight*, water tank: 4.0 kg
Volume, water tank: 0.004 m^3
Dispensing piping weight/module: 3.5 kg
Water tank material: stainless steel
Tubing: 6.25 mm stainless steel
Graduated reservoir, size: 30 ml
Graduated reservoir, material: acrylic plastic
Dispensing valve, Lixit

*NOTE: Common with primate water tank

6.2.2.5 Lighting Subsystem

The lighting system shall provide adequate illumination to the specimen cages.

The primate cage shall contain four 3-watt fluorescent light fixtures with two located at each front corner of the cage. This arrangement provides redundant lighting and adequately provides for the restrained primate concept where a divider separates the cage in two parts and two restrained primates occupy the cage.

The rat module contains four 3-watt fluorescent light fixtures, each fixture furnishing light for two cages.

Performance Summary

Weight, primate unit:	0.7 kg
rat unit:	0.45 kg
Envelope volume, primate:	1,148 cm^3
rat:	2,423 cm^3
Specification, primate:	cool white, 3W
rat:	cool white, 3W

6.2.2.6 Data Management Subsystem

The data management subsystem shall provide for data acquisition, monitoring and control and shall include sensors, controls, display panels, receivers, signal conditioners, and other hardware to receive, condition, transfer and display experiment data from the BSHF and enclosed specimens. Presented below are detail requirements of major portions of the data management subsystem.

Habitat Instrumentation

Habitat instrumentation shall monitor the major environmental parameters encountered in the cages by specimens. Included are pressure, temperature, humidity and sound sensing devices. Behavioral activities are also monitored as well as food and water consumption rates for the primate cages.

Performance Summary

Sensor	Measurement Range	Sample Rate	Number of Channels Primate Cage	Number of Channels Rodent Module
1. Pressure transducer	0 to 0.34 bar (0 - 5 psid)	0.1 s/sec	1	1
2. Polarographic O_2 sensors	150 to 170 torr	0.1 s/sec	1	1
3. Infrared CO_2 sensor	0 to 8 torr		1	1
4. Thermistor	18 to 27°C		2	2
5. Relative humidity sensor	40 to 65%		1	1
6. Accoustimeter	32 to 142 db		N/A*	N/A*
7. Photocell matrix			1	8
8. Feeder microswitch		0.1 s/sec	2	Manual
9. Waterer microswitch	100 to 2000 ml/hr	0.1 s/sec	1	Manual

(*) Only one required per laboratory, in vicinity of BSHF.

Telemetered Signal Receiver

FM equipment is used for transmission of data from implanted sensors within the specimens. The sensors and transmitter are provided by the experimenter but an FM receiver, demodulator and signal amplifier is required as part of the BSHF. One receiver is required for each four primate cages and for each rodent module. This receiver shall be tunable to select the specimen to be monitored.

Performance Summary

Receiver size: 400 cm^3

Receiver weight: 0.4 kg

Receiver power: 8 watts

Signal Conditioner Assembly

Signal conditioners shall be provided for each of the habitat instrumentation items. The signal conditioners are packaged in egg-crate-type rack adapters to be placed in a Spacelab rack.

Performance Summary

Sensor	Signal Conditioner Output	Response	No. of Signal Conditioners Primate Cage	Rodent Module
1. Pressure transducer	5 V	1 msec	1	1
2. Polarographic O_2 sensor	5 V	100 msec	1	1
3. Infrared CO_2 sensor	5 V	15 sec	1	1
4. Thermistor	5 V	20 sec	2	2
5. Relative humidity sensor	100 mV	1 msec	1	1
6. Acoustimeter	5 vp-p	200 msec	N/A	N/A
7. Photocell matrix			1	1
8. Feeder microswitch			1	Manual
9. Waterer microswitch			1	Manual

Section 7
EFFECTIVENESS ANALYSIS

The operational reliability, maintainability, and system safety analyses of the BSHF were performed and are summarized in the following.

7.1 RELIABILITY ANALYSES

System reliability estimates were made based on a 30-day mission. Aircraft equipment failure rates were used as the basis for estimating failure rates for BSHF hardware items. It is considered that the estimates provided are conservative when considering the lower environmental stress factor for space and the usually higher qualification standards imposed.

Figure 7-1 shows the failure-per-flight estimates for a laboratory equipped with four rhesus monkey cages and two rodent cages as a function of mission time. This is measured in terms of expected failures and is linear with time.

Table 7-1 shows the BSHF failure estimates for the four monkey cages by subsystem. The total estimate of failures has been apportioned to various effects expected; (1) 51% of the failure risk (0.687 failures in 30 days) is associated with animal health items (ventilation, water, humidity); (2) 25% (0.335 failures) will cause discomfort and unrest (air contamination, reduced lights); and (3) 22% will cause loss of experimental data (urine samples, temperature, etc.).

The results can be viewed as an indication that maintenance/repair actions will be required on the average of about 1-1/2 times per 30-day mission if all causes of failure are corrected. Approximately 40% of subsystem weight would be required in spare parts to provide a very high probability of adequate spares to correct all experienced faults. Priority should be given to equipment that is necessary to maintain animal health and to certain test

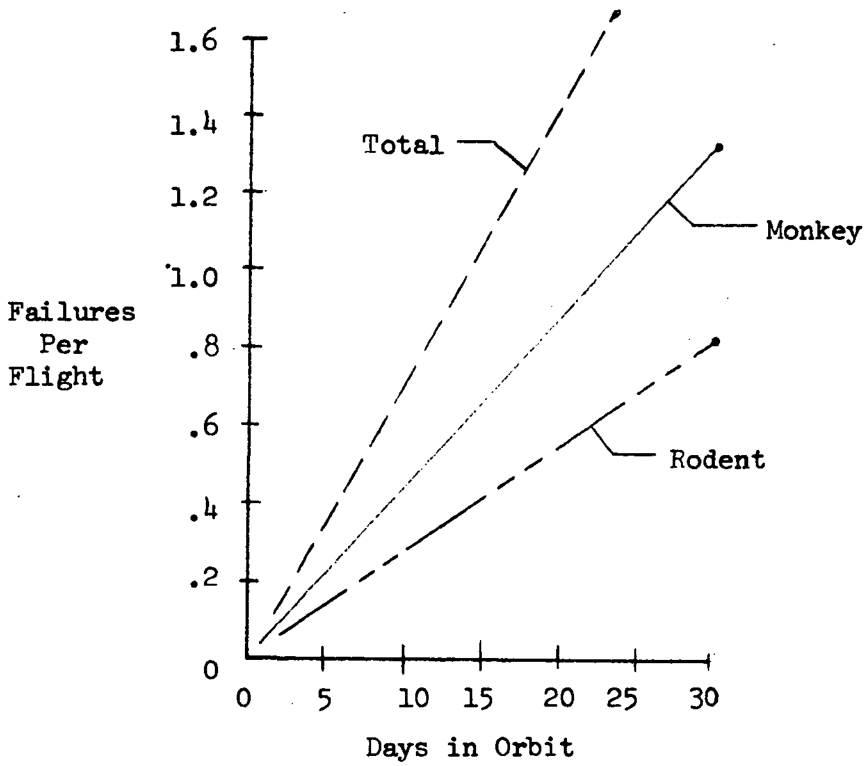


Figure 7-1. Expected Failures of BSHF Equipment as a Function of Mission Time

data. Test conductor action to manually control certain functions can be traded for repair time and spares weight, to increase probability of success.

A similar analysis was conducted for the rodent cages. The results are shown in Table 7-2. The two sets of rodent cages have only 63 percent the failure risk of the four monkey cages, indicating the probability for one maintenance action per 30-day orbit.

Common blowers, ventilation fans, water valves, sensors, valve actuators, door locks, etc., are essential to minimize the weight of spare parts for total BSHF support. These were assumed common in developing a spares list, which is discussed in Section 7.3.

Worksheets used in developing system reliability estimates are included in Appendix B. Worksheets should be reviewed periodically during the design phase to verify changes in repair times and allowable downtimes. Should allowable downtimes be too high and are actually less than repair times shown, then some redundancies may have to be included in the system.

Table 7-1

BSHF RELIABILITY ESTIMATE FOR FOUR RHESUS MONKEY CAGES

Primate Cage Subsystem		Expected Failures — 30 Days in Space with Effects Shown if not Corrected				
		Total Failures	Animal(s) Health	Animal Discomfort	Loss of Test Data	Lab Contam
1.0	Structure	0.024			0.024	
2.0	Environmental control	0.721	0.414	0.291		0.016
3.0	Waste management[1]	0.097[1]	0.045[1]		0.048[1]	0.004
4.0	Feeder (replaceable)					
5.0	Waterer	0.101	0.099		0.002	
6.0	Illumination	0.044		0.044		
7.0	Power (from Orbiter/lab)					
8.0	Instrumentation	0.351	0.129		0.222	
	Total monkey experiment	1.338	0.687	0.335	0.296	0.020

[1] Flush water tank and pressure system included only in monkey subsystem; 1 required per 6 cages total

Table 7-2

BSHF RELIABILITY ESTIMATE FOR TWO 8-RODENT CAGES

	Rodent Cage Subsystem	Total Failures	Expected Failures — 30 Days in Space Effects Shown if Failures not Corrected: Animal(s) Health	Animal Discomfort	Loss of Test Data	Lab Contam
1.0	Structure	0.024			0.024	
2.0	Environmental control	0.361	0.207	0.145		0.008
3.0	Waste management(1)	0.030(1)	0.004(1)		0.024(1)	0.002
4.0	Feeder (replaceable)					
5.0	Waterer	0.079	0.077		0.002	
6.0	Illumination	0.175		0.175		
7.0	Power (from Orbiter/lab)					
8.0	Instrumentation	0.176	0.065		0.111	
	Total Rodent Experiment	0.845	0.353	0.320	0.161	0.010

(1) Tank and pressure system (1 each) included in monkey system totals; not repeated here.

7.2 SYSTEM SAFETY

A system safety analysis was conducted on the BSHF. No specific safety problems were determined. However, a number of changes were recommended and incorporated in system design. Included were the following:

A. The addition of a flapper valve in the lower recirculation duct. In case of failure of the recirculation blower, the valve is closed and air is drawn in by the bleed air fan through the recirculation duct, down the cage and out through the outlet filters. Similarly, in case of failure of the bleed air fan the valve is closed and air is drawn in by the recirculation blower, but at a reduced rate due to higher resistance in this circuit.

B. The inclusion of access provisions to permit manual cleaning of the screens in the ducts from the lower plenum to the fan/blower.

C. The addition of access provisions to permit changing hydrophobic screens in case of contamination and intolerable odors.

7.3 MAINTAINABILITY AND SPARES PROVISIONING

A system maintainability analysis was made to estimate feasible downtimes for repair and to estimate allowable downtimes before there would be serious degradation of experiment value or risk to animal health.

The following maintainability criteria were developed for use as guidelines in the BSHF system design:

A. Provide placards labeling access provisions for mission critical equipment.

B. Use internal wrenching (Allen type) captive screws for all mechanical attachments. The 3/16-in bolts with 5/32 in across flats on head preferred as standard for all light stress attachments.

C. Provide Chevron clamps for attaching blowers and ducts. Make clamps captive to permanently installed ducts and housings. The 1/4 turn breechlock is an acceptable substitute if easy to install.

D. Sensors should be plug-in and turn type where possible. If two connectors are required, they should be of different configuration to prevent interchange.

E. Design all attachments to permit visibility of maintenance work space and to permit one hand positioning and fastening unless leg lock provisions are provided.

None of the BSHF estimated repair times provided a sufficiently low probability of repair in time to warrant installation of redundant components. Incorporating redundance is usually heavier than carrying spares and providing for repair access. For example, two spares provide excellent backup for six blowers.

Table 7-3 shows the list of replaceable items with sufficient risk of failure to be considered for sparing. The failure risk covered by spares (1.785) represents 82 percent of the 2.183 total risk of failure in a 30-day mission. Only the five highest risk items would warrant carrying spares for the 7-day mission. Spares quantities are shown for two probabilities of sufficiency.

Figure 7-2 is a spares estimating chart used for determining quantities as a function of failure risk.

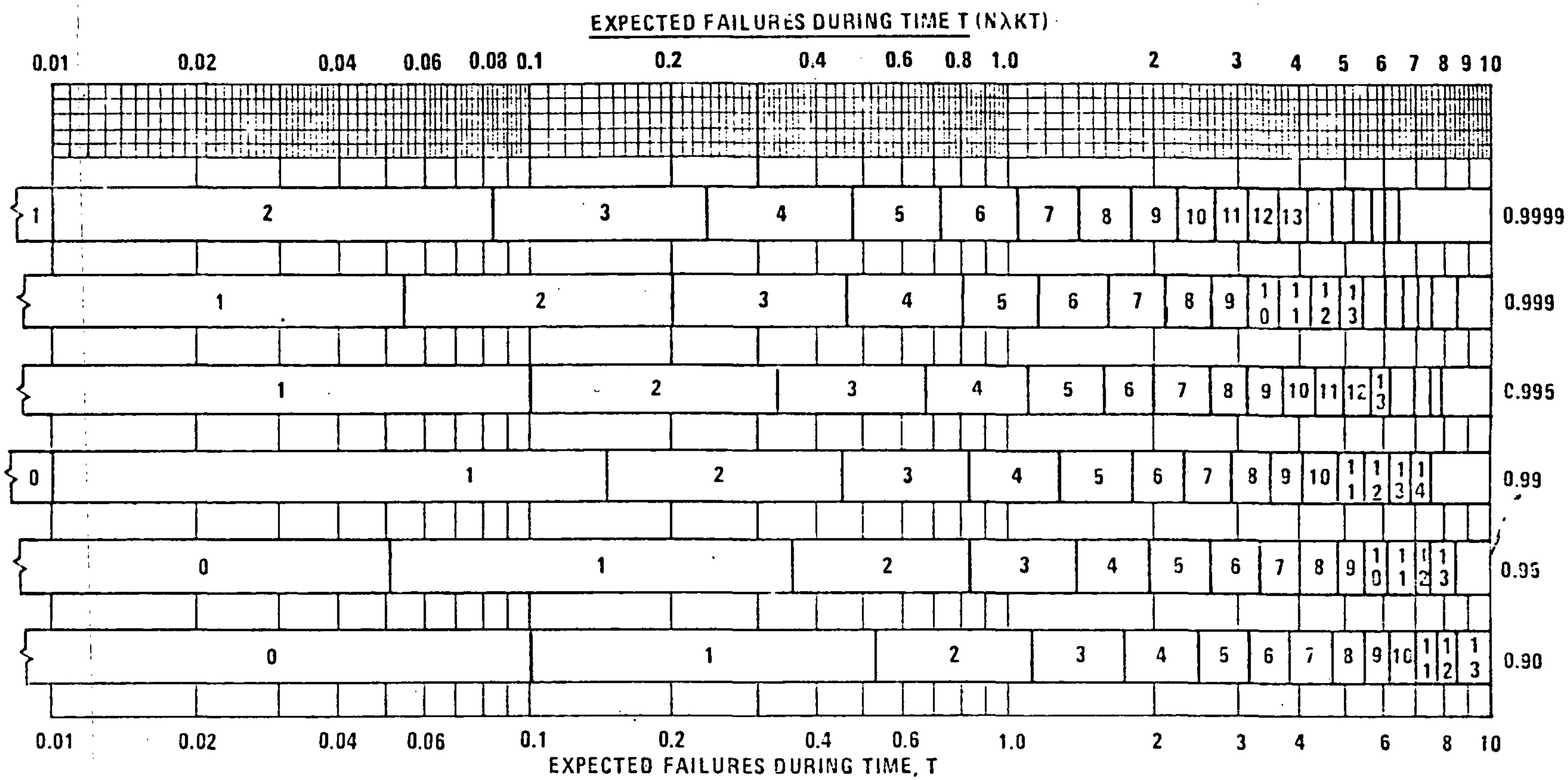
Individual spare quantities are determined by entering at the expected failures value and reading the corresponding number of spares for the desired probability. The reason for selecting a high probability for individual items is to provide a high probability of not running out if all failures occur in the same item. For example, with the expectation of 2.18 failures per mission, there is a 10 percent chance that there will be as many as four failures on any single mission. The probability value at the right side of each column shows the probability that the spares quantity shown will be sufficient to satisfy the worst case.

Table 7-3

REPLACEABLE ITEMS LIST

Item Code*	Name	No. Instal in Lab	Exp. Fail — 30 Days	Spares Level f/Probability Value Shown (0.999)	(0.990)
6.1, 6.11	Fluorescent tubes	16	0.130	2	1
8.6	Signal conditioner module	1	0.432	3	2
8.4	Air velocity sensors	6	0.043	1	1
8.1	Total pressure sensors	6	0.026	1	1
2.6	Temp sensor and controls	6	0.173	2	2
2.17	Humidity sensor and control	6	0.173	2	2
2.23	Differential pressure sensor	6	0.302	3	2
2.1	Circulation blower	6	0.089	2	1
2.4	Fresh air valve actuator	6	0.086	2	1
1.1	Door locks	20	0.037	1	1
2.3	Fresh air valve	6	0.043	1	1
2.7	Bleed air blower	6	0.028	1	1
3.2	Hydrophobic screen	8	0.058	2	1
3.3	Waste mgmt water tank	1	0.007	1	0
3.4	Waste mgmt N_2 pressure regulator	1	0.029	1	1
5.6	Drinking water solenoid valve	4	0.043	1	1
5.5	Monkey drinking tube	4	0.017	1	1
5.12	Lixit dispenser	16	0.069	2	1
	Total expected failures		1.785		
	Total probability of proper spare for worst-case flight			0.982	0.835

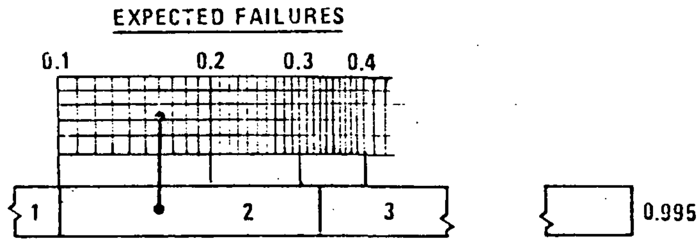
*Item code from Appendix B.



METHOD OF USE

1. DETERMINE EXPECTED NUMBER OF FAILURES (NλKT) FOR COMPONENT

2. READ NUMBER OF SPARES TO PROVIDE DESIRED PROBABILITY



PROBABILITY THAT QUANTITY OF SPARES WILL EQUAL OR EXCEED MAXIMUM SPARES DEMAND

Figure 7-2. Spares Estimating Chart

Section 8
RECOMMENDED SUPPORTING RESEARCH AND DEVELOPMENT

One of the fundamental approaches to the study was to use, whenever possible, available space-qualified or commercially available hardware in the BSHF conceptual designs. A cataloging of potentially applicable space-qualified ECS hardware from such programs as Apollo, Skylab and others, was conducted and is reported in Volume V of this report. Modification or repackaging of existing components was considered as a second alternate to meet designated design purposes. Thirdly, new designs based on existing technologies were considered. Lastly, recommendations are made for supporting research and development effort for components that require additional advancement in technology.

Items recommended for supporting research and development are the following:

	Item	Supporting Research and Development Category
1.	Waste management subsystem with feces/urine/air separation	Advanced technology
2.	Waste management sample collection	Advanced development
3.	Microbial and radioactive contaminants removal from cage exhaust air	Advanced technology
4.	Specimen holding units with closed atmospheres	Advanced development
5.	Holding units for plants and cells and tissues	Advanced development

8.1 SUPPORTING RESEARCH AND DEVELOPMENT CATEGORY DEFINITION

The two categories of supporting research and development identified above are defined as follows.

8.1.1 Advanced Technology

Advanced technology activities are those required to advance the state-of-the-art through the application of science and engineering. This category of activities requires the initiation of analysis and/or testing to advance the state of the art in methods and techniques. These activities should be completed before the start of Phase C, if program risk is to be minimized.

8.1.2 Advanced Development

Advanced development is the activity of developing systems, subsystems, or components which are recognized as having long development times, before Phase D approval of the project in which they will be utilized. Subsystems and/or components listed in this category are those which are felt to require long development lead times. These activities normally start during Phase B but in some selected cases may start some months prior to this time and extend into the design phase (Phase C). The prime reason for performing this type of supporting research and development is to firm up the performance requirement portion of the particular specification associated with the subject hardware.

For the problem areas discussed in this category, the technology is present and the broad feasibility has been shown, but there remains the long-term task of integrating the elements into a workable subsystem and demonstrating operational capability in the space environment.

8.2 SUPPORTING RESEARCH AND DEVELOPMENT ITEMS

A brief description of the supporting research and development items listed above, indicating available technology, and program benefits, is presented in the following.

8.2.1 Waste Management Subsystem with Feces/Urine/Air Separation

This subsystem comprises a novel concept for the separation and collection of both urine and feces from the specimens. Subsystem components include the blower, collector, selector valve, phase separator and storage tanks. This concept will be one of the first to satisfy the research requirement of automatically obtaining separate analytical urine and feces samples from the caged specimens. The main technological problem involved in this item is the zero-gravity phase separation of solids, liquids, and gases. It is particularly important to show the design for operational features necessary to reduce cross-contamination of urine and feces to an acceptable level which will allow collection of acceptable samples of each. The concept developed in this study is promising but it requires analysis, development and testing to provide a working prototype prior to the fabrication of the flight unit. As a long-lead-time item, this waste management item requires immediate initiation of development effort.

8.2.2 Waste Management Sample Collection

The concept considered for sample collection involves the utilization of individual urine and feces collection bags for each of the specimens. In case of the rodent module, this requires the installation of a collection bag on each line emanating from the selector valve. Each bag will be used for one day's collection of urine and flush water. An aliquot will then have to be extracted from the bag and either analyzed or stored in the freezer for later analysis. Fecal samples are also collected daily in special bags constructed as attachments to the vacuum cleaner hose tip. The individual bags, each collected from a separate cage, are then taken to the life sciences laboratory waste processor and storage unit. This is an advanced development item that requires long lead time development effort.

8.2.3 Microbial and Radioactive Contaminants Removal from Cage Exhaust Air

This is an advanced technology item to develop a cage exhaust air filter for microbial and radioactive contaminants. The filter will be required to trap microbial organisms generated within the cage and deliver pathogen-free exhaust air to the cabin. In cases where the air is contaminated with radioactive materials such as when radioisotope tracers are used, the filter will also be required to render the exhaust air harmless to the crew. The utilization of this type of a filter is mandatory for system operation.

8.2.4 Specimen Holding Units with Closed Atmospheres

Holding units utilizing special atmospheres that should not be leaked into the laboratory environment are required for some specific experiments. These units will be self-contained, provided with their own gas supplies and environmental control equipment. Power, data management and heat rejection provisions will be supplied by the Spacelab subsystems through given interfaces. The units will be configured for mounting within the Spacelab racks. No technological problems or advances are anticipated in the development of these units which are considered as advanced development items.

8.2.5 Holding Units for Plants and Cells and Tissues

It is recommended that a long-lead-time effort be started to develop holding units to meet the many requirements of varied species of plants and cells and tissues. The development of these plug-in type units is regarded as a cost effective approach to the BSHF program as it would help concentrate the major effort on the development of holding units for the primary specimens. The plants and cells and tissue holding units are considered as advanced development items.

Section 9
DESCRIPTION OF EXPERIMENT SUPPORT CAPABILITY

The approach used both in the development of experiment requirements and in the definition of holding facility experiment support capability levels was the analysis of experiments described in the literature which used the rat and monkey as experimental animals. The 82 analyzed experiments included those actually flown such as the primate biosatellite flight, those designed and planned for flight such as the Orbiting Primate Experiment, those used as demonstration experiments in the MSFC or the JSC Spacelab Mission Simulations, and, finally, those described in feasibility studies as examples of experiments that could be conducted onboard space vehicles. As part of the analysis, the experiments were categorized by research areas and the major measurements associated with each area identified. Tables 9-1 and 9-2, derived from these analyses, illustrate the capability of the primate and rat holding facilities for supporting procedures and measurements of experiments in each of the following research areas:

A. Cardiovascular/Hemodynamics
B. Musculoskeletal Research
C. Fluid/Electrolyte Balance
D. Hematological Research
E. Neurophysiology
F. Metabolic Studies
G. Behavior and Performance
H. Pulmonary Function and Respiratory Research
I. Endocrine/Reproduction Studies
J. Excretory Research
K. Injury/Tissue Repair

Table 9-1 (Page 1 of 9)

EXPERIMENT SUPPORT CAPABILITIES FOR PRIMATE EXPERIMENTS

Experiment Measurements	Included Research Activities	Holding Facility Support Capabilities
I. Cardiovascular/ Hemodynamics Research		
a. Electrocardiogram (EKG), blood pressure (arterial or venous), blood flow, cardiac output, blood temperature.	a. Recording from implanted sensors and transmitters.	a. Primate cage module equipped with installed antenna and associated receivers for relay of sensor signal to Spacelab DMS.
b. Hardwire electrocardiogram, phonocardiogram.	b. Application of sensors and leads to primate.	b. "Squeeze-cage" mechanism allows access to temporarily restrained primate through front cage bars. Sensors and leads may be attached or primate can be anesthetized for subsequent manipulation.
c. Blood pressure by means of automatic inflatable cuff.	c. Attachment of cuff and associated hardware.	c. Similar to "b" above. Cuff may be attached to temporarily restrained primate or primate may be anesthetized.
d. Lower body negative pressure (LBNP).	d. Installation of primate into LBNP device.	d. No provisions for LBNP device inside of holding unit. Primate must be removed from unit for measurement.
II. Musculoskeletal Research		
a. Mineral (Ca, P, Mg, etc.) balance and protein metabolism.	a. 1. Dietary intake.	a. 1. Food pellet nutrient composition may be established before flight. Number of pellets consumed automatically monitored and recorded.
	a. 2. Acquisition of urine samples for analysis of mineral concentrations.	a. 2. Urine collected and retained in liquid form. Urine volume can be measured and aliquots removed for analysis or preservation.

Table 9-1 (Page 2 of 9)

EXPERIMENT SUPPORT CAPABILITIES FOR PRIMATE EXPERIMENTS

Experiment Measurements	Included Research Activities	Holding Facility Support Capabilities
	a. 3. Acquisition of fecal samples for measurement of mineral content.	a. 3. Feces automatically separated from urine by holding facility waste management system. Feces may be removed daily or more or less frequently for preservation and/or analysis.
	a. 4. Acquisition of blood samples for blood levels of minerals and protein metabolites.	a. 4. It may be possible to acquire blood sample from primate while restrained by squeeze mechanism; otherwise the monkey must be anesthetized and removed for sample acquisition.
b. Exercise tolerance, muscular strength.	b. Use by trained monkey of specially designed exercise devices and dynomometers.	b. No provision included in holding facility for making these measurements. Installation of such devices on an experiment specific basis would prevent operation of cage squeeze mechanism.
c. Bone density Total cell mass	c. Bone densitometry Whole body 40_K count	c. Either procedure requires anesthetization and removal of primate from facility. No provisions are included for these measurements to be made within the facility.
d. Calcium turnover studies	d. Tracer studies with ^{45}Ca, ^{47}Ca, ^{32}P, or 85_{Sr}	d. No restrictions to accommodation of primates containing radioactive isotopes other than ^{14}C and ^{3}H. Tracers should not, however, generally be administered within the holding unit and the same rules and guidelines used in terrestrial labs should be observed.

Table 9-1 (Page 3 of 9)

EXPERIMENT SUPPORT CAPABILITIES FOR PRIMATE EXPERIMENTS

Experiment Measurements	Included Research Activities	Holding Facility Support Capabilities
III. Fluid/Electrolyte Balance		
a. Water balance	a. 1. Water intake measurement	a. 1. Water intake automatically measured at the dispenser and relayed to the Spacelab DMS.
	a. 2. Water output measurement	a. 2. Automatic urine collection; see II. a. 2; and fecal collection; see II. a. 3. No provisions for measurement of evaporative water loss.
b. Fluid compartment shifts (Total body water, plasma volume, extracellular fluid volume, intracellular fluid volume.)	b. Radioisotopic tracer dilution studies including ^{14}C and ^{3}H:	
	b. 1. Isotope administration	b. 1. Isotopes should be administered outside of facility but animal may then be maintained within the facility.
	b. 2. Isotope management	b. 2. Facility design provides for incorporation of scrubber for $^{14}CO_2$ and $^{3}H_2O$, if ^{14}C and ^{3}H are utilized.
	b. 3. Blood sampling	b. 3. Blood samples may possibly be acquired with the primate restrained by the "squeeze" mechanism; however, it is more likely that animal will be anesthetized and removed from facility for blood samples as well as for isotope injections.

Table 9-1 (Page 4 of 9)

EXPERIMENT SUPPORT CAPABILITIES FOR PRIMATE EXPERIMENTS

	Experiment Measurements	Included Research Activities	Holding Facility Support Capabilities
c.	Electrolyte balance — Na^+, K^+, SO_4^-, Cl^-, etc.	c. 1. Electrolyte intake	c. 1. Same as II. a. 1.
		c. 2. Urine electrolytes	c. 2. Same as II. a. 2.
		c. 3. Fecal electrolytes	c. 3. Same as II. a. 3.
		c. 4. Serum electrolytes	c. 4. Same as II. a. 4.
IV.	Hematological Research		
a.	Red blood cell mass, plasma volume, total blood volume	a. 1. Blood sample acquisition	a. 1. Same as II. a. 4.
		a. 2. Isotope administration	a. 2. Same as III. b. 1.
b.	Hematocrit, cell counts, blood sample analysis, blood clotting, etc.	b. 1. Blood sample acquisition	b. 1. Same as II. a. 4.
V.	Neurophysiological Research		
a.	Electroencephalogram (EEG), electro-oculogram (EOG), electromyogram (EMG), nerve potentials, cortical evoked potentials, etc.	a. Recording from implanted sensors and transmitters	a. Same as I. a.
b.	EEG, EOG, EMG (hardwire)	b. Application of sensors and leads	b. Primate restrained with cage "squeeze" mechanism, anesthetized or tranquilized, and removed from cage for experimental procedures
c.	Vestibular stimulation	c. Linear or angular acceleration of primate	c. Same as b above.

Table 9-1 (Page 5 of 9)

EXPERIMENT SUPPORT CAPABILITIES FOR PRIMATE EXPERIMENTS

Experiment Measurements	Included Research Activities	Holding Facility Support Capabilities
VI. Metabolic Research		
a. Body temperature	a. Recording from implanted sensor and transmitter	a. Same as I. a.
b. Body temperature (manual)	b. Attachment or insertion of thermometer, probe, or thermistor	b. Cage "squeeze" mechanism restrains primate against front cage bars. Access to primate potentially available for attachment or insertion of temperature sensor. Anesthetization of primate possible alternative.
c. O_2 consumption, CO_2 production, respiratory exchange ratio	c. 1. Collection and analysis of exhaled gases	c. 1. Holding unit contains no provisions for respiratory gas collection or measurement. Primate must be transferred to experiment specific unit.
	c. 2. Measurement of inlet and exhaust air composition	c. 2. Holding unit inlet and exhaust air automatically monitored for total pressure, P_{O_2}, P_{CO_2}, temperature, and relative humidity.
d. Body heat production	d. Increase in environmental temperature and relative humidity	d. Holding unit does not provide sufficiently accurate measurements of temperature and relative humidity to permit the derivation of body heat production. Such a unit would be experiment specific.
e. Metabolic balance	e. 1. Dietary intake	e. 1. Same as I. a. 1.
	e. 2. Water intake	e. 2. Same as III. a. 1.
	e. 3. Excretion of metabolites or metabolic by-products	e. 3. Same as I. a. 2.

Table 9-1 (Page 6 of 9)

EXPERIMENT SUPPORT CAPABILITIES FOR PRIMATE EXPERIMENTS

Experiment Measurements	Included Research Activities	Holding Facility Support Capabilities
	e. 4. Fecal loss of metabolic substances	e. 4. Same as I. a. 3.
f. Feeding and drinking activity	f. Frequency of eating and drinking, amounts consumed per unit of time, eating and drinking cycles.	f. Each actuation of food pellet and water dispensers by primate is sensed and information about frequency and amount of intake is relayed to DMS.
VII. Behavior and Performance		
a. Activity cycles	a. 1. Movement of primate in holding unit versus time	a. 1. Movements of primate are sensed by four photocells installed within the holding unit. An integrated signal from these will be relayed to the Spacelab DMS which will relate activity to time.
	a. 2. Feeding and drinking activity	a. 2. Same as VI. f.
b. Appearance	b. 1. Visual, photographic, or video observation	b. 1. Primate may be viewed or photographed through view window in front of cage. No provisions are made for camera installation within holding unit.
	b. 2. Detailed inspection	b. 2. Close inspection may be made of primate restrained by cage "squeeze" mechanism.
c. Sleep/wake cycles	c. 1. Cessation of movement within cage	c. 1. Same as VII. a. 1. above.
	c. 2. Visual observation or photographic recording	c. 2. Same as VII. b. 1. above.
	c. 2. Electroencephalographic correlates of sleep	c. 3. Same as V. a.

Table 9-1 (Page 7 of 9)

EXPERIMENT SUPPORT CAPABILITIES FOR PRIMATE EXPERIMENTS

Experiment Measurements	Included Research Activities	Holding Facility Support Capabilities
d. Circadian rythms/ photoperiodicities	d. 1. Visual, photographic, or video recording	d. 1. Same as VII. b. 1.
	d. 2. Activity cycles	d. 2. Same as VII. a. 1.
	d. 3. Body temperature variations	d. 3. Same as VI. a.
	d. 4. Variations in light intensity and light/ dark cycles	d. 4. Illumination in primate holding unit controllable both in intensity and cycle length and frequency.
e. Performance and behavioral tasks	e. 1. Visual observation or photographic or video recording of behavior	e. 1. Same as VII. b. 1.
	e. 2. Conditioned response tasks	e. 2. Primate holding unit "squeeze" mechanism would not be compatible with the installation of a performance test console. The "squeeze" mechanism is currently necessary for the anesthetization of the primate for removal from cage.
VIII. Pulmonary Function and Respiratory Research		
a. Respiratory rate	a. Recording from implanted sensors for EKG or impedance pneumograph	a. Same as I. a.
b. Respiratory minute volume	b. 1. Collection of expired volume	b. 1. No provision for collection within unit.

Table 9-1 (Page 8 of 9)

EXPERIMENT SUPPORT CAPABILITIES FOR PRIMATE EXPERIMENTS

Experiment Measurements	Included Research Activities	Holding Facility Support Capabilities
	b. 2. Derived from impedance pneumograph	b. 2. Same as VIII. a.
c. Pulmonary function tests	c. Spirometry	c. Holding unit provides no capability for testing pulmonary function.
d. Pulmonary tolerance	d. 1. Exposure to lung irritants	d. 1. If irratant is also toxic to man, holding unit has no provision for closed ECS to prevent irritant from entering Spacelab atmosphere.
	d. 2. Exposure to disease organisms	d. 2. Holding unit not designed for use with disease organisms.
e. Chemoreceptor sensitivity	e. Exposure to low P_{O_2} or high P_{CO_2}	e. Holding unit design does not provide for supply of atmospheres with compositions other than standard (Spacelab)
IX. Endocrine/Reproduction Research		
a. Hormone levels in blood and urine	a. 1. Blood sample acquisition	a. 1. Same as II. a. 4.
	a. 2. Urine sample acquisition	a. 2. Same as II. a. 2.
b. Sperm viability	b. Sperm sample acquisition	b. Sample acquisition requires removal of primate from holding unit (see V. b.).
c. Genetic changes — sperm and ovum	c. Biopsy or autopsy	c. Requires removal of primate from facility.
d. Hormone/organ relationships	d. Biopsy or autopsy	d. Same as c above.

Table 9-1 (Page 9 of 9)

EXPERIMENT SUPPORT CAPABILITIES FOR PRIMATE EXPERIMENTS

Experiment Measurements	Included Research Activities	Holding Facility Support Capabilities
X. Excretory Research		
a. Renal function tests	a. 1. Injection of test substances	a. 1. Same as II. a. 4.
	a. 2. Blood sample acquisition	a. 2. Same as II. a. 4.
	a. 3. Urine sample acquisition	a. 3. Same as II. a. 2.
b. Urine analysis	b. Urine sample acquisition	b. Same as II. a. 2.
c. Renal response to water/salt loads and to dehydration	c. 1. Introduction of water/salt into primate	c. 1. This implies a forced (non-voluntary) introduction of fluids into primate; no provisions for this are included in holding facility design.
	c. 2. Water deprivation	c. 2. Supply to water dispenser can be interrupted.
	c. 3. Urine collection and sampling	c. 3. Same as II. a. 2.
XI. Injury/Tissue Repair		
a. Bone fracture and skin lesion healing	a. 1. Injury production	a. 1. Requires removal of primate from facility.
	a. 2. Primate observation inspection	a. 2. Same as VII. b
b. Radiation tolerance and radiation injury healing	b. Specimen radiation	b. No capability for incorporation of a radiation source is included in holding unit design.

Table 9-2 (Page 1 of 8)

EXPERIMENT SUPPORT CAPABILITIES FOR RAT EXPERIMENTS

Experiment Measurements	Included Research Activities	Holding Facility Support Capabilities
I. Cardiovascular/ Hemodynamic Research		
a. Electrocardiogram (EKG)	a. Recording from implanted sensor and transmitter	a. Rat holding unit equipped with installed antenna and associated receiver for relay of EKG signals to Spacelab DMS.
b. Other telemetered signals	b. Same as a.	b. Holding unit can receive and relay other signals with characteristics similar to EKG without modification. Some adaptation of the receiver may be required for those with dissimilar characteristics.
c. All other cardiovascular measurements	c. Various activities	c. Removal of rat from holding unit is required for the conduct of all other cardiovascular measurements.
II. Musculoskeletal Research		
a. Mineral balance and protein metabolism	a. 1. Dietary intake	a. 1. Nutrient composition of rat diet may be established before flight. Amount of diet consumed may be manually measured at selected time intervals.
	a. 2. Urine volume measurement and sample acquisition	a. 2 Liquid urine collected as a pool of urine from all rats in holding unit. No provisions for obtain liquid urine sample from individual rats.
	a. 3. Urine chemical analysis	a. 3. Analysis may be performed on pooled urine or absorbent pads may be installed in each cage as alternative collection method; urine volume cannot be measured by this method but chemicals in pad may be analyzed.

Table 9-2 (Page 2 of 8)

EXPERIMENT SUPPORT CAPABILITIES FOR RAT EXPERIMENTS

Experiment Measurements	Included Research Activities	Holding Facility Support Capabilities
	a. 4. Fecal sample acquisition	a. 4. Rat facility design provides for the collection of feces, unmixed with urine, from each individual cage module at selected time intervals.
	a. 5. Blood analyses — blood sample acquisition	a. 5. Removal of the rat from the holding unit is required for blood sampling.
b. Bone metabolism and calcium turnover studies	b. 1. Administration of radioactive tracers (^{45}Ca, ^{47}Ca, ^{32}P, ^{85}Sr)	b. 1. Rat should be removed from holding unit for the administration of radioactive tracers.
	b. 2. Maintenance of radioactive animal	b. 2. With the observance of terrestrial guidelines for the maintenance of radioactive specimens, the design of the rat holding unit is compatible with their maintenance.
	b. 3. Acquisition of blood samples	b. 3. Same as II. a. 5.
	b. 4. Acquisition of urine samples	b. 4. Same as II. a. 3.
	b. 5. Acquisition of fecal samples	b. 5. Same as II. a. 4.
c. All other musculo-skeletal measurements (e.g., exercise tolerance, lean body mass, bone density)	c. Various required activities	c. Removal of the rat from the holding unit is required for all other muscloskeletal measurements.

Table 9-2 (Page 3 of 8)

EXPERIMENT SUPPORT CAPABILITIES FOR RAT EXPERIMENTS

Experiment Measurements	Included Research Activities	Holding Facility Support Capabilities
III. Fluid/Electrolyte Balance		
a. Water balance	a. 1. Water intake measurement	a. 1. Water consumption per individual cage module may be measured at selected time intervals by measuring amounts remaining in the individual supply reservoirs.
	a. 2. Urine output	a. 2. Same as II. a. 2.
	a. 3. Fecal water loss	a. 3. Same as II. a. 4.
	a. 4. Evaporative water loss	a. 4. Holding unit includes no provisions for measurement of evaporative water loss.
b. Fluid compartment shifts (Total body water, plasma volume, extracellular fluid volume, intra-cellular fluid volume)	b. Radioisotropic tracer dilution studies	
	b. 1. Isotope administration	b. 1. Same as II. b. 1.
	b. 2. Maintenance of animal with radioactive ^{14}C or ^{3}H	b. 2. Facility design provides for incorporation of scrubbers for removal of $^{14}CO_2$ and $^{3}H_2O$.
	b. 3. Maintenance of animals with other radioactive tags	b. 3. Same as II. b. 2.
	b. 4. Acquisition of blood samples	b. 4. Same as II. a. 5.
	b. 5. Acquisition of urine samples	b. 5. Same as II. a. 2.
c. Electrolyte balance (Na^+, K^+, SO_4^-, Cl^-, etc.)	c. Electrolyte intake, urine sampling, fecal sampling, blood sampling.	c. Same as II. a. 1, II. a. 2, II. a. 4, II. a. 5, respectively

Table 9-2 (Page 4 of 8)

EXPERIMENT SUPPORT CAPABILITIES FOR RAT EXPERIMENTS

	Experiment Measurements		Included Research Activities		Holding Facility Support Capabilities
IV.	Hematological Research				
a.	All measurements	a.	Isotope administration and blood sampling	a.	Removal of rat from holding facility is required for all hematological research activities.
V.	Neurophysiological Research				
a.	All measurements (telemetered signals, hardwire measurements, stimulations and stresses)	a. 1.	Telemetry recording	a. 1.	Same as I. b.
		a. 2.	Application of sensors, stimulation procedures, etc.	a. 2.	Removal of rat from holding facility is required for the conduct of all other activities foreseen for neurophysiological research activities.
VI.	Metabolic Research				
a.	Body temperature	a.	Recording from implanted sensor and transmitter	a.	Same as I. a.
b.	Body temperature (manual)	b.	Attachment or insertion of thermometer, probe, or thermistor	b.	Removal of rat from holding unit is required for the conduct of these research activities.
c.	O_2 consumption, CO_2 production, respiratory exchange ratio	c. 1.	Collection and analysis of exhaled gases	c. 1.	Holding unit contains no provisions for respiratory gas collection or measurement. Rat must be transferred to experiment specific unit.
		c. 2.	Measurement of inlet and exhaust air	c. 2.	Inlet and exhaust air automatically monitored for total pressure, P_{O_2}, P_{CO_2}, temperature and relative humidity.

Table 9-2 (Page 5 of 8)

EXPERIMENT SUPPORT CAPABILITIES FOR RAT EXPERIMENTS

Experiment Measurements	Included Research Activities	Holding Facility Support Capabilities
d. Body heat production	d. Increase in environmental temperature and relative humidity.	d. Holding unit does not provide sufficiently accurate measurements of temperature and relative humidity to permit the derivation of body heat production.
e. Metabolic balance	e. Dietary intake, water intake, urine sampling, fecal sampling	e. Same as II. a. 1, III. a. 1, II. a. 2, and II. a. 4, respectively
f. Feeding and drinking activity	f. Frequency of eating and drinking, consumption rates, eating and drinking cycles.	f. Holding unit contains no provisions for these measurements other than specimen observation and photography.
VII. Behavior and Performance		
a. Activity cycles	a. 1. Movement of rat within holding unit versus time	a. 1. Movements of rats are sensed by photocells, one installed in each cage module. Signals are relayed to the Spacelab DMS.
	a. 2. Feeding and drinking activity	a. 2. Same as VI. f.
b. Appearance	b. 1. Visual observation, photographic or video recording	b. 1. Each rat may be viewed or photographed through view window in front of cage. No provisions are included for camera installation within holding unit.
	b. 2. Detailed inspection	b. 2. Removal of rat from holding unit is required to conduct a detailed inspection.
c. Sleep/wake cycles	c. 1. Cessation of activity	c. 1. Same as VII. a.
	c. 2. Visual or photographic monitoring.	c. 2. Same as VII. b.

Table 9-2 (Page 6 of 8)

EXPERIMENT SUPPORT CAPABILITIES FOR RAT EXPERIMENTS

Experiment Measurements		Included Research Activities	Holding Facility Support Capabilities
		c. 3. Electrophysiological correlates of sleep	c. 3. Rat holding unit contains insufficient electrophysiological monitoring capability for sleep measurements.
d.	Circadian rhythms/ photoperiodicities	d. 1. Visual, photographic, or video monitoring	d. 1. Same as VII. b.
		d. 2. Activity cycles	d. 2. Same as VII. a.
		d. 3. Body temperature variations	d. 3. Same as VI. a.
		d. 4. Variations in light intensity and light/ dark cycles	d. 4. Illumination in rat holding unit controllable both in intensity and cycle length and frequency, separately for pairs of cage modules.
e.	Performance and behavior tasks	e. 1. Visual, photographic, or video monitoring of behavior	e. 1. Same as VII. b.
		e. 2. Conditioned response tasks	e. 2. The rat holding unit could potentially be modified for the accommodation of some forms of rat performance test consoles.
VIII.	Pulmonary Function and Respiratory Research		
a.	Respiratory rate volume	a. Recording from implanted sensors for EKG or impedance pneumograph	a. Same as I. a.
b.	Respiratory minute	b. 1. Collection of expired volume	b. 1. No provisions for collection within unit

Table 9-2. (Page 7 of 8)

EXPERIMENT SUPPORT CAPABILITIES FOR RAT EXPERIMENT

	Experiment Measurements		Included Research Activities		Holding Facility Support Capabilities
		b. 2.	Derived from impedance pneumogram	b. 2.	Same as VIII. a.
c.	Pulmonary function tests	c.	Spirometry	c.	No capability provided in holding unit.
d.	Pulmonary tolerance and chemoreceptor sensitivity	d.	Exposure to respiratory irritants, infectious agents, or non-standard atmospheres	d.	No capability for use of such gases or agents within holding unit.
IX.	Endocrine/Reproduction Research				
a.	Hormone levels, sperm viability, genetic changes in gametocytes, hormone/organ relationships	a.	Blood samples, sperm samples, biopsy, autopsy, etc.	a.	Removal of rat from holding unit required for the conduct of all activities.
X.	Excretory Research				
a.	Renal function tests	a.	Injection of test substances, blood samples, individual urine samples	a.	No capability within holding unit for any of the research activities. Rat removal required.
b.	Urine analysis	b.	Urine sample acquisition	b.	Same as II. a. 2.
c.	Renal stress responses	c.	Various activities	c.	Removal of rat required for most measurements in this research area.

Table 9-2. (Page 8 of 8)

EXPERIMENT SUPPORT CAPABILITIES FOR RAT EXPERIMENTS

Experiment Measurements	Included Research Activities	Holding Facility Support Capabilities
XI. Injury/Tissue Repair		
a. Fracture, radiation, skin lesions	a. Injury production, specimen radiation	a. Requires removal of rat.
	b. Observation and inspection	b. Same as VII. b.

Appendix A
LOADING AND OFF-LOADING OF SPECIMENS

Three methods of loading and off-loading of specimens have been evaluated. In the first two methods the specimens are loaded into the Spacelab through the scientific airlock hatch and off-loaded either through the tunnel or through the airlock hatch. In the third method the specimens are ferried onboard the Orbiter, transferred to the Spacelab when orbit is attained and then returned to the Orbiter at the end of the mission for return to earth. Given below is a description of each of the three methods evaluated, including system modifications and equipment cost estimates. Preferred concept selection and rationale are also included.

CONCEPT 1
HATCH LOADING/TUNNEL OFF-LOADING

OPERATIONAL DESCRIPTION

In this concept the specimens are loaded through the scientific airlock while the Spacelab is in the vertical position on the launch pad. Loading will be during a 3.5-hour hold initiated at T-3.5 in the KSC launch pad allocation. Off-loading of the specimens is accomplished through the transfer tunnel. Off-loading will occur during a 4-hour hold initiated at landing +3 hours in the KSC turnaround allocation. The loading and off-loading of the specimens in this concept will be accomplished in ground transfer cages which have the overall dimensions of 12 by 18 by 36 in. The primates will be placed on a couch and restrained while in the cage. The cages will be provided with air from a portable air conditioning unit. The primate will be supplied with a bottle of water but will not be given any food during transfer. Specimen monitoring while in the cage will be limited to visual observation.

1. Loading: In this concept, entry is accomplished through the scientific airlock with the Orbiter/Spacelab vertical on the pad, as shown in Figure A-1. An access platform is used in the Payload Changeout Room (PCR) for loading

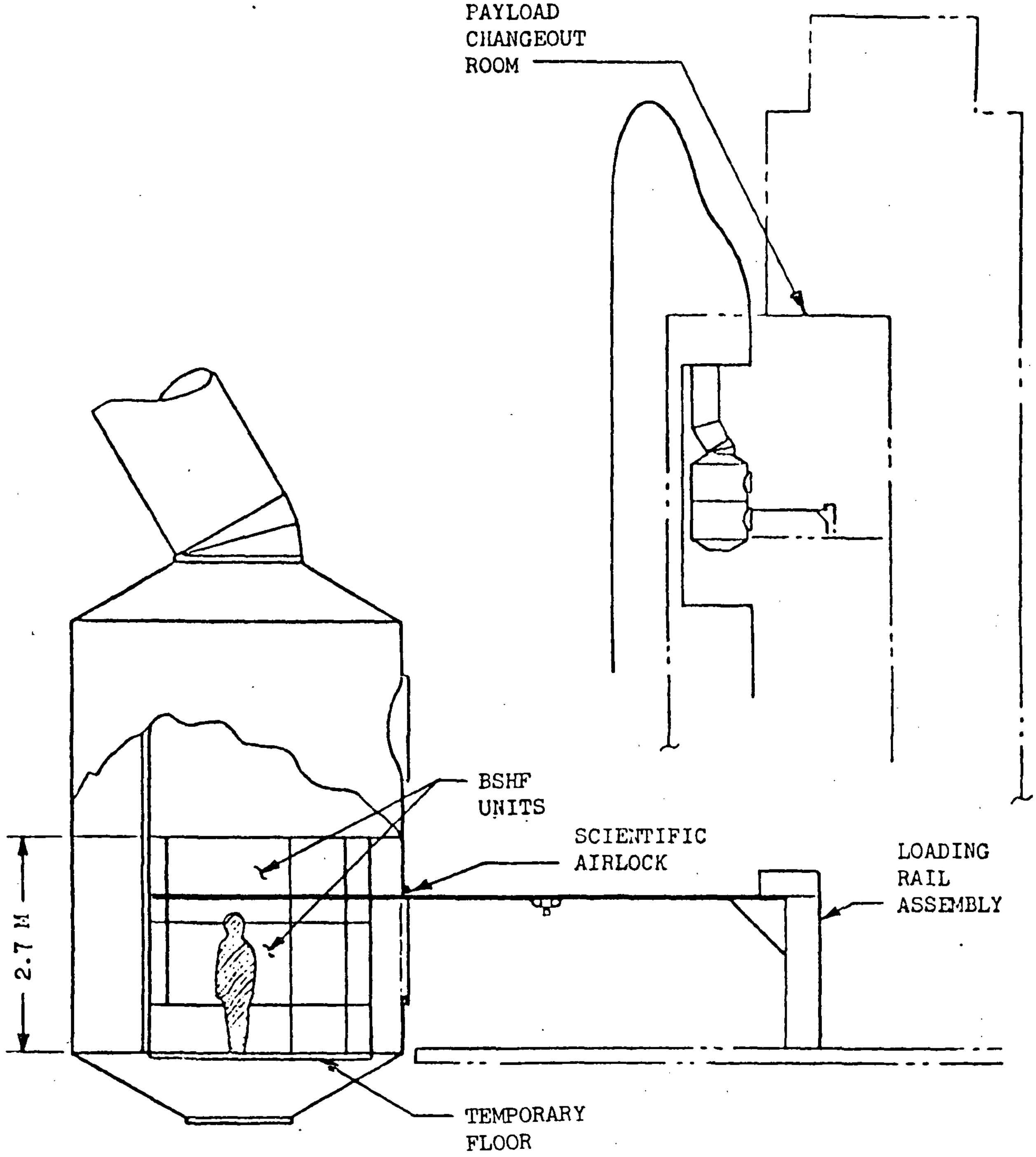


Figure A-1. Specimen Loading Configuration the specimen transfer cages into the Spacelab. The transfer cages are loaded on a loading ramp (or via a monorail) that projects through the airlock hatch and into the Spacelab. Once inside, the transfer cage is handled by two men standing on a temporary floor. The primate is tranquilized and transferred from the transfer cage into the flight cage. The transfer cage is then disconnected and removed from the Spacelab. The maximum duration for the specimens in the transfer cages will be 4 hours.

2. Off-Loading: The specimens are off-loaded in the OPF via the tunnel using transfer cages and tunnel cart with adapter. The specimens are tranquilized and transferred from the flight cages into the transfer cages which are then transported through the tunnel via a monorail type fixture. The tunnel design should allow one-g operations. Two men will be required to handle each transfer cage through the tunnel. The cages will be tethered during the tunnel transfer so as to preclude any inadvertent damage to the tunnel structure. Spacelab/tunnel off-loading configuration is shown in Figure A-2.

CR40-11

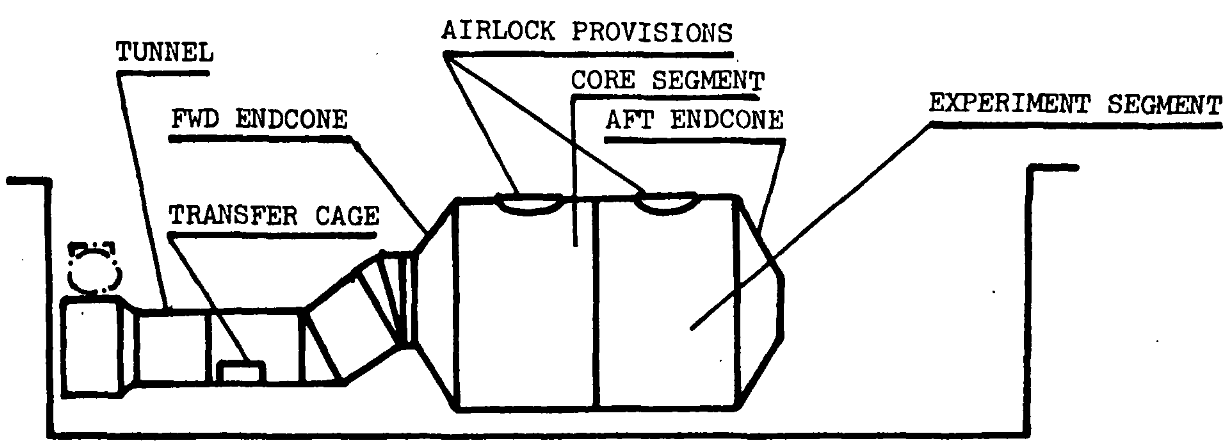


Figure A-2. Spacelab/Tunnel Off-Loading Configuration

SYSTEMS MODIFICATIONS

Modifications to the Spacelab and ground support systems will be required as follows:

1. The scientific airlock hatch has to be modified for quick release.
2. An artificial floor will be installed in the Spacelab as shown in Figure A-1 so as to enable the ground crew to load the specimen while the Spacelab is in the vertical position.
3. Power, data management and cooling provisions will be provided from TBD minutes before loading specimens and continuously through the mission and up to 7 hours postlanding.
4. The tunnel should be designed for one-g operations. Structural modifications or other support equipment may be required for this purpose.
5. Safety waivers will be required for experimenter to access Spacelab during tow and initial OPF operations.

EQUIPMENT COST

Cost estimates were made for the support equipment and system modifications required for this concept. The equipment considered were (1) transfer cages and supporting ECS; (2) loading rail; and (3) protective cover for edges of scientific airlock. It was assumed that the vertical access kit for the Spacelab in the vertical position and tunnel access kit for the horizontal position, including a tunnel cart adapter, are provided as GFE. No operations cost was included in this analysis. The breakdown for equipment cost estimated for this concept is given as follows:

Engineering	$ 96,900
Manufacturing	66,800
Materials	3,600
Software	1,900
TOTAL	$169,200

CONCEPT 2
HATCH LOADING AND OFF-LOADING

OPERATIONAL DESCRIPTION

Both loading and off-loading of the specimens in this concept are accomplished through the scientific airlock hatch. Loading is with the vehicle in the vertical position and off-loading in the horizontal position. As in Concept 1, loading will be during a 3.5-hour hold initiated at T-3.5 in the KSC launch pad operation. Off-loading will be performed at landing plus 13 to 16 hours without impacting KSC turnaround allocation. The loading and off-loading of the specimens in this concept are accomplished utilizing the same transfer cages described in Concept 1.

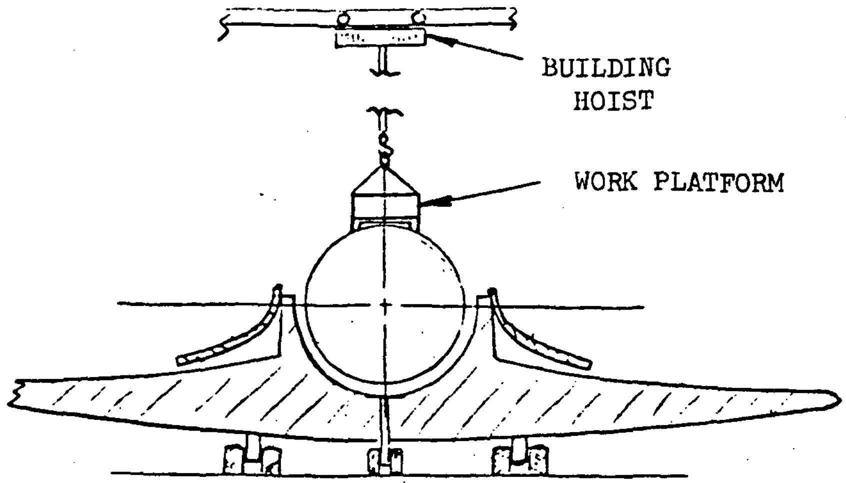
1. Loading: This concept utilizes the same procedure followed in Concept 1 for loading the specimen in the Spacelab while it is in the vertical position on the launch pad.

2. Off-Loading: The specimens are off-loaded in the OPF via the scientific airlock hatch utilizing a work platform, sling and an access ladder, as shown in Figure A-3. Off-loading is initiated after the Orbiter is parked and the cargo bay door opened. An overhead hoist/crane is used to lower the work platform to rest on the Spacelab. The protective cover will be in place around the edges of the scientific airlock. The scientific airlock hatch will then be opened and the access ladder lowered, placed on Spacelab floor and attached to work platform. The transfer cages will be lowered in the Spacelab by means of the hoist sling. The specimens will be tranquilized, removed from the flight cages and put into the transfer cages. The transfer cages are subsequently hoisted through the scientific airlock, lowered to the ground and loaded into the transport van.

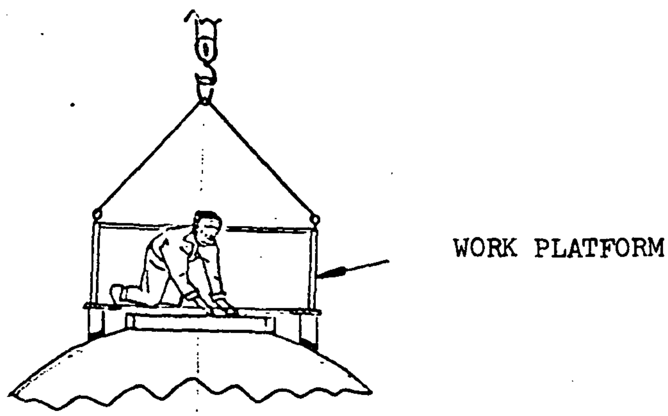
SYSTEM MODIFICATIONS

The following modifications to the Spacelab and ground support subsystems will be required.

1. The scientific airlock hatch has to be modified for quick release.
2. Power, data management and cooling provisions will be provided from TBD minutes prior to loading the specimens and continuously up to 16 hours after landing.
3. The tunnel should be designed for 1-g operations without GSE to permit experimenter access to the Spacelab at landing plus 30 minutes.
4. Safety waivers are required for experimental access to Spacelab during tow and initial OPF operations.

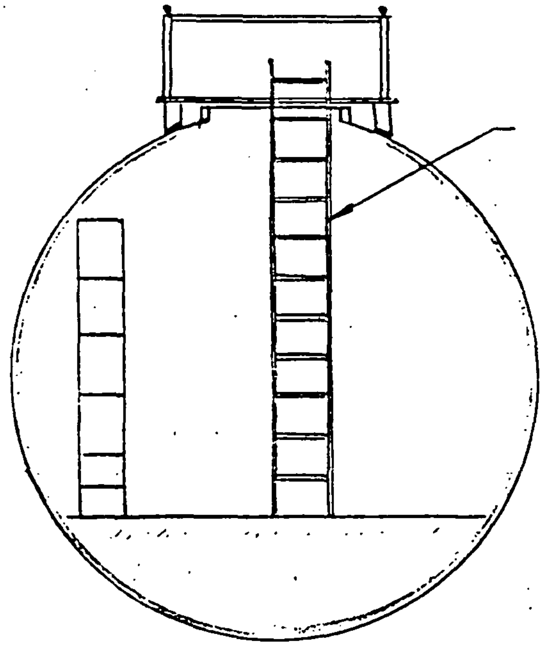


STEP 1 - LOWER WORK PLATFORM ONTO SCIENTIFIC AIRLOCK

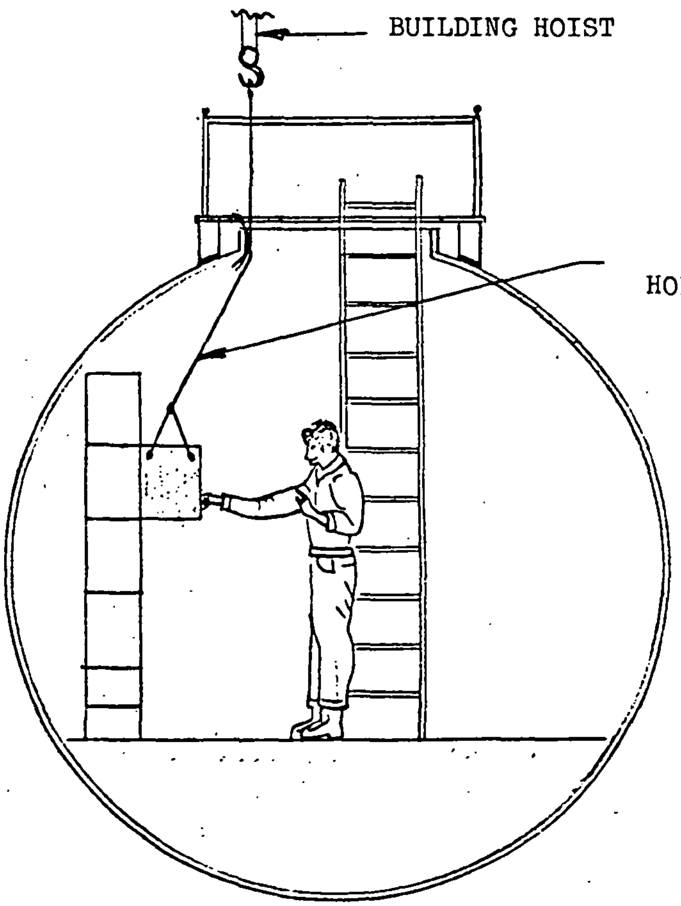


STEP 2 - UNBOLT SCIENTIFIC AIRLOCK COVER

Figure A-3. Concept 2 — Specimen Removal from Spacelab Scientific Airlock



STEP 3 - INSTALL ACCESS LADDER



STEP 4 - LOWER TRANSFER CAGE AND MATE TO FLIGHT CAGE FOR ANIMAL TRANSFER

Figure A-3. Concept 2 – Specimen Removal from Spacelab Scientific Airlock (Cont.)

EQUIPMENT COST

The cost estimates for this concept include all the items specified in Concept 1 for loading through the airlock hatch. In addition, a work platform, a hoist sling and an access ladder are included. The crane and carts to hold the cages are assumed to be provided as GFE. The equipment cost breakdown is as follows:

Engineering		$115,900
Manufacturing		80,000
Materials		4,300
Software		2,300
	TOTAL	$202,500

CONCEPT 3
ORBITER LOADING AND OFF-LOADING

1. Loading: In this concept, specimens are loaded into flight-qualified transfer units at the ground laboratory facility, transported to the launch pad and positioned in the payload changeout room for loading into the Orbiter for launch. Specimen loading is accomplished during a 3.0-hour hold initiated at T-3.5 hours in the KSC launch pad allocation. The transfer/flight units are loaded through the main ingress/egress hatch via a loading ramp or monorail and placed on lifting fixtures located on the GSE access platform (artificial floor). Reference Figure A-4. The fixture and transfer/flight unit (cage) are elevated by use of the hand crank and positioned into the storage rack on the forward bulkhead and locked into place by using tethered ball-lock type pins. The transfer/flight units house the specimens during launch and ascent providing ECS, food and water, but not electromechanical waste management. It is planned that the primates be diapered for waste control.

2. On-Orbit Transfer: On-orbit transfer occurs twice, upon attaining orbit and prior to reentry. Upon reaching orbit, the transfer/flight units (cages) are removed from the storage rack, the primates tranquilized, and the cages moved into the Spacelab via the tunnel using a monorail device similar to that described in Concept 1. Specimens are transferred into the Spacelab BSHF and the transfer cages returned to the Orbiter for storage during mission

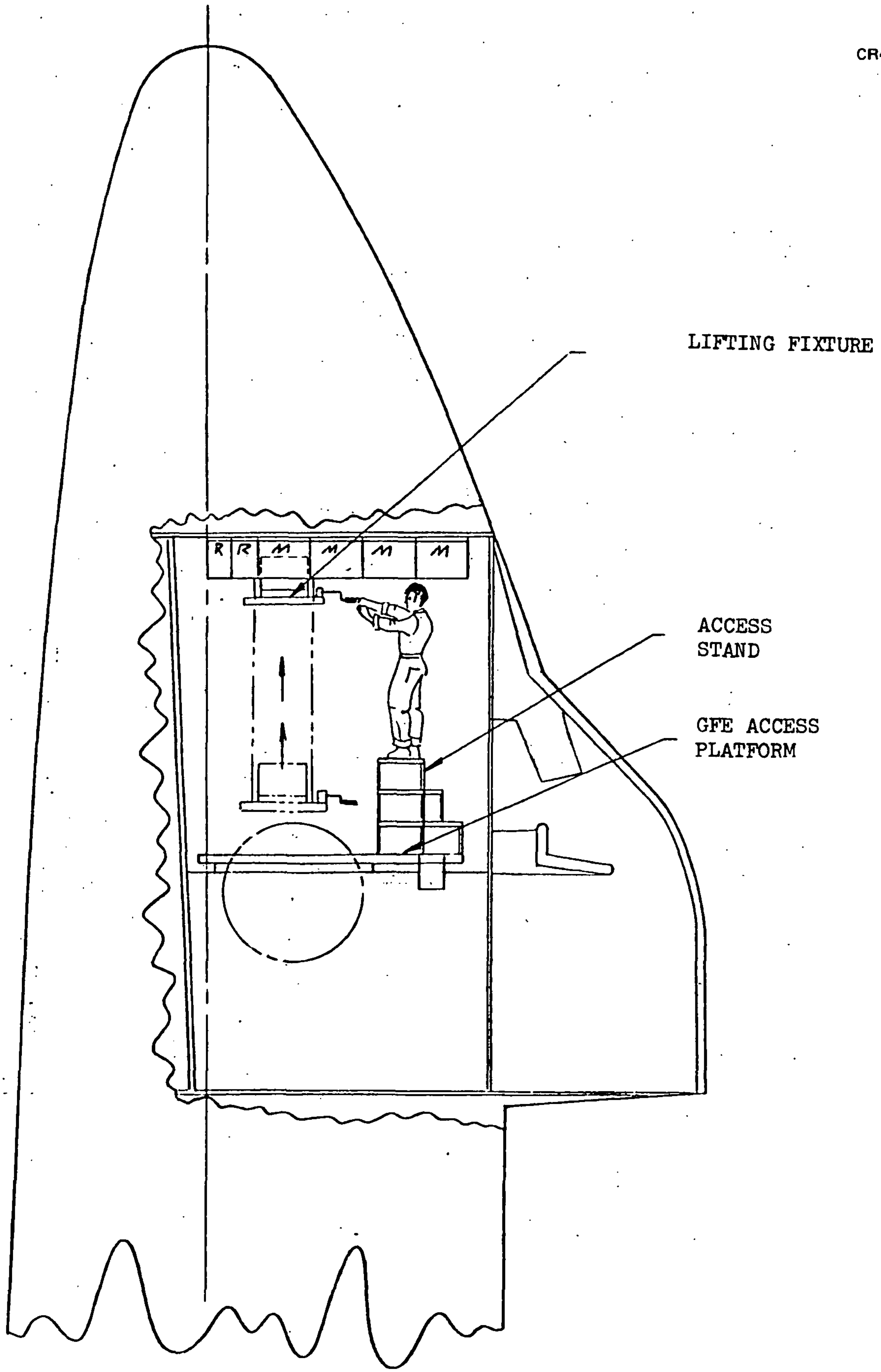


Figure A-4. Concept 3 – Specimen Loading operations. Prior to reentry, this process is reversed with the specimens returned to the Orbiter for storage in the rack during reentry and landing.

3. Off-Loading: Specimens will be off-loaded during a 1.0 hour hold in the KSC turnaround allocation initiated at landing plus 1.0 hours. Transfer/flight cage units will be off-loaded through the main ingress/egress hatch via a loading ramp or monorail and returned to the ground holding laboratory by means of the mobile van.

SYSTEM MODIFICATIONS

Modifications to the Orbiter and ground support systems will be required as follows:

1. It is assumed that the forward wall of the Orbiter mid-deck will not need modification to support transfer/flight units during launch and landing. (Approximately 440 lbs occupying 33.8 ft^3.)
2. Concept required GSE access platform (temporary floor) with related Orbiter interface attachments.
3. A loading ramp for vertical loading and horizontal off-loading operations is required and design must consider interface with Orbiter main ingress/egress hatch.
4. Concept requires flight-qualified transfer units which install into rack mounted onto the forward bulkhead (mid-deck). These units must provide ECS for up to 16 hours with minimal instrumentation, no electromechanical waste management, food and water on an ad libitum basis, and microbial filtration. Cage size is 12 by 18 by 36 in.
5. Safety waiver is required for delay in tow of Orbiter to OPF from landing strip.

EQUIPMENT COSTS

Cost estimates were made for the support equipment and system modifications required for this concept. The equipment considered were: (1) flight-qualified transfer cages (units) and supporting ECS; (2) loading ramp; and (3) transfer/flight unit storage rack.

Cost estimates for this concept are given as follows:

Engineering		$ 207,477
Manufacturing		125,333
Materials		15,697
Software		11,767
EL&S (Qual and Dev Tests)		380,700
Penalty (Orbiter)		
Weight	200 kg	910,000
Volume	0.95 m^3	608,000
Power	0.74 kw	260
Crew Time	12 hrs	25,704
Credit (Battery Pack)		
Weight	113.4 kg	(515,970)
Volume	0.0538 m^3	(34,432)
Power	1 kw hr	(350)
	TOTAL	$1,734,182

CONCEPT SELECTION

Pertinent data from the foregoing concept descriptions are presented in Table A-1 for easy comparison of the trade factors.

Both quantitative and qualitative criteria are pertinent in the concept selection. Based upon the quantitative criteria of cost, the order of preference is Concept 1, 2 and 3. Because the cost of Concept 3 is more than a factor of 8 greater than Concepts 1 or 2, this concept was eliminated from further considerations. From a qualitative standpoint, Concept 1 is preferred over Concept 2. Thus, the specimens may be subjected to earlier detailed examinations in ground-based laboratory to obtain data prior to specimen readaptation to 1-g. Also, of major concern, the requirement for power and cooling for operation of Spacelab systems is decreased by 9 hours.

Concept 1 is selected as the preferred method of operating based upon the above rationale and the assumption that the cost of tunnel modification is not excessive.

Table A-1
CONCEPT TRADE MATRIX

Loading Concept	Comply with LS Access Rqm't	Impact to KSC Turnaround Allocation	Impacts/Constraints on Spacelab and Orbiter	Cost	Remarks
1. Load after hypergolic service through scientific airlock hatch via transfer cages into flight BSHF in Spacelab. Offload specimens in OPF via tunnel using transfer cages, tunnel cart with adapter.	Yes	3.5 hr-load 3.0 hr-off-load	Loading 1. Scientific airlock hatch cover modification for quick release, re-seal, and seal verification, approximately 15 min. 2. Power and cooling required for ECS and data management systems TBD minutes prior to loading specimens and continuously until specimens off-loaded. 3. BSHF systems must operate for up to 6 hours pre-launch while rotated 90° from normal "up-down" orientation. 4. Ground transfer units required to hold specimens for approximately 4 hours during transport from ground laboratory until loaded into BSHF. Off-Loading 1. Tunnel design for 1-g operations to permit specimen off-loading. 2. Power and cooling required for systems operation until specimen off-load at approximately landing plus 7 hours. 3. Safety waivers required for experimenter access to Spacelab during tow and initial OPF operations.	169.2K	1. 3.5 hour hold in KSC pad allocation at T-3.5 for specimen load. 2. 4.0 hour hold in KSC allocation at landing plus 3.0 hours for specimen off-load.
2. Load – same as Concept 1. Off-load specimens in OPF via scientific airlock hatch using transfer cages, work platform, hoist, sling, and access ladder.	Yes	3.5 hr-load none-off-load	Loading Same as loading for Concept 1. Off-Loading 1. Tunnel design for 1-g operations without GSE to permit experimenter access to Spacelab at landing plus 30 minutes. 2. Power and cooling required for systems operation until specimen off-load at approximately landing plus 16 hours. 3. Safety waivers required for experimenter access to Spacelab during tow and initial OPF operations.	202.5K	1. 3.5 hour hold in KSC pad allocation at T-3.5 for specimen load. 2. Specimen off-load at landing plus 13 hours to 16 hours without impact to KSC allocation.
3. Load after hypergolic service through Orbiter main ingress/egress hatch via flight-qualified transfer units and stow on Orbiter forward bulkhead. Off-Loading Flight-qualified transfer units off-loaded through main ingress/egress hatch.	Yes	3.0 hr-load 1.0 hr-off-load	Loading 1. Requires flight-qualified transfer units which install into rack mounted onto forward bulkhead. Provides ECS for up to 16 hours, minimal instrumentation, and no electro-mechanical waste management. Provides food, water and microbial filtration. 2. Loading GSE required including Orbiter "artificial floor." 3. Forward bulkhead must support approximately 1,000 lbs rack/transfer units which occupy approximately 33.8 ft^3 (0.95M^3). On-Orbit Operations 1. Movement of transfer units through tunnel is safety hazard at beginning and end of on-orbit operations. Off-Loading 1. Safety waiver required for delay in tow of Orbiter to OPF.	1,734.2K	1. 3.0 hour hold in KSC pad allocation at T-3.5 for specimen load. 2. 1.0 hour hold in KSC allocation at landing plus 1.0 hour for specimen off-load.

Appendix B

RELIABILITY AND MAINTAINABILITY DATA WORKSHEETS

WORKSHEET - BSHF

RELIABILITY AND MAINTAINABILITY DATA

MODULE ______

SUBSYSTEM ______ DATE ______ INIT. ______

CODE	ITEM	FAILURE MODE	EFFECT				FAILURE PROB. ANAL.					MAINT. TIME (HRS)		
			S	M	E	D	α	N	λ F/10^6 HRS	TIME HRS.	ε	REP/ MEN	TIME	ALLOW DOWN
1.	Structure - Monkey Cage													
	Door and lock						.5	1	10	720	3600		.3	1.0
	Back panel actuat.						.2	1	15		2160		1.0	2.0
	Tracks support						.05	2	10		360		2.0	24
1.	Structure - Rat Cage													
	Doors and locks						.2	8	10	720	11520		.3	1.0
	Tracks support						.05	2	10	720	360		2.0	24
2.	Environmental Control													
2.1	Blower (circ)		x		x		1.0	1	20.7	720	14904		.5	1.0
2.2	.5μ filter		x		x		1.0	1	.5		360		.25	1.0
2.3	Fresh air valve		x		x		.5	1	20		7200		.3	1.0
2.4	Fresh air actuator		x		x		.5	1	40		14400		.2	1.0
2.5	Screen (clean)				x	x	1.0	2	.5		720		.3	5.0
2.6	Temperature sensor/cont.		x		x		1.0	1	40		28800		.3	1.0
2.7	Bleed air blower		x		x		1.0	1	6.5		4680		.5	1.0
2.8	Odor filter		x		x		1.0	1	.5		360		1.0	1.0

Effect: S - Safety; M - Mission Critical; E - Experiment Loss; D - Degradation; α Portion of Time in Use

Failures (λ and ε) are shown separately for each effect code.

WORKSHEET - BSHF

RELIABILITY AND MAINTAINABILITY DATA

MODULE ____

SUBSYSTEM ____ DATE ____ INIT. ____

CODE	ITEM	FAILURE MODE	EFFECT				FAILURE PROB. ANAL.					MAINT. TIME (HRS)		
			S	M	E	D	α	N	λ F/10^6 HRS	TIME HRS.	ε	REP/MEN	TIME	ALLOW DOWN
3.0	Waste mgmt													
3.1	Tray				x		1.0	1	-	720	-		.3	24
3.2	Hydrophobic screen			x	x		1.0	1	10	720	7200		.3	24
3.3	Water reservoir		x		x		1.0	1*	10		7200		1.5	1.0
3.4	N_2 regulator		x		x		1.0	1*	40		28800		.3	1.0
3.5	H_2O shutoff valve		x		x		.1	1	30		2160		.3	1.0
3.6	H_2O flush manifold		x		x		.05	1	1		36		1.5	3.0
3.7	Rotating valve			x	x		.05	1	100		3800		.5	6.0
3.8	Phase separator			x	x		.05	1	25		900		.5	6.0
3.9	Urine valve			x	x		.05	1	30		1080		.3	6.0
	Total - risk of needing repair				x						.015176 x	4 =	.061	
	Risk - repair to retain monkeys'	health	x								.036000 x .002196 x	1 = 4 =	.036 0.009	
	Risk - repair to prevent loss of	data		x			(1*	per	assembly)		.012980 x	4 =	0.052	
4.0	Feeder - monkey													
4.1	Tube pellet		x					2	replaceable				.1	4.0
4.0	Feeder - rat													
4.1	Paste feeder		x					8	replaceable				.1	4.0

Effect: S - Safety; M - Mission Critical; E - Experiment Loss; D - Degradation; α Portion of Time in Use

Failures (λ and ε) are shown separately for each effect code.

WORKSHEET - BSHF

RELIABILITY AND MAINTAINABILITY DATA

MODULE ______

SUBSYSTEM ______ DATE ______ INIT. ______

CODE	ITEM	FAILURE MODE	EFFECT				FAILURE PROB. ANAL.					MAINT. TIME (HRS)		
			S	M	E	D	α	N	λ F/10^6 HRS	TIME HRS.	ϵ	REP/MEN	TIME	ALLOW DOWN
2.9	Particulate filter		x		x		1.0	1	5	720	3600		1.0	1.0
2.10	Upper wick				x	x	1.0	1	20		14400		1.0	4.0
2.11	Fecal grid				x	x	1.0	1	10		7200		1.5	4.0
2.17	Humidity sensor		x		x		1.0	1	40		28800		.3	1.0
2.18	Humidity & flush cont.		x		x		.2	1	30		4320		.3	1.0
2.19	Check valves		x		x		.2	2	.5		144		1.0	1.0
2.23	Diff. pressure sensor				x	x	1.0	1	70		50400		.3	1.0
	Risk of needing repair				x						.180288/cage		0.721/mission	
	Risk - repair to prevent discomfort					x					.072720	X4 =	0.291	
	Risk - " " " loss of test data			x							0		0	
	Risk - " " retain monkey health		x								.103608		0.414	
	" " cabin contamin										.003960		0.016	
	Risk - Rodents - 1/2 of above													

Effect: S - Safety; M - Mission Critical; E - Experiment Loss; D - Degradation; α Portion of Time in Use

Failures (λ and ϵ) are shown separately for each effect code.

WORKSHEET - BSHF

RELIABILITY AND MAINTAINABILITY DATA

MODULE ____________

SUBSYSTEM ____________ DATE ________ INIT. ________

CODE	ITEM	FAILURE MODE	EFFECT S	EFFECT M	EFFECT E	EFFECT D	FAILURE PROB. ANAL. α	N	λ $F/10^6$ HRS	TIME HRS.	ε	MAINT. TIME (HRS) REP/MEN	TIME	ALLOW DOWN
5.	Waterer - monkey													
5.1	Collapsible tank		x		x		1.0	1*	10	720	7200		1.0	2.0
5.2	Gas pressure source		x		x		1.0	1*	4		2880		1.0	2.0
5.3	Pressure regulator		x		x		1.0	1*	40		28800		.5	2.0
5.4	Fill and drain valve				x	x	.05	1*	30		1080		.3	2.0
5.5	Drinking tube		x		x		.05	4	120		17280		.5	2.0
5.6	Solenoid valve		x		x		.50	4	30		43200		.5	2.0
5.7	Counter				x	x	.05	1*	20		720		.3	2.0
					x						.101160			
			x								.099360			
5.	Waterer - rodents													
5.11	Spring loaded tank		x		x		1.0	1*	10	720	7200		1.0	2.0
5.12	Lixit dispenser		x		x		.05	16	120		69120		.5	2.0
5.13	Recharge valve		x		x		.05	1*	30		1080		.5	2.0
5.14	Flow recorder				x	x	.10	1*	20		1440		.5	2.0
							TOTAL				.078840			
			x								.077400			
									(1* = 1 per assembly per type)					

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WORKSHEET - BSHF

RELIABILITY AND MAINTAINABILITY DATA

MODULE ______

SUBSYSTEM ______ DATE ______ INIT. ______

CODE	ITEM	FAILURE MODE	EFFECT				FAILURE PROB. ANAL.					MAINT. TIME (HRS)		
			S	M	E	D	α	N	λ F/10^6 HRS	TIME HRS.	ε	REP/ MEN	TIME	ALLOW DOWN
6.	Illumination - monkey													
6.1	Fluorescent tubes						1.0	2(R)	30	720	43200		.3	10.0
6.2	Switches						1.0	1	10	30 C	300		.4	10.0
											.043500 x	4 = .	174	
									$(.0432^2$	+ 300) =	.002166	x 4	= .009	
6.	Illumination - rodent													
6.11	Fluorescent tubes						1.0	4	30	720	86400		.3	10.0
6.12	Switches						1.0	4	10	30 C	1200		.4	10.0
											0.087600	0.175		
7.	Power (Spacelab)													1.0
8.	Instrumentation													
8.1	Total pressure sensor				x	x	1.0	1	6	720	4320		.3	1.0
8.2	O_2 partial pressure sensor		x		x		1.0	1	3		2160		.3	1.0
8.3	CO_2 partial pressure sensor		x		x		1.0	1	3		2160		.3	1.0
8.4	Air velocity				x	x	1.0	1	10		7200		.5	1.0
2.6 ref	Air temperature				x	x	1.0	1	ref		-		.3	1.0
2.17 ref	Relative humidity				x	x	1.0	1	ref		-			1.0
8.6	Signal condit				x	x	1.0	5	20		72000		.25	1.0

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