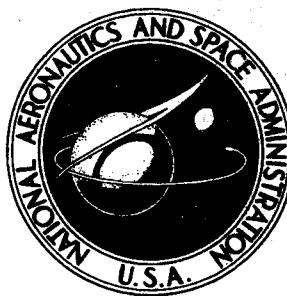


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EXTENDED DURATION, RECOVERABLE PRIMATE SATELLITE

Prepared by

THE JOHNS HOPKINS UNIVERSITY

APPLIED PHYSICS LABORATORY

Silver Spring, Md.

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JANUARY 1968

EXTENDED DURATION, RECOVERABLE PRIMATE SATELLITE

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Prepared under Navy Contract No. R-21-009-014 by
THE JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
Silver Spring, Md.

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TABLE OF CONTENTS

	<u>Page</u>
List of Figures	vi
List of Tables	viii
 1.0 INTRODUCTION	 1
 2.0 TECHNICAL APPROACH	 4
2.1 Critical Problem Areas	8
2.1.1 Gaseous Atmosphere	8
2.1.2 Food and Water	10
2.1.3 Waste Management	10
2.1.4 Physiological Measurements	11
2.1.5 Recovery	11
2.2 Other Considerations	13
2.2.1 Attitude Control	13
2.2.2 Electrical Power	14
2.2.3 Thermal Management	16
2.2.4 Telemetry	16
2.2.5 Ground Support	22
2.2.6 Command	23
2.3 Overall Configuration	25
 3.0 TECHNICAL CONSIDERATIONS OF THE BIOSYSTEM	 29
3.1 Requirements	29
3.1.1 Total Life Cell Pressure	29
3.1.2 Oxygen Partial Pressure	30
3.1.3 Contaminant Removal	30
3.1.4 Air Circulation	33
3.2 Atmosphere Composition and Impurity Control	33
3.2.1 Criteria for System Selection	35
3.2.1.1 Atmosphere Control by O ₂ Sensing	36

TABLE OF CONTENTS (Cont.)

	<u>Page</u>
3.2.1.2 Atmosphere Control by Fixed Overboard Leakage	36
3.2.1.3 Atmosphere Control by Fixed Rate of Gaseous Release From Storage	40
3.2.1.4 Atmosphere Control by Selectively Permeable Membrane	45
3.2.1.5 Atmosphere Control by Chemical Oxygen Release	47
3.2.2 Contaminant Control	49
3.2.2.1 Carbon Dioxide Control by Absorption	51
3.2.2.2 Carbon Dioxide Control Through Selectively Permeable Membrane	52
3.2.3 Humidity Control	52
3.2.3.1 Humidity Control by Absorption	54
3.2.3.2 Humidity Control by Permeable Membrane	55
3.3 Atmospheric Circulation	56
3.3.1 Gas Circulation by Electric Power	58
3.3.2 Gas Circulation by Compressed Gas Power	58
3.3.3 Gas Circulation by Animal Work	58
3.4 Waste Management	60
3.5 Feeding	61
3.5.1 Food Storage Containers	64
3.5.2 Food Dispensers	65
3.5.3 Water System	69
3.5.4 Medication	72
3.6 Work Stations	74
3.6.1 Work and Feeding Schedule	75
3.6.2 Monitoring	76
3.6.3 Mass Measurement Device	76
3.7 Mechanical Configuration	76
 4.0 PHYSIOLOGICAL DATA ACQUISITION AND INSTRUMENTATION	 78
4.1 Physiological Monitoring Components	78
4.1.1 General Considerations	78

TABLE OF CONTENTS (Cont.)

	<u>Page</u>
4.1.1.1 Passive Implanted Components	80
4.1.1.2 Active Implanted Components	82
4.1.1.3 Other Implanted Components	82
4.2 Non-Implanted Instrumentation Components	84
4.2.1 Recording From Work Station Sensors	84
4.2.2 Other Techniques	85
4.2.3 Respiration Rate Instrumentation	85
4.2.4 Body Temperature Measurement	86
4.3 Mass Measurement	86
4.4 Related Data Instrumentation	87
4.1.1 Systems Design	89
4.2.2 Systems Using Implanted Components	91
4.4.2.1 Passive Component System	91
4.4.2.2 Active Component System	94
4.4.3 Systems Using Non-Implanted Components	94
4.5 Work Panel Instrumentation	97
4.6 Television	99
5.0 APPENDIX A: Emergency Call Down	100
5.1 Stabilization and Orientation	101
5.1.1 Ground Controlled Magnetic Stabilization and Orientation	101
5.1.2 Three-Axis Gravity Gradient Stabilization	106
5.1.3 Gyroscopic and Gravity Gradient Stabilization	110
5.2 Retrofire Parameters	111
5.2.1 Re-entry Protection	113
5.2.2 Retardation	113
5.2.3 Recovery	120
5.3 Life Support During Re-entry and Recovery	120
5.3.1 Atmosphere Supply	120
5.3.2 Sealing Food and Water Lines to Life Cell	124
5.3.3 Physical Support of Primate	124
6.0 APPENDIX B: Evaluation of Thin Films	126
6.1 Experimental Procedure	126
6.2 Results	127

LIST OF FIGURES

	<u>Page</u>
FIGURE 2-1 Feasible Primate Experiment Locations in Apollo	6
FIGURE 2-2 Telemetry System	18
FIGURE 2-3 Digital Data (Telldatales)	20
FIGURE 2-4 Typical Telemetry Frame	21
FIGURE 2-5 Command System	24
FIGURE 2-6 Pallet Passenger	26
FIGURE 2-7 LEM Substitute	27
FIGURE 2-8 LEM Companion	28
FIGURE 3-1 Volume Percent Oxygen in Atmosphere	31
FIGURE 3-2 Volume Percent CO ₂ in Atmosphere	31
FIGURE 3-3 Variation in Life Cell Oxygen Concentration With Variation in Animal Metabolic Use Rate, Fixed Leak Rate 0.28 Pounds/Day	39
FIGURE 3-4 Variation in Life Cell Oxygen Concentration With Variation in Animal Metabolic Use Rate, Fixed Supply Rate 0.455 Pounds/Day	42
FIGURE 3-5 Variation in Life Cell Oxygen Concentration With Variation in Animal Metabolic Use Rate, Silicone Rubber Membrane Control	48
FIGURE 3-6 Variation in Life Cell Carbon Dioxide Concentration With Variation in Animal Oxygen Use Rate, Carbon Dioxide Removal Through Permselective Membrane	53
FIGURE 3-7 Food Dispensing Unit (Flat Type Tape)	66
FIGURE 3-8 Food Dispensing Unit (Casing Type Tape)	67
FIGURE 3-9 Water Dispenser System	70

LIST OF FIGURES (Cont.)

		<u>Page</u>
FIGURE 3-10	Water Storage Tank	71
FIGURE 3-11	Feeding and Water System	73
FIGURE 4-1	Passive Telemetering Components	81
FIGURE 4-2	Active Telemetering Components	83
FIGURE 4-3	"Massing" Station Instrumentation	88
FIGURE 4-4	Data Acquisition and Handling (Passive Biomedical Telemetry Techniques)	93
FIGURE 4-5	Data Acquisition and Handling (Active Biomedical Telemetry Techniques)	95
FIGURE 4-6	Data Acquisition and Handling (No Implants Used)	96
FIGURE 4-7	Work Station Instrumentation	98
FIGURE 5.1.1-1	View of Spin Stabilized Satellite in the Orbital Plane	103
FIGURE 5.1.1-2	Spin Stabilized Satellite as Seen Perpendicular to Orbital Plane	104
FIGURE 5.1.2-1	Stabilization for a Satellite of Arbitrary Moment of Inertia Distribution	108
FIGURE 5.2-1	Range to Impact vs. Magnitude and Direction of Velocity Change for 300 N. Mi. Circular Orbit	112
FIGURE 5.2-2	Atmospheric Entry Angle vs. Altitude for Optimal Thrust Orientation	114
FIGURE 5.2-3	Peak Deceleration During Reentry vs. Altitude for Optimal Thrust Orientation	115
FIGURE 5.2-4	Thrust Axis Orientation and Stabilization	116
FIGURE 5.2.1-1	Pallet Passenger	117
FIGURE 5.2.1-2	LEM Substitute	118
FIGURE 5.2.1-3	LEM Companion	119
FIGURE 6.1-1	Test Apparatus for Water Vapor Permeability	132
FIGURE 6.2-1	Determination of Optimum Downstream Flow Rate for 193PUD-0 Regenerated Cellophane	133
FIGURE 6.2-2	Determination of Water Vapor Permeability at Various Flow Rates of Air for 193PUD-0 Regenerated Cellophane	134
FIGURE 6.2-3	Determination of Optimum Downstream Flow Rate for 215PD Regenerated Cellophane	135
FIGURE 6.2-4	Determination of Water Vapor Permeability at Various Flow Rates of Air for 215PD Regenerated Cellophane	136
FIGURE 6.2-5	Determination of Optimum Downstream Flow Rate of Cellulose Acetate	137
FIGURE 6.2-6	Determination of Water Vapor Permeability at Various Flow Rates of Air for Cellulose Acetate	138

LIST OF TABLES

	<u>Page</u>
TABLE 1 Alternate Mission Profiles	9
TABLE 2 Main Commutation Channel Allocations	17
TABLE 3 T. M. Channel Assignments	19
TABLE 4 Monkey Food and Water Requirements	63
TABLE 5 Pellet Food Storage Requirements	63
TABLE 6 Water Vapor Permeability Data for 193PUD-0 Regenerated Cellophane	128
TABLE 7 Water Vapor Permeability Data for 215PD Regenerated Cellophane	129
TABLE 8 Water Vapor Permeability Data for Cellulose Acetate	130
TABLE 9 Summary of Water Vapor Permeability of Various Films	131

Many questions presently exist relating to man's ability to spend extended periods of time in space without adverse physiological or behavioral effects. It is essential that answers to most of these questions be secured as soon as possible in order that the manned space flight program may proceed without delay.

This report presents the results of a brief engineering study by the Applied Physics Laboratory of a proposed six-month orbital physiological experiment generally referred to as the "Primate Orbital Experiment". In this proposed Apollo application experiment, two live squirrel monkeys would be placed into a low earth orbit, then recovered alive approximately six months later, for examination on the ground.

The scope of this study includes all spacecraft systems, life support, and instrumentation for an experiment package which could be transported into orbit by an Apollo spacecraft and function autonomously until picked up six months later through rendezvous with a second Apollo spacecraft. This report presents approaches to possible ways of integrating the animal carrying satellite with Apollo during launch, indicates feasible life support and instrumentation techniques to maintain the animals alive in orbit for six months and suggests techniques for retrieval.

The design proposed in the report is represented only as a feasible approach to design of the spacecraft and not as a final design inasmuch as accurate values were not available for many significant design parameters needed in this study.

Throughout the brief study, attention has been focussed primarily upon the life support system and its associated instrumentation. Only modest attention has been devoted to those aspects related to standard engineering support services and requirements such as power, telemetry, ground command and etc.

Guidelines that have been followed in the study have been essentially of two types:

Firstly, those implicit as to size, weight and environmental conditions of the experiment which would be imposed

by possible locations within the Apollo spacecraft and attendant Apollo orbit. No attempt has been made to prosecute the design in enough detail to guarantee that all support requirements such as weight and power are satisfactory. However, since it is evident that such requirements will be nominal there is no reason to feel any problem will exist on an Apollo mission.

Secondly, all life support considerations have been developed to satisfy guidelines and requirements as stated by personnel of the Naval Aerospace Medical Institute.

Objectives

The objectives of this experiment, as we understand them, may be summarized as follows:

A. Primary

1. Study of long term effects of weightlessness and other stresses of space flight on basic physiological functions of primates.
2. Study of long term effects of weightlessness and other stresses of space flight on behavioral mechanisms, especially orientation.
3. Study of recovery and orientation mechanisms of primates following extended exposure to space flight.

B. Secondary

1. Evaluation of specialized instrumentation techniques for securing physiological data on unrestrained primates.
2. Evaluation of long term passive life support techniques.

Requirements

The successful accomplishment of the above six month experiment is conditional upon provision of suitable life support and instrumentation facilities for the two squirrel monkey animals to be

used in the experiment. These requirements have been informally stated by members of the staff of the Naval Aerospace Medical Institute, who have considerable experience with these animals, as follows:

Life Support

Animal "Payload": Two squirrel monkeys, 540 grams each

Atmosphere Required: Two gas, approximately 21% oxygen, remainder nitrogen (except for carbon dioxide and moisture)

Nominal Atmosphere Pressure: 14.7 ± 2.7 pounds/square inch

Allowable Carbon Dioxide Concentration: 1% nominal

Allowable Relative Humidity: 30 - 70%

Oxygen use per animal: 0.001 pounds/hour

Food Requirement per animal:

If Schwarz liquid diet, half water, 45 grams/day

If C.I.B.A. solid food 30 grams/day

Water consumed: 0.11 pounds/day

Fecal generation:

If Schwarz diet 3-5 grams/day

If C.I.B.A. diet 10-15 grams/day

Life Cell Temperature: $79^{\circ} \pm 3^{\circ}\text{F}$ air temperature

Instrumentation:

Electrocardiogram (EKG)

Respiration

Animal Weight

Body Temperature

Television

Animal food consumption

Animal water consumption

Life cell temperature

Life cell pressure

2.0 TECHNICAL APPROACH

This experiment is viewed exclusively as an earth-orbiting Apollo applications mission, making the fullest practicable use of available Apollo hardware and services. Axiomatically, then, it would be placed in orbit by an Apollo booster and the subjects would be recovered by rendezvous with a manned Apollo spacecraft after the intended period in orbit. It also follows that the astronauts, whenever available, would perform various supporting functions that cannot readily be automated or remotely controlled. These cardinal features establish the basic mission profile, which divides conveniently into the following major phases:

(1) Pre-Orbital

This phase begins with the initial assembly of experiment hardware into the Apollo vehicle, whether in the factory or at the launch site. It includes the insertion of the animal subjects into the experiment package, and all pre-launch supporting and monitoring activities except for animal training and preparation, which are beyond the scope of this study. It continues through count down, lift-off, and the ascent to orbit.

(2) Astronaut Attendance

This begins with post-injection events such as separation from the booster, transposition, and docking, and continues until the accompanying astronauts are no longer in proximity. It might last for several days or weeks, depending on other program considerations, during most of which period the experiment would either be attached or readily accessible to the command/service module, and the astronauts would be available for scheduled or emergency support. If necessary, they would recover the live animals.

(3) Unattended

After the astronauts have departed, the orbiting animals would remain unattended in a virtually g-free environment

for several months. During this period telemetered housekeeping and physiological data would be received via the Manned Space Flight Network frequently enough for effective monitoring of essential subsystems and general vitality. Ground commands would be issued as found necessary, to adjust feeding schedules, gaseous flow rates, and other vital functions. Live recovery during this phase of the mission is feasible, but would require special provisions for initiating and surviving re-entry, and for the emergency deployment of recovery forces. Because of their profound and readily identified effects on mission cost and complexity, such possible provisions are discussed separately in Appendix A.

(4) Rendezvous/Recovery

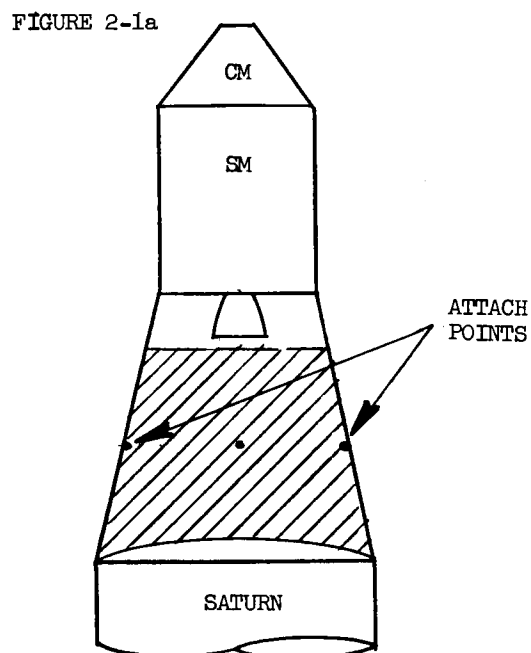
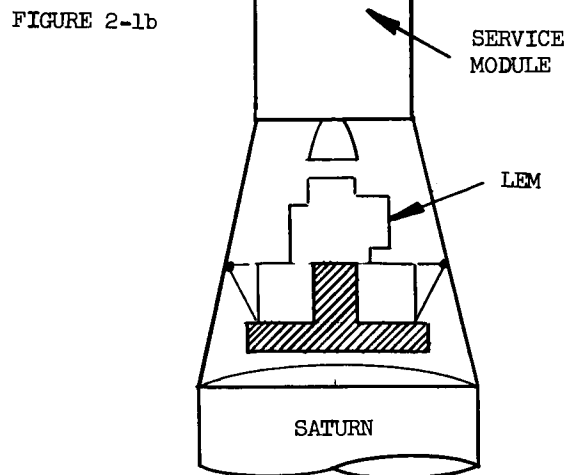
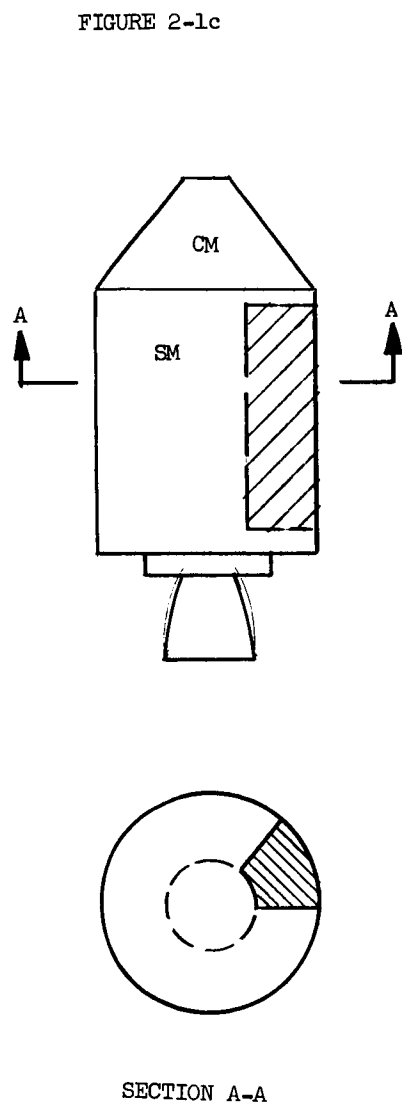
Shortly before the intended conclusion of Phase (3) another manned Apollo spacecraft would be orbited on an applications mission that would include live recovery of the animals as an objective. It would rendezvous with the experiment package while an astronaut transfers the subjects from their cages to the command module in life-supporting containers. Re-entry would occur within a few hours, and the subjects would be removed for examination shortly after impact. (A similar procedure would be employed for premature recovery during Phase (2), by the initially accompanying astronauts.)

In its finer structure the mission profile must be tailored to some specific combination of launch configuration and orbital operations dictated largely by other Program considerations. Therefore, it is appropriate to examine some of the more probable situations at this stage of investigation, to establish that plausible designs or procedures can be devised for each, and to ascertain whether one overall technical approach can accommodate any reasonably postulated combination. They are defined as follows:

LEM Substitute

If no LEM is to be launched, the experiment package might occupy the space indicated in Figure 2-1a, with *LEM-like

* LEM = Lunar Excursion Module



FEASIBLE PRIMATE EXPERIMENT LOCATIONS IN APOLLO

FIGURE 2-1

provisions for separating from the booster and docking with the transpositioned command/service module.

LEM Companion

If a LEM is to be launched with no descent engine, which probably will be the usual condition, the experiment package might occupy the space indicated in Figure 2-1b. It might be jettisoned early in Phase (2) to minimize interdependence with the LEM, or it might remain attached throughout that phase to facilitate astronaut attendance. It might even be retained permanently if the recovering vehicle must also rendezvous with the LEM for other reasons.

Pallet-Space Passenger

The experiment might have to be carried into orbit by the service module, occupying most of the space in which the standardized experimenters' pallet would ordinarily be mounted, as illustrated in Figure 2-1c. It would profitably be jettisoned early in Phase (2), but such action might be considerably delayed in deference to other program objectives. In any event, it must be orbiting solo prior to the astronauts' departure.

Various combinations of these postulated situations are presented in Table I, from which the likely spectrum of configurational and procedural problems can be derived.

Some initial consideration was also given to the possibility of mounting the entire experiment inside a Lunar-Excursion Module. It would be assembled within the pressurized volume of the ascent module, all elements being small enough to enter through the hatches. Electrical power would be obtained from the LEM batteries, which appear to be sufficiently large for the full mission with some margin for other LEM functions, and use would be made of the LEM communications and thermal

control systems. It was concluded, though, that the payload integration task would be excessively difficult and costly with this approach, and that the nearly exclusive obligation of a complete LEM for this experiment could not be justified. Accordingly, no detailed investigation was conducted along these lines.

2.1 Critical Problem Areas

The experiment must autonomously provide all of its supporting services while orbiting solo, which situation applies to nearly all of the mission profiles outlined in Table I. It should also be virtually autonomous while attached to the parent Apollo vehicle, to minimize interface problems. Certain services pose particularly challenging design problems, either because they must be autonomously provided for long periods or because degrading interactions with the parent vehicle cannot readily be avoided. A brief summary of these critical problem areas, and of their plausible solutions, follows. They are discussed more fully later in the text.

2.1.1 Gaseous Atmosphere

Perhaps the most challenging technical problem is that of providing a two-gas atmosphere of acceptable composition for a six month period in the absence of a long-lived sensor for partial pressure of oxygen. Fortunately, though, weight and volume are not severely limiting, so compressed gas storage can reasonably be considered; this would obviate the admittedly otherwise formidable task of adapting a cryogenic design to the variety of thermal environments that are implicit in Table I. Also helpful is the fact that an astronaut would be able to monitor and adjust the actual in-orbit performance for at least a few days, with adequate instrumentation.

TABLE I

ALTERNATE MISSION PROFILES

<u>Mission Phase</u>	<u>Possibilities</u>													
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>	<u>11</u>	<u>12</u>	<u>13</u>	<u>14*</u>
I. <u>Pre-orbital</u>														
LEM Substitute	X	X	X	X	X	X								
LEM Companion							X	X	X	X				
Pallet Space Passenger											X	X	X	X
II. <u>Astronaut Attendance</u>														
Docked	X	X	X											
LEM Companion							X	X						
Pallet Space Passenger											X	X		
Solo				X	X	X			X	X		X	X	X
III. <u>Unattended</u>														
LEM Companion							X	X						
Solo														
IV. <u>Rendezvous/Recovery</u>														
EVA Docked	X	X	X	X	X	X			X	X	X	X	X	X
EVA Hovering				X			X		X		X			
Inside Transfer Docked		X			X			X		X		X		X

* The respective columns represent a plausible mission configuration sequence.

These factors make quite feasible and attractive the simple forms of orificed open-loop atmosphere replenishment systems described in Section 3.

2.1.2 Food and Water

Over a six month period, two small primates consume a large amount of food and water. It must be supplied on a regulated basis or the supply might be exhausted early by over-consumption or willfull removal and loss. To provide this regulated consumption the animals can be trained to work for both food and water. This required work also provides one means of monitoring animal vitality. The problem of food storage and dispensing is particularly acute. Available feeders are not sufficiently reliable. It, therefore, is required to develop a more reliable feeder and also to provide increased reliability through redundancy. Since a large supply of food is required, it would be judicious to provide redundant feeders with a common food supply. It is appreciated that this requirement is limiting in that a failure terminates a successful experiment.

2.1.3 Waste Management

A most demanding problem, the solution of which dictates much of the philosophy and detail of life cell design, is that of waste management. Since it appears unlikely that the animals can be "toilet" trained, it will be necessary to provide for a waste management system which will provide adequate separation of the waste products without animal cooperation. In the zero-g state, there is no settling force so other techniques must be utilized. Perhaps the more meaningful potential separating force is that of air movement. Since air must be circulated for other purposes, it is attractive to use it here. Of course, when on the pad at one g, when being launched with increased artificial gravity loading, and during satellite maneuvering, the g-loadings must always be in the desired direction in regards to settling of the waste materials on the waste trap. If the satellite is gravity gradient stabilized

(which is quite attractive), this small settling force should complement the settling by air circulation. Although the animals cannot be trained, the cage design should induce waste ejection in the preferred direction.

2.1.4 Physiological Measurements

One of the firm guidelines for this experiment is that sufficient physiological data be collected to ascertain, on a continuing basis, the physiological condition of completely unrestrained animals without physiological embarrassment for the animals. Ideally, this should be done indirectly, as for example by television and remote or indirect physiological observation. Some physiological data can be collected indirectly and remotely by such techniques of obtaining temperatures and EKG signals from hand holds and recording pressure changes or sounds in the life cell for breathing and cardiac activity monitoring. It seems likely, however, that such techniques may not provide sufficient data so that other means will probably have to be employed. The present art holds the promise of using small implantable devices embodying both sensors and transmitters which would obtain more eloquent physiological data. It is appreciated that, in any event, the animals skin must not be violated by leads. Appropriate, previously surgically implanted devices would seem acceptable.

2.1.5 Recovery

It should be possible to stow the recovered subjects aboard an Apollo command module that carries the usual three man crew, to avoid excessive restrictions on overall program planning. Such is not possible if the entire life cell must be transferred, since the smallest practicable cage for the six month experiment would be too large for the storage space normally provided in a command module. Therefore, smaller transfer/storage containers must be used, suitably configured for the actually available space envelope.

It is assumed that two cylindrical vessels 8 inches in diameter and 16 inches long will be large enough for the monkeys, yet small enough to fit in the available space.

Once the monkeys are aboard the command module, there should be no intrusion of atmosphere or contents from their containers into the cabin, and at no time should the astronauts handle (or even touch) the subjects directly. These prohibitions stem largely from the firmly expressed feelings of several questioned astronauts. More subtle forms of contamination, such as gas leakage from the life cell onto a space-suited astronaut during the transfer operation, are not specifically prohibited, but their avoidance is considered a design goal. Detachable sealed containers can certainly be made compatible with all of the above requirements and goals, whether the transfer operations are performed in vacuo or in a 5 psi all-oxygen atmosphere, although the best method of inducing the subjects to vacate is still somewhat in doubt. Such provisions also obviate the troublesome problem of matching the life cell atmosphere to the command module composition just prior to transfer. The tightly sealed containers could maintain their sea-level atmosphere for the remaining few hours with no need for nitrogen make-up, therefore two-gas atmosphere control would be only a little more difficult than for an all oxygen environment.

2.2 Other Considerations

The various other services that must be provided to support the experiment present less of a challenge to the designer, since proven techniques are available. Accordingly, they have not been studied in depth and are considered mainly to establish that all of the required features can reasonably be incorporated in a composite design for each of the mission profiles outlined in Table I.

2.2.1 Attitude Control

To provide the most advantageous experiment conditions and secure maximum useful data, it is highly desirable to control the attitude of the spacecraft. The objectives and advantages of an attitude control system may be summarized as follows:

- (a) Provide the most efficient power generation from the spacecraft solar cells.
- (b) Provide a predictable attitude relative to the sun and earth for improved thermal control.
- (c) Enable the use of directional antennas and more effective communications.
- (d) Prevention of unacceptable angular rates by increasing the overall moment of inertia. This would avoid disorientation to the subjects and the imposition of unwanted g-loadings.

Among the possible systems for obtaining the above objectives are gravity gradient stabilization, ultra-slow spin rate control, and passive magnetic stabilization. It appears that any of these systems would satisfy most of the mission objectives.

A gravity gradient stabilization system (which we have chosen to illustrate in our overall configurational sketches)

that would passively maintain earth-orientation using thoroughly proven techniques appears to satisfy all requirements for all of the explored mission variations. The total weight of such a system need not exceed 20 pounds. The stabilizing boom would remain nested until the experiment has been properly oriented by an Apollo spacecraft or by ^{*}EVA, then extended when the astronauts are about to depart. In the exceptional case of continued attachment to the LEM (see Table I) the boom could be monitored on and extended from that vehicle. A variation of this technique could also be used to orient a retro-rocket for emergency call-down, as discussed in Appendix A. There has been considerable experience with gravity gradient stabilization at higher altitudes. For the low orbital altitude likely for this mission it is desirable to have a symmetrical drag configuration so that the aerodynamic torques are balanced about the center of mass of the system.

The development of semi-passive techniques for ultra-slow spin rate and attitude control of satellites has been developed to such a point that this type of system also gives promise of application in certain variations of the envisioned mission. The existence of a very low g field which can be secured by ultra-slow spin may possibly alleviate some of the very difficult design problems created by zero g conditions without compromising the basic experiment. The use of a semipassive ultra-slow spin control system for stabilization and attitude control makes certain optimizations possible in the power and thermal systems. Passive magnetic stabilization would be the simplest and most reliable method of all, but offers least opportunity for optimization.

2.2.2 Electrical Power

The average usage of electrical power is tentatively estimated to be 50 watts, assuming continuous telemetry and television transmission. This average rate could be maintained by a conservatively

* EVA = Extravehicular Activity

designed photo-voltaic system weighing less than 50 pounds, including batteries, for any of the visualized Apollo applications orbits. Such a system, however, could perform adequately only when its orientation is properly stabilized and when its solar array is optimally deployed, which conditions might not obtain until several weeks after launching. It might therefore prove necessary to add several hundred pounds of batteries to cover some of the situations outlined in Table I.

Also meriting consideration is the use of a radio-isotope thermoelectric (or conceivably thermionic) power generator, which would be competitive in weight with the photovoltaic system while avoiding its extreme performance dependence on orientation and geometry. Such a system would present rather severe thermal management problems during the early phases of the mission, though, and the acceptability of a nuclear device in this application is somewhat uncertain.

In view of the above, and since weight is not necessarily a critical factor, the possibility of an alternate all-battery system should also be explored. A 200 day mission at 50 watts would call for 240 kilowatt-hours of stored energy, which could be provided by about 4000 pounds of non-rechargeable batteries. (Coincidentally, the basic LEM LAB batteries yield 274 KW hours of energy for experiments and lab housekeeping, and additional batteries are contemplated that would raise the total to 592 KW hours.) The required battery-space volume would then be roughly 25 cubic feet, which could readily fit within any of the available space envelopes indicated in Figure 2-1. All of the overall configurations depicted in this report, however, are based on the assumption that weight limitations will dictate the lighter but less flexible solar cell concept.

2.2.3 Thermal Management

By means of a judicious combination of attitude orientation and control of conducted heat by the appropriate choice of materials, it should be quite feasible to maintain the life support system and instrument packages within reasonably specified temperature limits. The relatively constant heat input from the primates will not create any special design problems.

Additional thermal control may be secured by design of the structure and appropriate surface treatment. If detailed design study later indicates that it is essential or desirable, provision for active temperature control may be provided. The general design would provide that the passively obtained expected internal temperature would be slightly lower than desired. Modest power for heating would then provide the desired temperature.

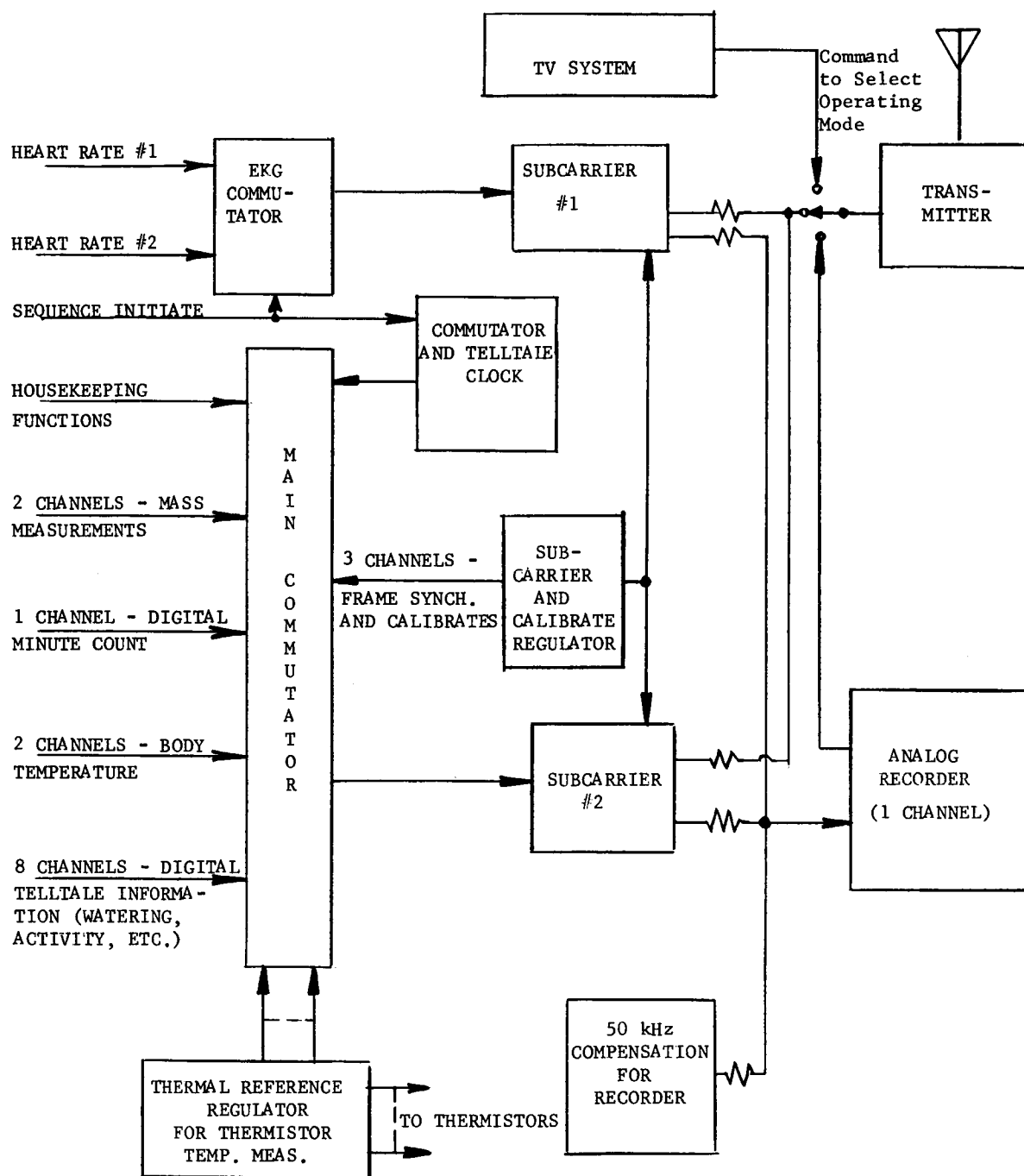
2.2.4 Telemetry

An analog PAM/FM/PM system could transmit both life support data and standard housekeeping data, such as battery voltages and currents, various temperatures and other information concerning the state of the system. It might consist of one 35 channel main commutator and one 4 channel EKG commutator, each modulating a different subcarrier oscillator (SCO). The outputs of the two SCO's could be summed linearly in two separate networks, one of which would also be summed with a 50 KC signal. The combined signal might then be routed to an analog recorder while the other network output is routed to the transmitter. In normal operation, the two summed SCO's would modulate the transmitter. At the same time, the composite signal, consisting of the two SCO outputs and the 50 KC signal, could be recorded. If there have been periods of time when real time viewing of the desired data has not been possible, the recorder may be commanded into an accelerated playback mode such that the entire recorder contents are dumped during

one pass. During the accelerated playback time, the recorder, rather than the real time signal, will be used to modulate the transmitter. (It is not at all certain that a recorder would be needed to assure sufficiently continuous data.) A block diagram is shown in Figure 2-2 and a preliminary list of TM assignments is given in Tables 2 and 3. It should be noted that the transmitter would also be time shared by the television system on a command basis.

TABLE 2
Main Commutator Channel Allocations

<u>Channel</u>	<u>Function</u>
1	+0.25V calibrate and frame synch.
2	0.0V calibrate
3	-0.025V calibrate
4	Digital minutes and telltales
5	Body temperature, monkey 1
6	Body temperature, monkey 2
7	Mass of monkey 1
8	Activity count, monkey 1 and telltales
9	Lever pulls, monkey 1 and telltales
10	Feeding count, " "
11	Water count, " "
12	Mass of monkey 2
13	Activity count, monkey 2 and telltales
14	Lever pulls, " "
15	Feeding count, " "
16	Water count, " "
17 - 35	Housekeeping functions



TELEMETRY SYSTEM

FIGURE 2-2

TABLE 3

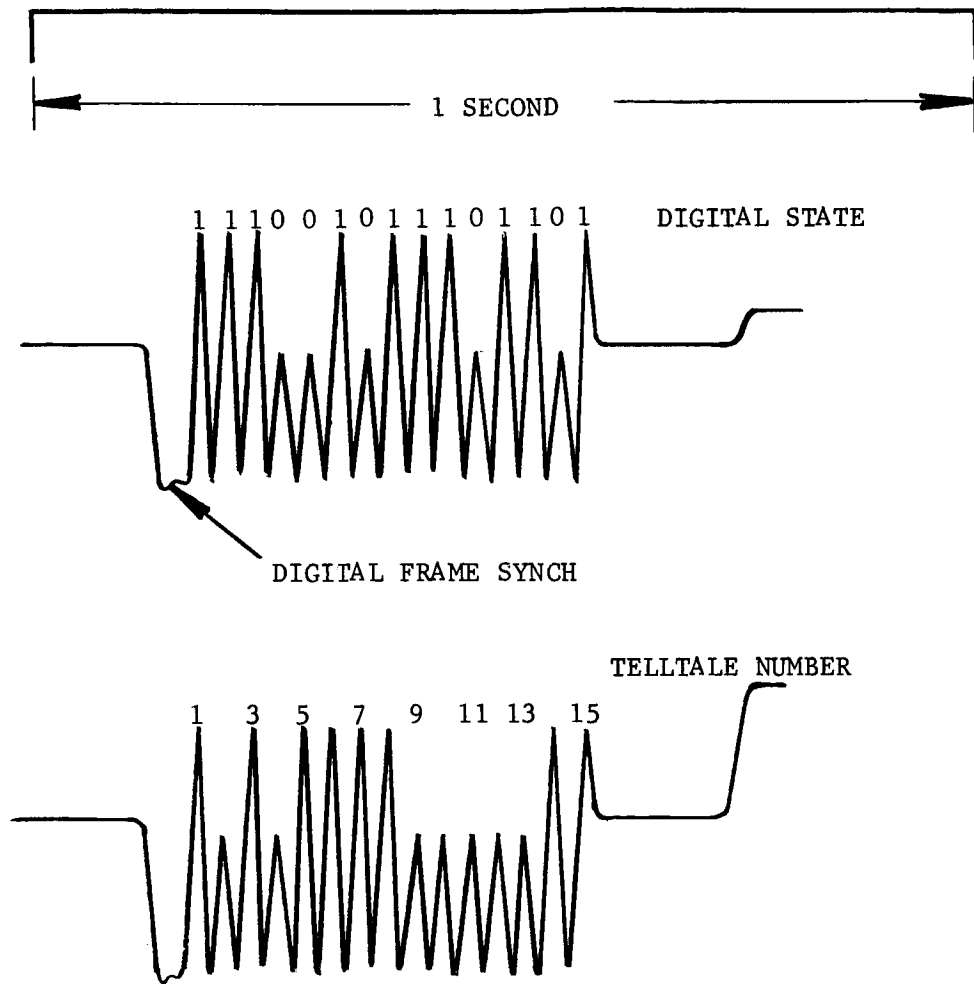
T.M. CHANNEL ASSIGNMENTS

<u>Channel</u>	<u>Function</u>
1	+0.25V calibrate & frame synch.
2	0.0V calibrate
3	+0.25V/-0.25V EKG recognition
4	EKG #1/EKG #2

As a supplement to the analog data, telltale registers might be provided for transmission of digital data. For example, in Figure 2-3 the "1" (or high telltale) in telltale position three might be representing the function, "transmitter ON high power" in which case transmitter ON low power would be represented by a "0". Telltale data is gathered in 15 bit registers and read out serially during one time slot on the main commutator as illustrated in Figure 1-9.

The commutator and telltale clock will provide the signals which control the data rate of the main commutator and the EKG commutator. It also allows synchronization and duty cycling of the main commutator. Both commutators will have a frame time of approximately 24 seconds. The main commutator will have a channel dwell time of .63 second. This time is further divided into 75% on-time and 25% off-time to allow discrimination between channels. The EKG commutator does not have duty cycling since its four channels are easily located (see Figure 2-4). By observing channel 3 of the frame desired, it may be determined which EKG is being transmitted. If channel 3 is high (indicated by the dotted lines in Figure 2-4), EKG #1 is being transmitted. If channel 3 is low (indicated by the solid lines in Figure 2-4), EKG #2 is being transmitted.

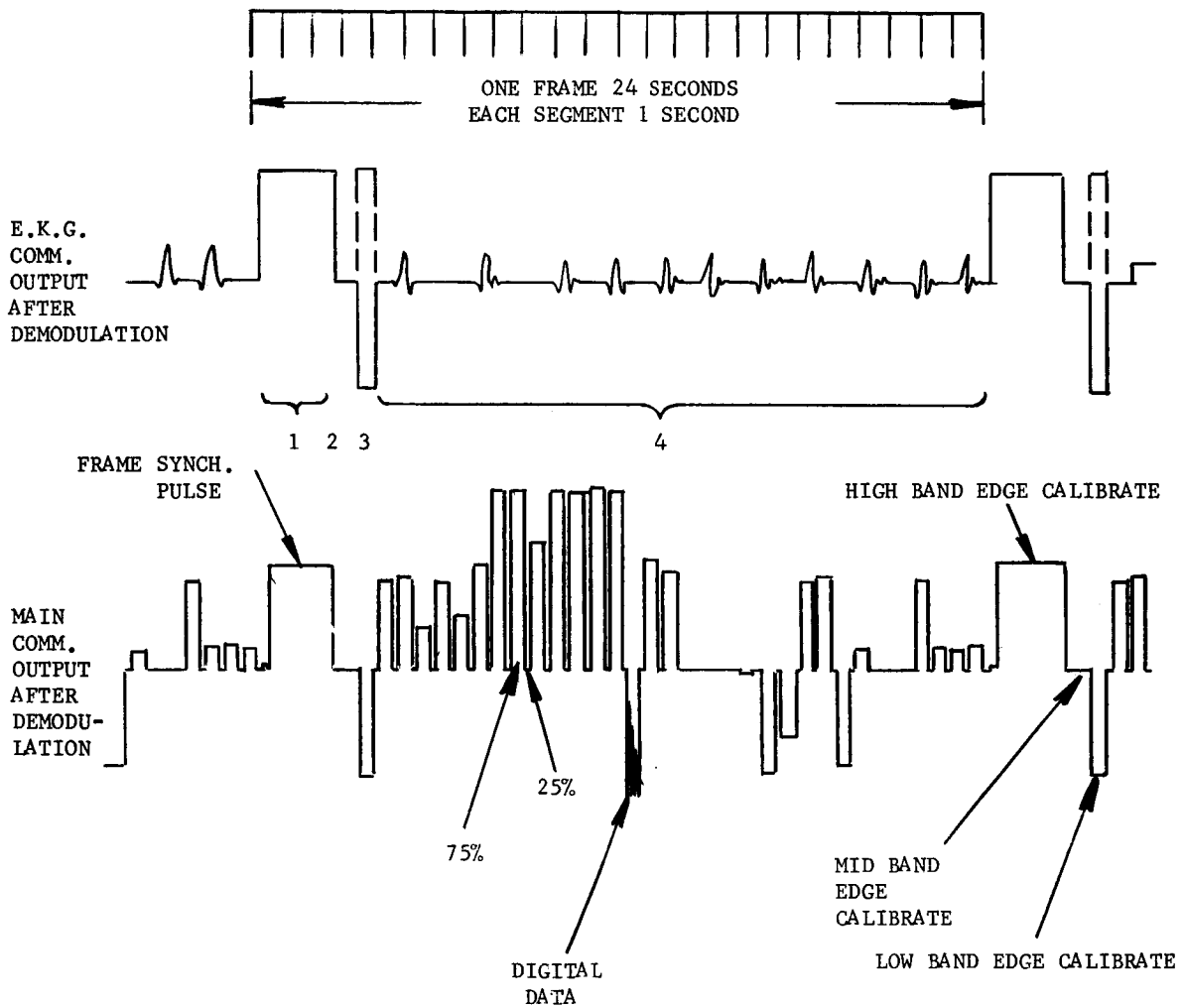
In addition to setting the data rate, the clock also synchronizes the telltale registers with the main commutator.



Note:
 1 = High
 0 = Low

DIGITAL DATA (TELLTALES)

FIGURE 2-3



TYPICAL TELEMETRY FRAME

FIGURE 2-4

Temperature measurements on the satellite will be accomplished in a standard manner using a thermistor-resistor divider network excited by a known constant voltage from the thermal referred regulator. The thermistors will be mounted at points where temperature measurements are desired. Since the resistance of a thermistor is a function of temperature, the voltage out of the divider network is then a known function of temperature. These voltages will be routed to the commutator.

A command function will be provided to address the main commutator to stop on any desired channel, thereby permitting continuous monitoring of that channel. Another command will restart the commutator.

In general, all components except the recorder which are shown in the block diagram of Figure 2-2 are standard flight items which have been flown many times.

Television coverage of the subject animals has been assumed highly desirable and is discussed in Section 4.6. Overall T.M. and T.V. power requirements are not discussed in any detail as preliminary investigation indicated Apollo power capabilities should be more than adequate.

2.2.5 Ground Support

Ground support equipment for field operations and tests can be provided by a standard telemetry rack, modified to complement the type of format required by the real time telemetry transmission from the satellite. Elements of the telemetry rack include a receiver, discriminators, and a strip chart recorder for displaying the outputs of the discriminators.

As a means of automatically reducing real time telemetry data, a processor determines the commutator channel from the discriminator output, and directs a DVM to "read" the value of this channel output at the proper time. This output, along with the channel number is then sent to a digital recorder for printout.

A real-time display of the telltale values is also presented on a lighted panel. Also, a decoded numerical display of watering counts, activity counts, feeding counts, and lever pulls for each monkey is presented on the panel.

In addition to providing telemetry reception and reduction, the ground support equipment would provide the capability needed to command the system. This would include a command encoder, modulator, and transmitter. In addition to the ground support equipment for telemetry and command, launch site facilities must be provided for standby and countdown support of the life cell, and for placing the subjects aboard the Apollo vehicle. These needs which were recognized in the definition of mission Phase I, have not yet been studied in enough detail to discuss meaningfully here.

2.2.6 Command

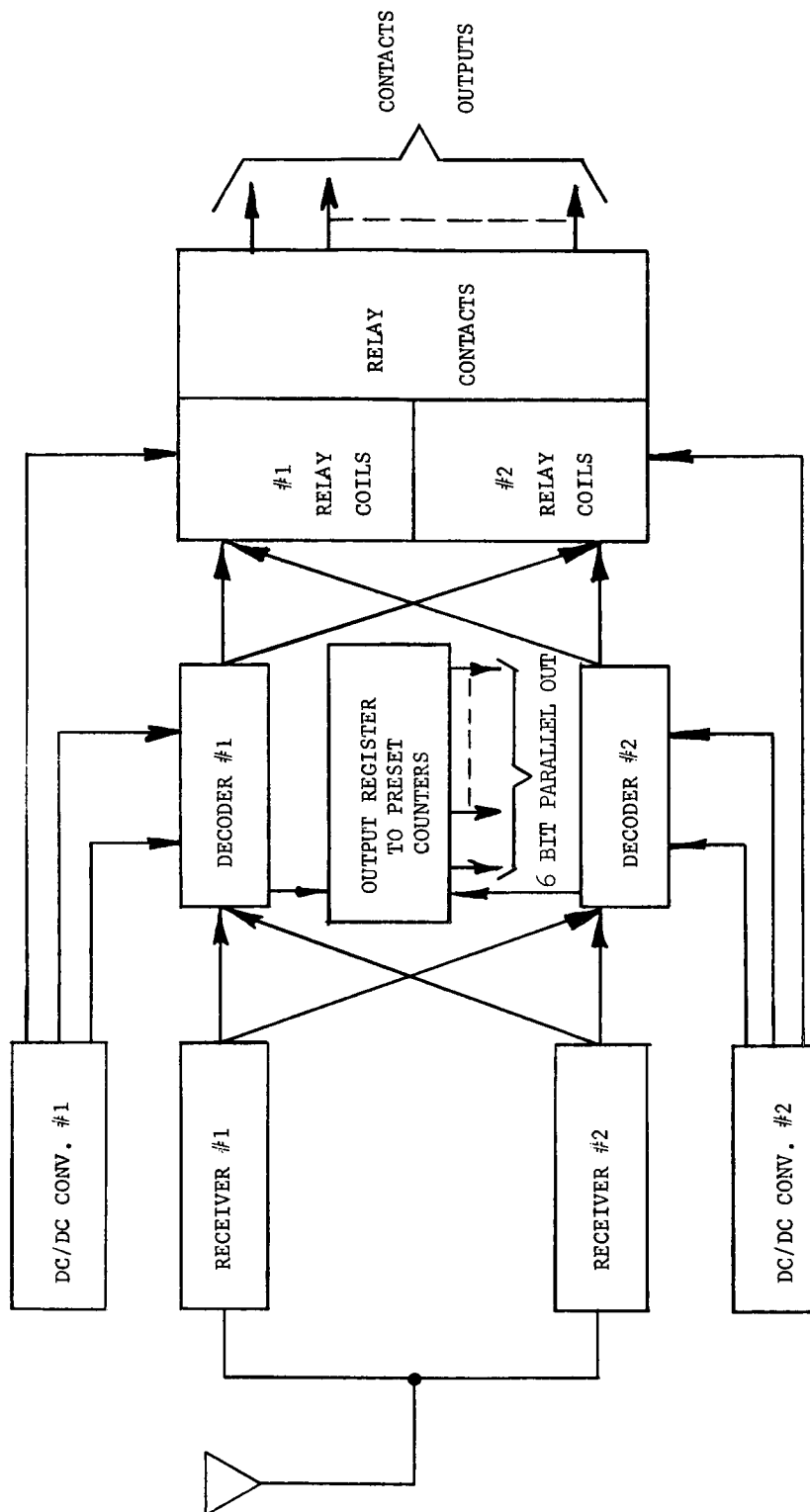
The command system (Figure 2-5) visualized as adequate for this mission, will have a capacity of 32 random access ON/OFF relay commands. In addition, it will be capable of loading six-bit numbers in any one of four registers, facilitating ground reset of on-board counters.

The system will utilize a two-tone PCM format in which each tone frequency represents either a binary "1" or "0". The command signal will be compatible with NASA ground facilities.

Several features may be included in the spacecraft hardware to enhance reliability such as (1) complete parallel subsystem redundancy utilizing two DC/DC converters, two receivers, two decoders, and dual coil access to the relays; (2) extensive use of flight-proven integrated circuits; and (3) removal of power from most of the system until the beginning of a command is sensed.

Four relay type commands, paralleled "form C" contacts will be provided. The relays will be dual coil magnetic latching units, with either coil capable of both setting and resetting the unit depending on the direction of current flow in the coil.

FIGURE 2-5



COMMAND SYSTEM

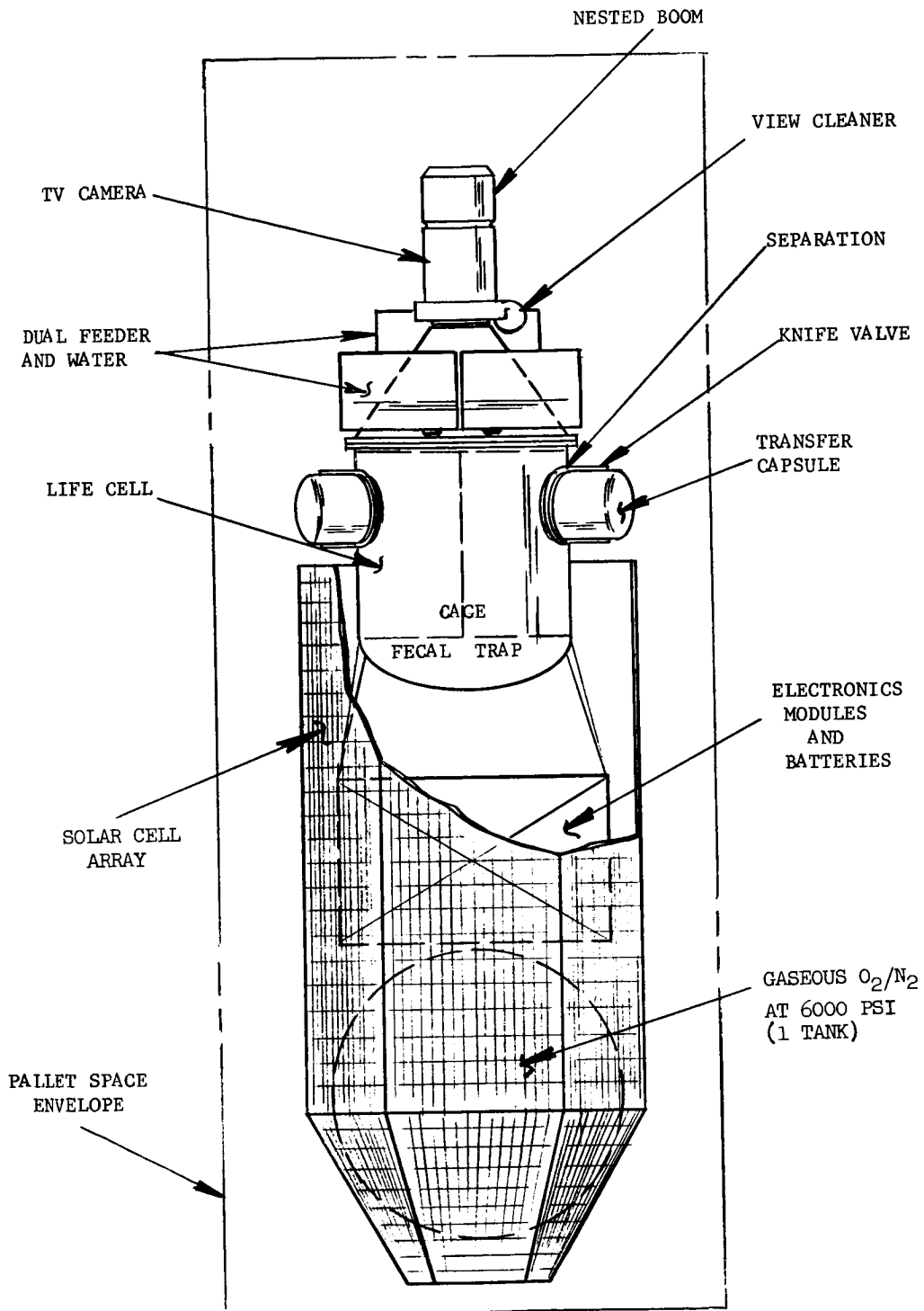
FIGURE 2-5

Direct ON/OFF instruction will be used, as opposed to toggling type systems in which the relay state changes with each command. Therefore, it will not be necessary to know the relay state before sending a command. However, adequate telltales indicating the states of selected relays can be provided to the telemetry system as required. This type of system has both system and hardware advantages over the "toggle" system, wherein a given code produces off-on conditions in the spacecraft. For example, if abnormal conditions exist and it is urgent to turn off a critical function, repeated off commands may be transmitted without concern over the exact number of commands sent as would be required in the "toggle" system

2.3 Overall Configuration

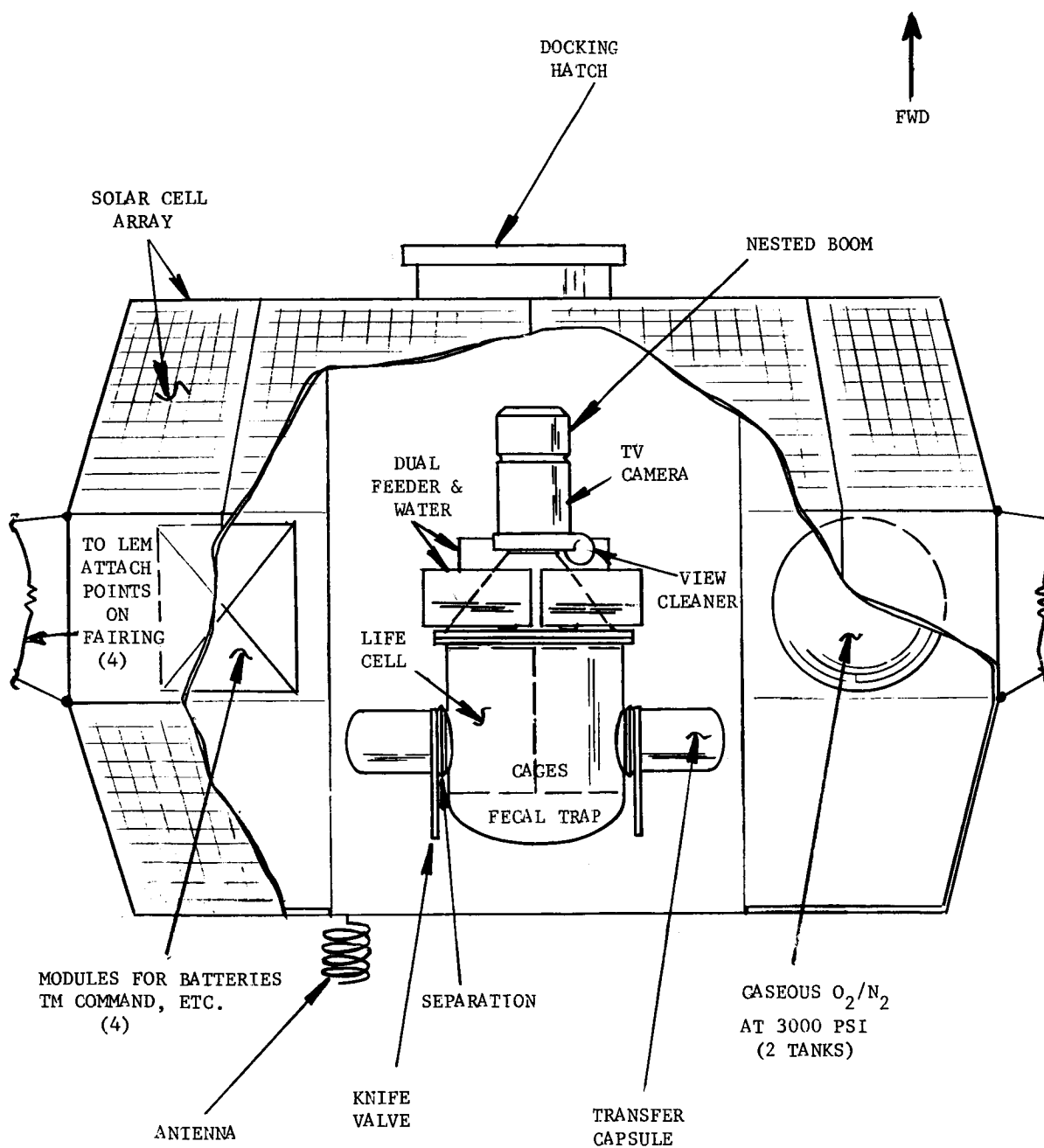
A single overall design concept is suggested which, with some adjustments in geometry, appears appropriate for any of the mission profiles outlined in Table I. In Appendix A it will be shown that this concept can also be adapted to include an emergency call-down capability using existing components and technology. While other concepts might be equally versatile, it is judged sufficient at this time to illustrate only one plausible approach.

Figures 2-6, 2-7 and 2-8 depict the three basic alternative geometries corresponding to the three forms of launching opportunities shown in Figure 2-1. Each of them could, in turn, be modified slightly to cover variations in the detailed mission profile, as outlined in Table I. Each design was pursued far enough to establish that all of the required elements can fit approximately as shown, with reasonable clearance and adequate access, and that a large enough solar array could be provided in some reasonable fashion (although not necessarily as indicated).



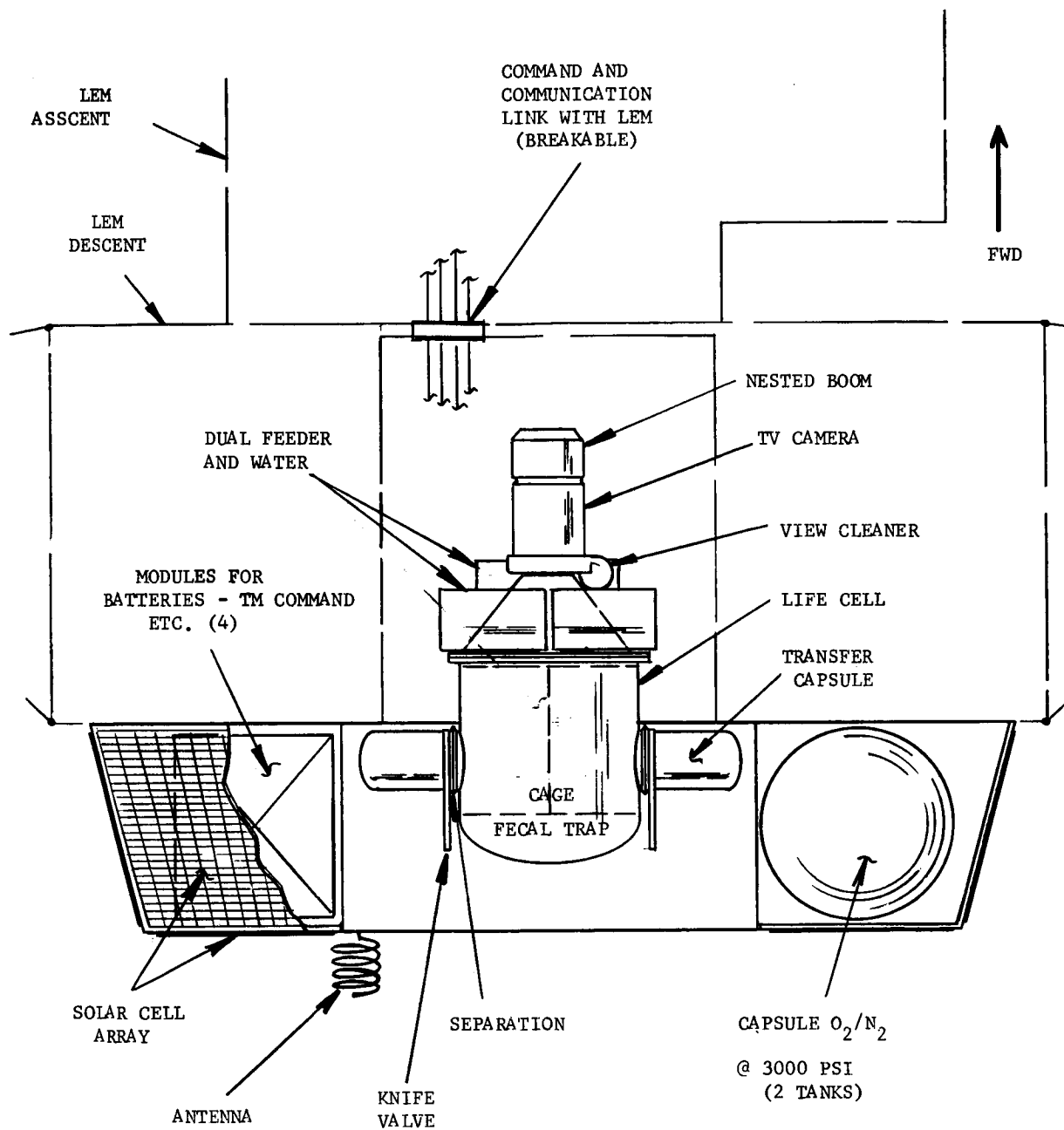
PALLET PASSENGER

FIGURE 2-6



LEM SUBSTITUTE

FIGURE 2-7



LEM COMPANION

FIGURE 2-8

3.0 TECHNICAL CONSIDERATIONS OF THE BIOSYSTEM

3.1 Requirements

The staff of the Naval Aerospace Medical Institute have formulated the principal requirements for the breathing atmosphere that would be required by the animals in the life space. There are four significant atmospheric parameters:

1. Pressure (total)
2. Composition
3. Contaminants
4. Circulation

Temperature of the life cell atmosphere will be maintained by means of circulation at the spacecraft temperature, and it, in turn, will be maintained by passive means within a range of temperature comfortable to the animals.

The staff of the Naval Aerospace Medical Institute have recommended that the animal life space atmosphere be at approximately 14.7 pounds per square inch pressure with oxygen maintained near the normal air value with nitrogen the principal inert gas composing most of the remainder except for the presence of tolerable amounts of gaseous impurities. Use of such an atmosphere will help insure that the animals will not be influenced during the six month orbital life by a change from a normal atmospheric environment. There are tolerances to these values which are moderately broad and can probably be inferred from studies upon human astronauts.

3.1.1 Total Life Cell Pressure

In regard to tolerances in total pressure, animals as well as humans tolerate altitude changes up to one mile if the change occurs over a half hour time period. As there is no indication that this tolerance to pressure change is one sided, a similar upward pressure deviation tolerance is probably acceptable. One can thus

aim for a spacecraft atmospheric pressure of approximately 14.7 pounds per square inch with a maximum tolerance of around ± 2.7 pounds per square inch.

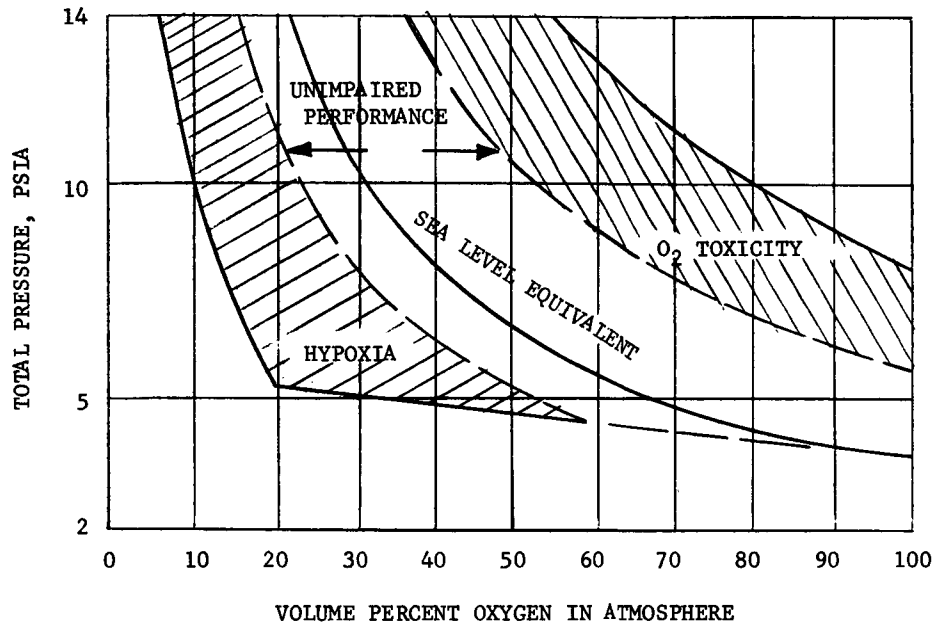
3.1.2 Oxygen Partial Pressure

The choice of nominal 14.7 pounds per square inch for the life cell pressure establishes that, extrapolating from human tolerances, the oxygen concentration must lie between 16 and 35 percent for comfortable survival. Within these tolerances, human beings survive comfortably at a nominal 14.7 pounds per square inch pressure, and one would expect that the primate animals could do as well. The median to the 16-35% oxygen tolerance is about 25% instead of the usual 21% concentration of atmospheric oxygen and may be a more attractive nominal oxygen concentration if animal oxygen metabolism varies. A high oxygen concentration is, of course, not tolerable simultaneously with life cell over-pressure but the high oxygen concentration is in fact desirable if the life cell pressure should fall. This relationship is shown in Figure 3-1 which is reproduced from Page 5 of NASA SP-3006, "Bioastronautics Data Book".

3.1.3 Contaminant Removal

The principal contaminants of the life cell atmosphere will be carbon dioxide and water; the former due to animal metabolism of oxygen and the latter due to perspiration and urination. Other atmospheric contaminants appear to be ammonia from the urine, and methane and hydrogen sulfide from feces. Figure 3-2 shows human tolerance for atmospheric carbon dioxide used again with the supposition that primate animals have a similar tolerance. Figure 3-2a shows the short term tolerance and Figure 3-2b the long term tolerance which is more applicable for a 6-month experiment. For the long term objective, a 0.5% maximum is indicated for carbon dioxide level, with, however, a rather large tolerance up to $2\frac{1}{2}$ percent with only

FIGURE 3-1



FROM PAGE 5, NASA SP 3006, "BIOASTRONAUTICS DATA BOOK"

FIGURE 3-2a

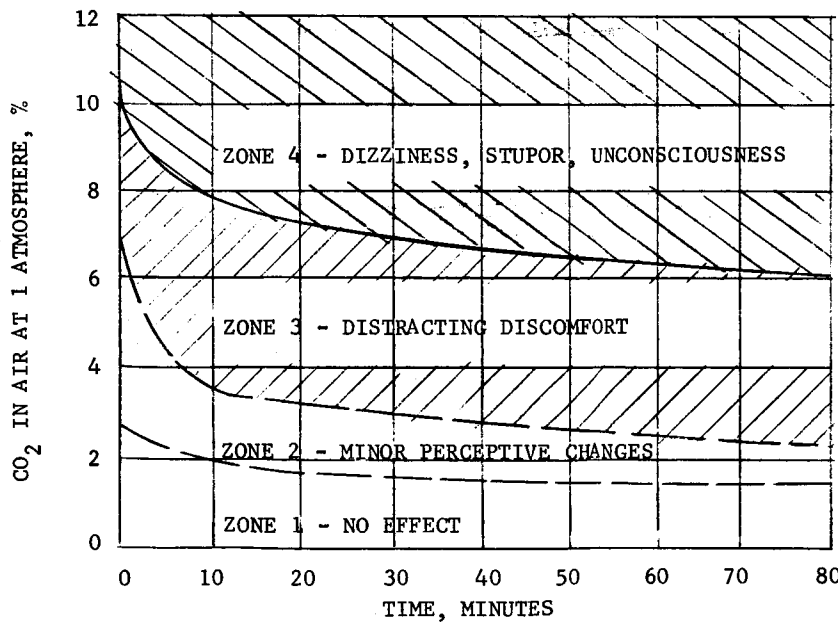
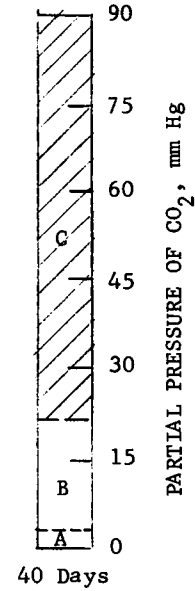


FIGURE 3-2b



FROM PAGE 8, NASA SP 3006, "BIOASTRONAUTICS DATA BOOK" FIGURES 3-1 & 3-2

minor discomfort. It may be reasonable to design life support atmospheric purification equipment to maintain carbon dioxide concentrations at or below 0.5% for normal activity and metabolism by the animals with allowance for higher rates of animal activity and metabolism to increase the carbon dioxide concentration upward so as not to exceed $2\frac{1}{2}$ percent for the short durations of high animal activity.

In a gravity-free space, it appears that all the animal urine will evaporate into the outgoing atmospheric gases from the life cell and render these gases relatively humid. The fluid ejected by the animals is likely to project against walls of the cage or to the fecal trap below the animals and evaporate from these surfaces. It is, therefore, important to have a moderately rapid circulation of relatively low humidity air through the life space to remove this moisture. The incoming air to the life space should not be too dry or else the animals may become uncomfortable. The target design for the dehumidifier to follow is to reduce the relative humidity of the life cell gases from about 50 percent (exit) to about 20% when the purified gases are re-introduced for two animals with normal daily water use rates. Death of one animal would result in decrease of moisture release (by urination) by a factor of one-half with consequent likely reduction of humidity in proportion. The reduction of humidity in the presence of a dead animal would have the desirable effect of drying out and "mumifying" the dead animal and thereby reducing the likelihood of its rotting and spreading some disease to the surviving animal.

Establishing control tolerances on other atmospheric contaminants such as ammonia from urine and methane and hydrogen sulfide from feces seems difficult in light of the lack of information concerning the amounts of these generated by the animals or tolerated by them. As an alternate it is proposed to provide an adequate amount

of activated charcoal in the atmospheric purifier and to provide a small continuous overboard leakage of the life cell gases to prevent buildup of trace contaminants not adsorbed by the activated charcoal.

3.1.4 Air Circulation

The air circulation requirements of the life cell space are established principally by the need to remove contaminants from the life space fast enough to keep their concentrations low. The required flow rate is that which transports liberated water vapor and carbon dioxide into the absorbers as fast as these substances are released by the animals. This implies an equality between the hourly rate of release of these substances to the product of the gas purification efficiency by the gas flow rate and the life cell impurity concentrations. The animals will release a great deal more water than carbon dioxide so that the removal requirement for water establishes the flow rate around 600 liters (21.2 cubic feet) per hour through the moisture and carbon dioxide removal traps.

3.2 Atmosphere Composition and Impurity Control

The requirement for a two-gas, oxygen-nitrogen atmosphere creates an atmospheric composition control problem for the following reason: it is probably impossible to build the animal space capsule absolutely leak tight, consequently, some of its atmospheric gases will leak out, removing oxygen and nitrogen roughly in proportion to their concentrations in the life space whereas at the same time the animals in the life space will be removing only oxygen from the atmosphere through their life processes, therefore, the composition of the makeup gas needed will depend on the ratio of the two removal rates. If atmosphere loss is through animal metabolism, only oxygen is removed and only oxygen must be added; if atmosphere loss were solely by leakage, the oxygen to nitrogen ratio needed in makeup gas composition would be that ratio desired in the life cell.

Five techniques appear worthy of consideration for providing a two-gas atmosphere maintained within reasonable tolerances of the desired oxygen-nitrogen ratio in face of possible variations in life cell leakage and animal oxygen metabolic use rate.

1. Use of oxygen and/or nitrogen composition sensors together with separate supplies of makeup oxygen or nitrogen atmospheric gases, with each gas fed in proportion needed to keep the desired oxygen percentage in the atmosphere and to maintain the desired life cell pressure.

2. Use a large life cell vent and to use gases having oxygen and nitrogen premixed in the desired ratio. This makes negligible the effect of oxygen usage by animal metabolism on atmosphere composition because of the large amount of oxygen contained in the flowing gases; thereby assuring that life cell atmosphere composition will approximate that in the supply gases. The gas supply would be controlled to maintain life cell pressure at a desired level.

3. Use of a premixed atmosphere gas, somewhat enriched in oxygen, fed at a constant rate to the life cell with the life cell vented through a controlled leak set to maintain the desired life cell pressure. The supply gas, being supplied at a constant rate, can be enriched to compensate for the nominal animal oxygen metabolism rate.

4. Use of a premixed atmosphere gas with controlled leakage through a membrane to space using a membrane material highly permeable to water vapor and carbon dioxide (as well as other organic impurities), and less permeable to oxygen and only slightly permeable to nitrogen. (Silicone rubber membranes possess such characteristics but are difficult to make absolutely free from pinholes.)

5. Use of an unvented (except for unintentional leaks) life cell, but incorporating a carbon dioxide chemical absorbent

bed which liberates oxygen to match the carbon dioxide which it absorbs and to replace thereby the oxygen used by animal metabolism. The atmospheric makeup gases used would be pre-mixed to the desired oxygen-nitrogen composition as the net gas loss would be by leakage and thence remove these gases in proportion to their concentration in the life space.

There are further possibilities through combinations of elements of several of these systems, combining uses of oxygen producing chemicals, selective membranes and controlled leaks. Of the systems discussed, those using a high flush rate of gases through the life cell or using selective permeability membranes would tend to eliminate carbon dioxide, water vapor, and low level impurities and thereby reduce the need for chemical absorption beds for impurity removal.

3.2.1 Criteria for System Selection

A selection needs to be made among the systems described above in terms of the following factors.

1. Ability of the system to maintain the composition of the life cell atmosphere within reasonable tolerances of the desired 21-25% oxygen, remainder nitrogen composition for normal animal and leakage use rates.

2. To minimize (within reason) the size of the atmospheric gas store needed to maintain the spacecraft for the required six month mission.

3. To provide a high level of inherent reliability so as to minimize the probability of mission failure due to the failure of system components which would lead to loss of maintenance of essential atmospheric characteristics and thereby produce death of the animals.

The characteristics of the atmospheric supply systems are reviewed in detail below with respect to the above mentioned considerations.

3.2.1.1 Atmosphere Control by O₂ Sensing

The atmospheric control could be attained through separate oxygen and nitrogen supplies used in conjunction with an oxygen (or nitrogen) concentration sensor and a measure of chamber pressure. The oxygen would be admitted to produce the desired oxygen partial pressure (21% of 14.7 pounds per square inch) and nitrogen added to raise the total chamber pressure to 14.7 pounds per square inch. The stored gases would need to contain approximately nine pounds oxygen to support animal oxygen metabolism, and additional oxygen (21%) and nitrogen (79%) to make up the estimated six month leakage loss.

This scheme has three basic shortcomings.

1. Stable oxygen (or nitrogen) concentration sensors are as yet unavailable with stabilities to operate accurately for six months time unattended.

2. A complex proportioning system is needed on the atmospheric supply to assure that the composition and pressure requirements are satisfied simultaneously.

3. A considerable stored gas allowance needs to be provided to allow for leakage of the life cell which will have to have a number of instrumentation and access openings possibly prone to small leaks. These might also be stressed and modified during launch into orbit with an unpredictable increase in leakage.

As will be discussed later, several of the following schemes obviate these difficulties and yet produce adequate passive control of life cell oxygen concentrations.

3.2.1.2 Atmosphere Control by Fixed Overboard Leakage

Atmospheric control may be accomplished by using a large fixed "leak" from the life cell, with atmospheric gas supplied at a constant pressure consisting of oxygen and nitrogen premixed in desired proportions. Since the gas supply is controlled to maintain a constant life cell pressure, the oxygen and nitrogen

supply must either be premixed or complicated proportioning controls provided to maintain the desired ratio of oxygen to nitrogen in the supply gases. Use of pressurized gas or supercritical cryogenic storage will permit premixing the gases and yet will provide the same gaseous composition on discharge. Subcritical cryogenic storage of mixed oxygen and nitrogen would result in prior preferential boil-off initially of nitrogen followed by oxygen. This would produce nitrogen over-rich life cell atmospheres initially for subcritical mixed oxygen-nitrogen storage. Since one cannot count upon the existence of an accidental leak of any specified size in the spacecraft, it will be necessary to make the flow through the intentional leak big enough so that the life cell oxygen concentration for normal metabolism depletes the life cell oxygen concentration to a desired nominal level around 25% and doubling the metabolism does not reduce the oxygen concentration below say, 16%.

One can calculate the variation of oxygen concentration with variation of animal metabolism using the fixed leak rate ventilation through the following material balance equations.

1. The oxygen input in steady state equals that metabolized by the animals plus the amount leaked overboard:

$$nf = mL + R$$

where; f is the supply gas feed rate, moles/ unit time

L is the leak rate, moles/unit time

n is mole fraction of oxygen in feed air

m is mole fraction of oxygen in life cell

R is the animal metabolism, uptake/unit time

The corresponding equation for nitrogen simply states that the nitrogen supplied in the makeup air must eventually leak overboard as the animals do not absorb it,

$$\text{thus: } (1 - n) f = (1 - m) L.$$

Combining these equations, one can solve for the relationship for m , that is, the oxygen content of the life space as a function of R ,

the animal metabolic rate,

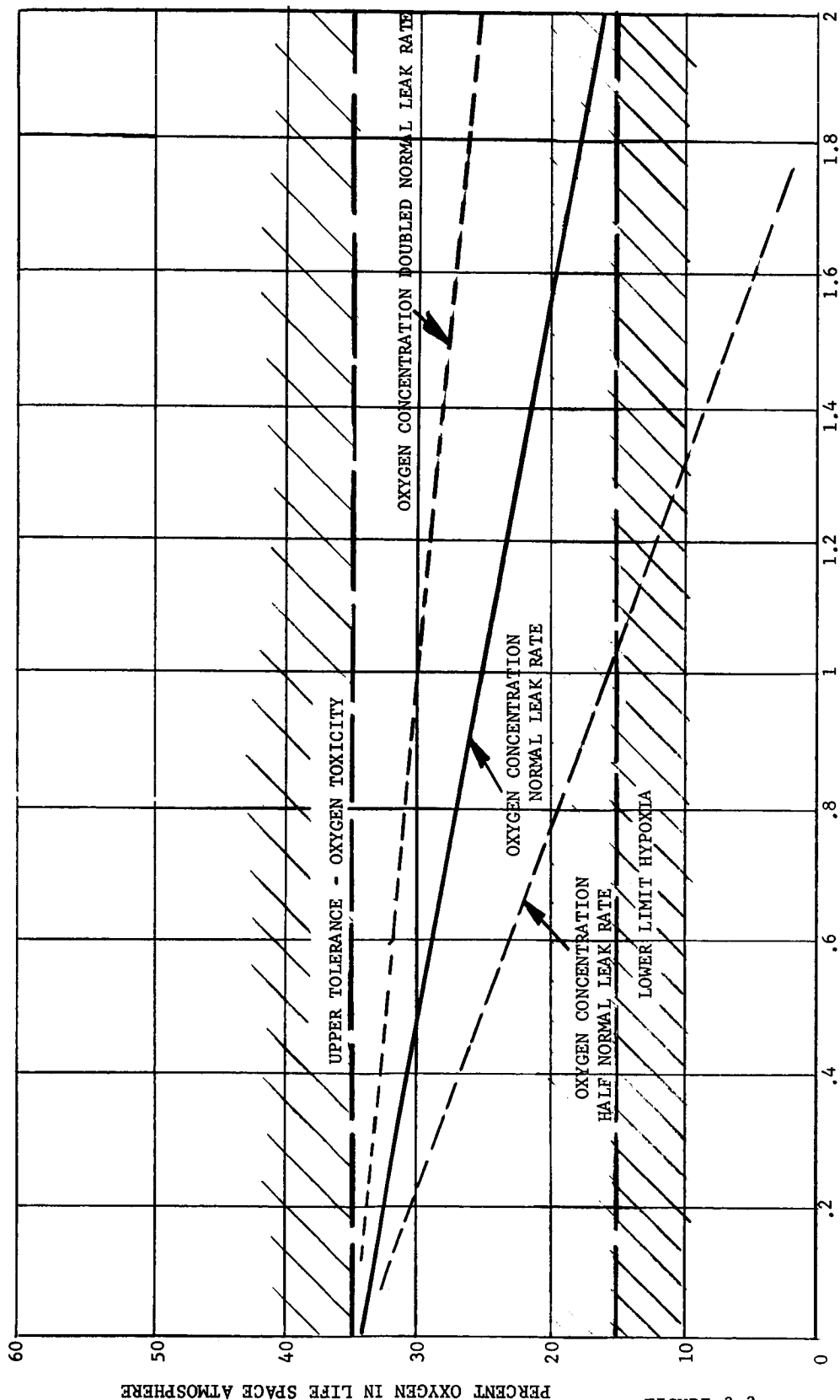
$$m = n - (1 - n) R/L.$$

Here we observe that n , the supply oxygen concentration, and L , the leak rate, are fixed quantities and thus m , the oxygen concentration in the life space, will vary with metabolic use, R .

The Naval Aerospace Medical Institute staff have estimated that a 1½ pound squirrel monkey will nominally metabolize about 0.024 pounds oxygen/day. If we now aim to maintain 25% oxygen in the animal space with normal metabolism and require that the atmospheric oxygen not fall below 16% for both animals steadily metabolizing oxygen at twice normal rate we obtain the results shown in Figure 3-3. Here one plots the variation in oxygen composition for a life space with a fixed leak releasing 0.28 pounds atmospheric gases/day with a makeup gas supply of 35% oxygen and the remainder nitrogen. For two animals metabolizing normally the arrangement produces a 25% oxygen atmosphere; if both animals simultaneously double their steady intake, the oxygen concentration falls to 16%; if one dies, halving the normal oxygen intake, the oxygen percentage increases only to 30%. The supply rate to the life cell must, of course, exceed the leak rate by the daily animal oxygen use so that the nominal daily atmosphere gas use rate is 0.33 pounds per day. For a 180 day mission, this would amount to 60 pounds plus allowances for accidental life cell leaks. If an accidental leak occurs, it produces a higher rate of life cell flushing and a decrease of oxygen vitiation. If the flush rate be doubled, the vitiation is halved with respect to the supply oxygen concentration. The dotted curve on Figure 3-3 shows the increase in life cell oxygen concentration which an accidental leak would produce if its size equalled the intentional leak. The nominal oxygen concentration becomes around 30%, a high and undesirable, but not serious, level. The loss of life cell gas increases to a total of 0.5 pound per day, or 90 pounds for a 180 day mission.

FIGURE 3-3

VARIATION IN LIFE CELL OXYGEN CONCENTRATION
WITH VARIATION IN ANIMAL METABOLIC USE RATE
FIXED LEAK RATE 0.28 POUNDS/DAY



RATIO OF ANIMAL METABOLIC OXYGEN USE TO NOMINAL
BOTH ANIMALS SIMULTANEOUSLY

FIGURE 3-3

The 0.28 pound per day flushing flow is not sufficient to control the large volume of water (approximately 135 grams) released daily by two animals and it is only partially effective in purging carbon dioxide from the life cell. Without other means of contaminant removal, the life cell gases would become saturated with water, liquid urine would accumulate, the carbon dioxide concentration would build up to 13%, or beyond a lethal level. This "leak rate" would have to be increased about 20 fold to purge carbon dioxide and water vapor to produce acceptably low water and carbon dioxide concentrations; such a 5.6 pound/day gas flow would be excessive and out of question for a 180 day mission.

This scheme has only three minor objections.

1. Oxygen and nitrogen must be premixed in storage for easy control.

2. Since the life cell leakage is not known, the gas storage must provide a large contingency for the added makeup gas flow needed to cope with the unknown as well as the normal flow. If the leak is large, the makeup gas flow control operating to maintain constant life cell pressure may be exhausted prematurely.

3. A partial closure of the vent (on a non-leaky life cell) will result in a mode of operation with a vitiated oxygen level. A closure to half initial for the fixed leak will reduce the oxygen concentration to the 16% marginal hypoxia level event at normal animal metabolic oxygen use levels.

3.2.1.3 Atmosphere Control by Fixed Rate of Gaseous Release From Storage

One can envision a simple change in the scheme of the above paragraph exchanging the fixed leak on the life space for a constant pressure relief valve set to hold the life space at 14.7 pounds per square inch by throttling the overboard leakage, and to provide the oxygen and nitrogen supply lines with constant flow

regulators instead of constant pressure regulators. Here, again, one selects a life space atmospheric flushing rate, now set on the supply instead of leakout side, such that variations in animal oxygen metabolism do not cause overly large changes in life space atmospheric oxygen concentration.

As in the above discussion one can again make a material balance analysis to determine the variation of life space oxygen concentration with animal metabolic oxygen uptake and gas supply rate.

Using the same equations as presented above except noting that the supply rate f is now fixed and the leak rate L an unknown variable to be eliminated in seeking a solution one has,

$$nf = R + mL: \quad \text{Oxygen balance supply/use and leakage}$$

$$(1 - n) f = (1 - m) L: \quad \text{Nitrogen balance supply/leakage.}$$

Eliminating leak rates, one secures a relationship for life cell oxygen concentration m , as a function of oxygen concentration in supply, and the ratio of metabolism to supply rate R/f :

$$m = \frac{n - (R/f)}{1 - (R/f)}$$

One can now select a supply gas composition, n percent oxygen and a supply rate f , such that one obtains a 25% oxygen concentration for normal rate of oxygen use and also maintain oxygen concentration at 16% for a doubled normal use rate by both animals. One finds that 0.455 pounds of $32\frac{1}{2}$ percent oxygen content atmospheric gases are needed per day. Figure 3-4 shows the effects for variations of sustained simultaneous variations of the animals' oxygen use rate upon the life cell oxygen concentration. Life cell oxygen concentration remains within safe limits for oxygen use between 0 and 200% of nominal values for the specified flushing rate. In Figure 3-4 the dashed sloping lines are drawn about the nominal oxygen concentration line showing the effects of varying the flushing

FIGURE 3-4

VARIATION IN LIFE CELL OXYGEN CONCENTRATION
WITH VARIATION IN ANIMAL METABOLIC USE RATE
FIXED SUPPLY RATE 0.455 POUNDS/DAY

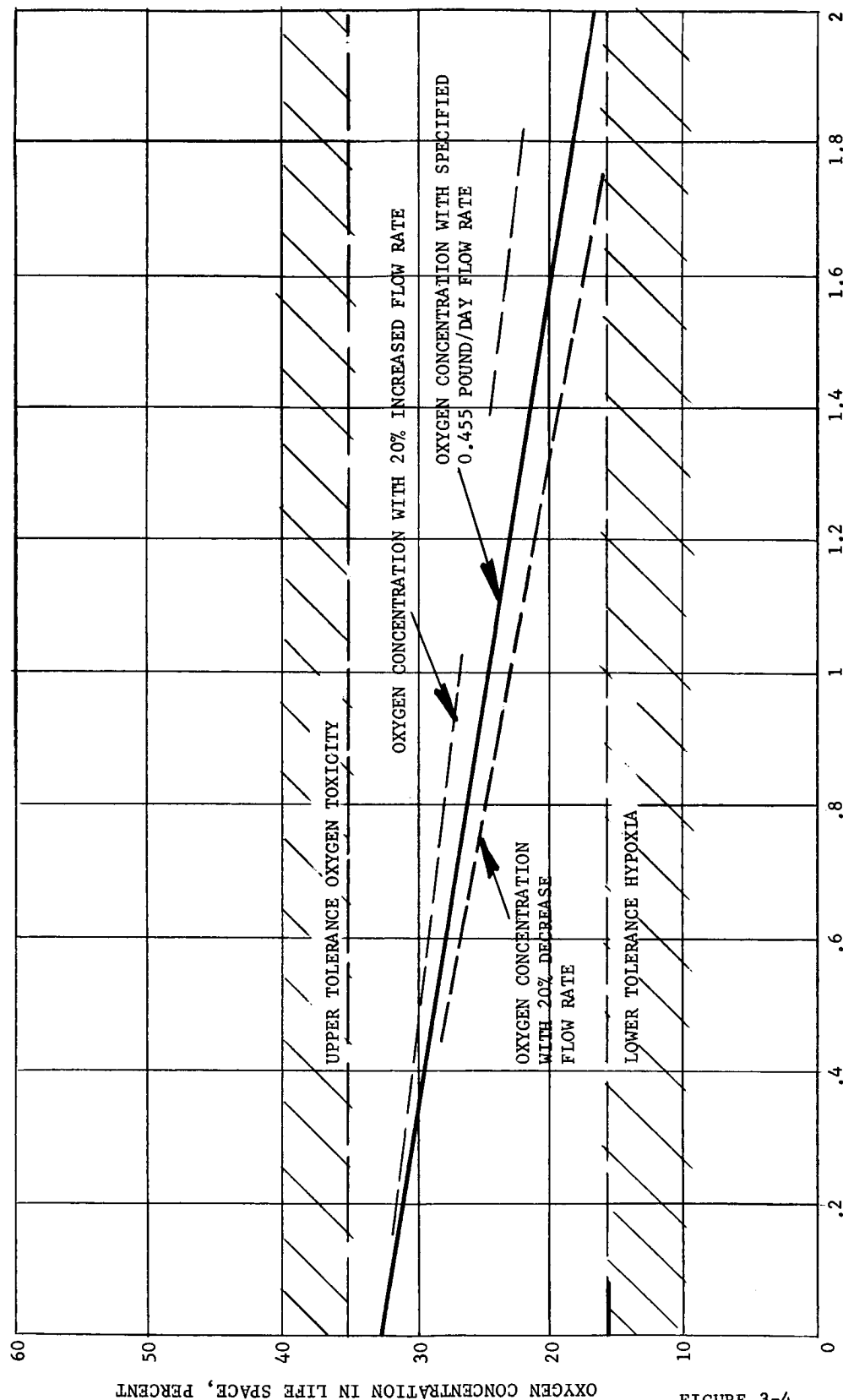


FIGURE 3-4

flow plus or minus 20%. The oxygen concentration variation at nominal oxygen use rate is seen to be only $\pm 2\frac{1}{2}$ percent out of 25%, thus the required flow regulation accuracy can be provided easily. For a 180 day mission, one would have to provide 82 pounds of stored gas to provide the required flow with a contingency allowance based upon these factors: (1) accuracy of flow rate control, (2) exact knowledge of duration of mission.

It appears likely that the flows can easily be controlled to $\pm 10\%$ through sensing of flow drop through a calibrated orifice in the supply system. Allowing for control inaccuracies, a 20% gas supply allowance should provide a sufficient safety margin. Since the vent valve releasing the overflow gases from the life cell will be providing a vent area to maintain life space pressure at the desired 14.7 pound per square inch level, any accidental leak will by-pass part of the flushing flow from the life cell pressure vent, thus simply allowing it to close. Thus no extra atmospheric gas allowance is needed to provide for accidental life cell leaks provided that the area of such leaks is not so large as to lower the pressure in the life cell to less than 14.7 pounds per square inch with the overboard vent closed. One would not fly the life cell with so great an initial leak but the leak might occur due to a life cell puncture by a micrometeorite or by damage during rendezvous-recovery.

At a small weight penalty, one can provide a second gaseous supply path through a regulator providing a parallel path to the first supply. The regulator would be set to maintain a constant 7.5 pounds per square inch pressure. During normal life cell operation without excess leakage, this regulator path would be closed as the life cell would be maintained at 14.7 psia by the outboard vent. During a casualty mode, this path would open whenever

life cell pressure dropped to this level. With $32\frac{1}{2}$ percent oxygen in the supply and high leak rates in the life cell in a casualty mode, the animals would survive at the reduced pressure as long as the stored supply of atmospheric gases remained adequate. This might permit several added days survival to permit emergency recovery.

In conclusion, this concept of constant rate supply of a mixed gas atmosphere with pressure controlled relief (and the emergency 7.5 psi parallel constant pressure supply path) promises an attractive system for the following reasons.

1. The components and controls involve only existing widely used technology.

2. Using reasonable ($\pm 10\%$) control tolerances, only a modest (20%) contingency is required upon the gaseous supply to allow for normal system inaccuracies.

3. The system is quite insensitive to small rates of leakage to space from the life cell atmosphere. Nominal atmospheric leakage rates in no way will affect orbital endurance.

4. Any small drift in the accuracy of the relief valve setting, say + 20%, only produces slow changes in life cell pressure analogous to a tolerable altitude (+ 5000 feet) change.

5. The system possesses an emergency survival capability in which the existence of the emergency is immediately apparent from the drop in life cell pressure. The life cell pressure during the period of high atmospheric gas loss rate is held at as low a pressure ($7\frac{1}{2}$ psi) at which the animals can safely survive.

The flushing rates in this system, as in the preceeding, involve moderate life cell gas flushing rates which do not remove water and carbon dioxide from the life cell rapidly enough to contribute to the life cell air purification process and so auxillary removal devices are needed to control atmospheric humidity, carbon dioxide and possibly odors.

3.2.1.4 Atmosphere Control by Selectively Permeable Membrane

The use of a silicone rubber selectively permeable membrane is another potentially attractive means for passive control of the animal life space atmospheric composition. Silicone rubber membranes are very highly permeable to water vapor, less highly permeable to carbon dioxide and organic vapors, moderately permeable to oxygen and still less permeable to nitrogen. If the life space were equipped with a suitable area of silicone rubber gaseous exchange membrane to free space, one could diffuse out the gaseous impurities to free space with only moderate loss of oxygen and nitrogen. It is necessary that the membrane be manufactured wholly free of pinholes and be mechanically supported to withstand the 14.7 pound per square inch pressure differential to space.

These silicone rubber membranes have been produced by the General Electric Company and used in underwater life support systems for small rodents (mice), amphibians (frogs), and insects (ants). The membranes used in these applications, however, are operated with equal total pressures on its two surfaces, but with differing gaseous atmosphere component partial pressures so that the life support atmosphere receives oxygen from that dissolved in the water to replace that used metabolically and also exchanges out carbon dioxide formed metabolically. Several samples of silicone rubber sheeting were secured from various sources in an attempt to locate a material which would permit the desirable gas exchange diffusion and yet not leak grossly through pinholes under a significant total pressure differential. None of the samples tested were sufficiently leak-free to be useful; all permitted such high rates of leakage under pressure that the desired selective removal of atmospheric contaminants was completely overwhelmed.

In theory, use of a 2000 square centimeter area silicone rubber membrane window on the life cell could vent out

to free space the carbon dioxide released by animal metabolism sufficiently rapidly to maintain carbon dioxide concentration normally at or below 1%. This same silicone rubber membrane being more water permeable would maintain the life cell relative humidity at around 15% for nominal animal water excretion. It would lose daily, by diffusion, assuming no leaks, 0.625 pounds of life support gas per day.

These desirable characteristics follow because of the widely different permeability of the membrane to different gases as indicated below (data furnished by General Electric Company, Research Laboratory). All permeabilities are given in gram molecular weights of gases passed per day at a 760 mm partial pressure difference per square centimeter area for a one one-thousandth inch thick film:

Nitrogen	3.25×10^{-3}
Helium	4.06×10^{-3}
Oxygen	6.96×10^{-3}
Hydrogen	7.65×10^{-3}
Carbon Dioxide	3.71×10^{-2}
Methane	1.09×10^{-2}
Acetylene	2.9×10^{-2}
Ammonia	6.8×10^{-2}
Water Vapor	0.43
Hydrogen Sulfide	7.53×10^{-2}

At present, the leakage rates through pinholes in these membranes are so great (orders of magnitude greater gas flow than by diffusion) that their use seems premature for a system to be built in the near future. Their promise is, however, so great that their development should be pursued for the great benefits this material may offer for passive atmospheric composition

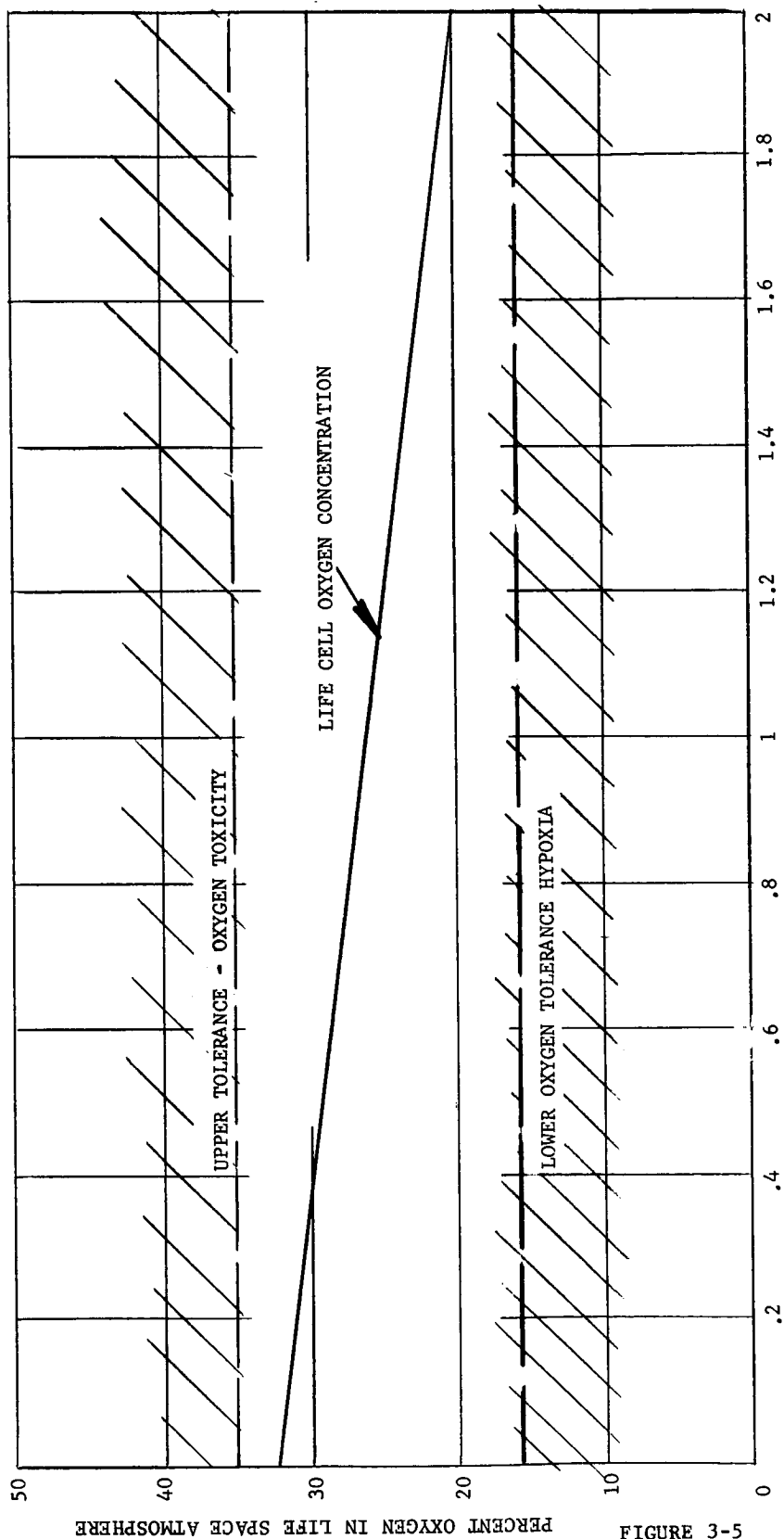
control. The membrane, through its higher permeability of oxygen to nitrogen, also produces an automatic compensation in composition as any decrease in atmospheric oxygen concentration causes a corresponding decrease in leak rate. Figure 3-5 shows the atmospheric composition control accomplished by such a selective permeable membrane (if perfectly leak free). Life cell oxygen concentration changes between from only 16% to 31% as the animal oxygen use is either halved or doubled.

3.2.1.5 Atmosphere Control by Chemical Oxygen Release

The final control technique for passive atmospheric composition control appears to be the use of a chemical which liberates oxygen upon absorbing carbon dioxide thus reversing the effect of the animals life metabolic processes which, of course, absorb oxygen and liberate carbon dioxide. Use of such a chemical is very attractive upon a weight basis. For example: a gram-molecular weight (71 grams) of potassium superoxide (KO_2) could, in principal, react with a half gram-molecular weight (22 grams) of carbon dioxide and liberate 32 grams of oxygen. In terms of weight storage efficiency, one could thus obtain all the breathing oxygen needed with a total weight burden only 2.2 times the weight of the oxygen needed over a six months time period, and one could absorb part of the metabolic carbon dioxide as well. Two problems appear; first, the life cell must have a two-gas oxygen-nitrogen atmosphere and any leak would remove both oxygen and nitrogen not replaced through the reaction of animal exhaled carbon dioxide with chemical; second, there is a variable relationship of exhaled carbon dioxide in respiration with respect to oxygen absorbed and also no chemical produces one gram-molecular weight of oxygen for each gram-molecular weight of carbon dioxide absorbed.

FIGURE 3-5

VARIATION IN LIFE CELL OXYGEN CONCENTRATION
WITH VARIATION IN ANIMAL METABOLIC USE RATE
SILICONE RUBBER MEMBRANE CONTROL



RATIO OF ANIMAL METABOLISM TO NOMINAL
SIMULTANEOUS VARIATION FOR BOTH ANIMALS
(NOMINAL METABOLIC LEVEL OF 0.024 POUNDS OXYGEN/DAY/ANIMAL)

FIGURE 3-5

The ratio of animal exhaled carbon dioxide (gram-moles) to oxygen inhaled and absorbed (gram-moles) is called the respiration coefficient, R.Q. For living animals, the R.Q. varies between 0.707 and 1.0 depending upon diet so that the chemical absorbant bed would have to be "tailored" to the inverse of this, namely to produce between 1 and 1.4 units of oxygen per carbon dioxide units absorbed. The available chemicals do not even provide a ratio of unity between carbon dioxide absorbed and oxygen liberated, and their reactions are in many cases influenced by atmospheric moisture. Potassium superoxide also reacts with atmospheric moisture to release oxygen. Life cell oxygen concent thus cannot be kept at a constant oxygen-nitrogen composition by such a chemical alone, but would have to be supplemented by addition of a mixed gas, (oxygen-nitrogen) to compensate for leakage. Further, a fixed "leak" might have to be provided to stabilize composition in case of over-activity of the chemical beds. The use of an oxygen liberating carbon dioxide absorber is thus only a minor improvement over providing the two-gas atmosphere from a premixed gas supply stabilized by a leak. The oxygen releasing chemical would serve simply to reduce the life cell oxygen concentration variations due to variations in animal oxygen metabolism

3.2.2. Contaminant Control

Animal life in the life cell will liberate feces, urine, flatus, and carbon dioxide. There is no indication that the animals will be trained to defecate or urinate into containers; consequently, their exhaled breath and excretions will add their volatile constituents to the life cell atmosphere. These contaminants can, in principal, be removed in three ways:

1. By adsorbents such as activated charcoal.
2. Through destruction by active chemicals such as superoxide.
3. Through purging to the free space vacuum surrounding the spacecraft. Such purging can occur either

through a controlled "leak" or through a selective permeable membrane.

The quantities of impurities other than carbon dioxide are microscopic and so the removal technique for these appears to be separate from carbon dioxide removal. Since no chemical data are available upon animal wastes, it appears appropriate to assume that their composition may resemble that of human wastes as presented in Section 13 of the NASA Bioastronautics Data Book SP 3006. These data indicate that the principal volatile components of wastes will be methane from feces and ammonia from urine, with additional methane and hydrogen sulfide from flatus. In absence of any scaling factor, it appears appropriate to scale urinary pollutants in terms of animal/man urinary volumes and similarly, for fecal quantities. On this basis, daily release of these pollutants may be as follows:

Ammonia	0.07 grams
Methane	30 cc or 32 milligrams
Hydrogen Sulfide	0.030 cc or 46 micrograms

Over a six-month time period, a total of only 18 grams of these pollutants would require removal. Activated charcoal (if protected from other adsorbable substances) would adsorb about one third to one half of its weight in organic gases or ammonia and hydrogen sulfide. A pound (452 grams) of activated charcoal would provide a maximum adsorptive capacity around ten times the amount needed for these trace impurities.

Carbon dioxide removal, however, requires a larger removal rate. As discussed earlier, atmospheric composition control through use of a vent to space produces also a measure of carbon dioxide removal but only in proportion to its partial pressure and thus at a low rate. A selectively permeable membrane such as the General Electric developed silicone is five times as permeable to

carbon dioxide as oxygen and so is much more effective in removing carbon dioxide. The two more suitable removal techniques for carbon dioxide removal are thus chemical absorbents such as lithium hydroxide or Baralyme or the use of a selectively permeable membrane.

3.2.2.1 Carbon Dioxide Control by Absorption

Control of life cell carbon dioxide buildup by a chemical absorber appears quite feasible in view of the wide use and relatively satisfactory chemical technology that has been developed employing lithium hydroxide or hydroxides of heavier alkalai metals such as sodium, potassium, calcium, or barium. Each animal in the life space will absorb daily approximately 0.024 pounds oxygen and exhale between 0.707 and 1.0 gram-moles carbon dioxide per gram-mole oxygen absorbed. One is therefore faced with the daily removal of about 0.057 pounds carbon dioxide daily for a 180 day total of 15 pounds.

The absorbtive capacities (to exhaustion) of typical carbon dioxide absorbents (pounds per pound) are as follows:

<u>Material</u>	<u>Absorbtive Capacity</u>
Lithium hydroxide	0.92
Sodium hydroxide	0.55
Baralyme	0.45

Of these, lithium hydroxide is the most attractive upon a weight basis but is prone to the generation of irritating dusts. These dusts could be readily trapped by arrangement of the carbon dioxide removal trap carrying the lithium hydroxide in series with the activated charcoal bed used to remove the low level organic pollutants. This dust would thus lodge upon the charcoal and not be carried on into the life space. The two beds would, of course, be separated from each other by partitions and an appropriate fiberglas filter mat. The weight of such a chemical absorbent trap would appear to be around 35 pounds.

3.2.2.2 Carbon Dioxide Control Through Selectively Permeable Membrane

The silicone rubber membrane discussed earlier in connection with two-gas atmosphere composition control possesses the very desirable characteristic of being highly permeable to carbon dioxide in comparison to oxygen and nitrogen. The use of the same 2000 square centimeter area silicone rubber membrane in the life space would (if the internal gases were circulated over its inner surface) maintain carbon dioxide at an appropriately low level. The carbon dioxide removal rate is proportional to the membrane area and the internal carbon dioxide concentration so that there would be a life cell atmospheric carbon dioxide concentration proportional to the animals' metabolic activity.

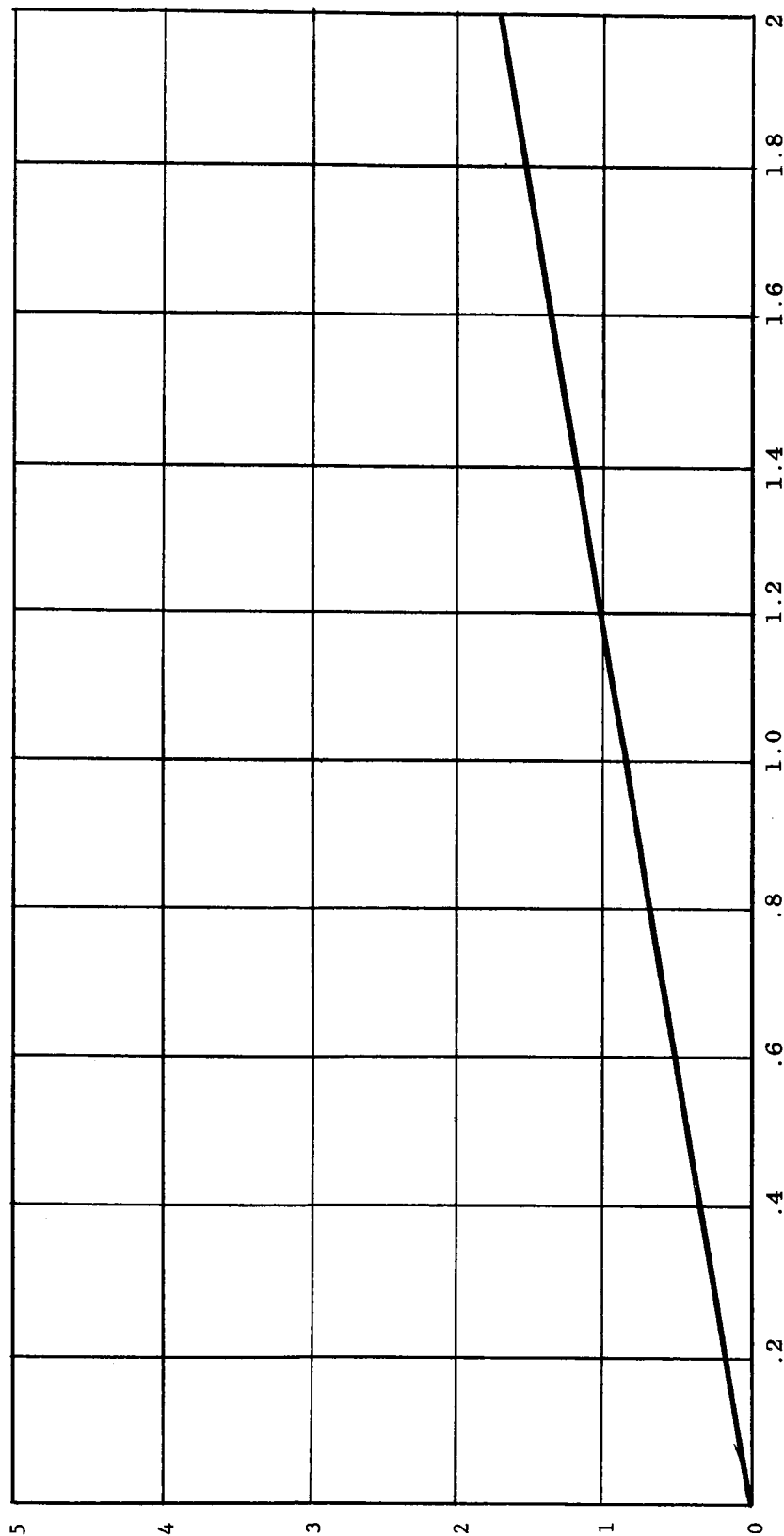
Figure 3-6 shows this variation of atmospheric carbon dioxide concentration vs. level of animal metabolic activity. Again, the possibilities of the membrane are attractive, but are conditional upon the production of pinhole free material. Membranes of some plastic films, such as cellulose butyrate, are somewhat permeable to carbon dioxide, but their permeability is so much less than silicone rubber that the required area of membrane to remove the animal metabolic carbon dioxide would be prohibitively large (about 1000 times as large as for silicone rubber).

3.2.3 Humidity Control

The two animals are expected to have a total average daily water intake around 135 grams. Except for a small water retention in animal growth, the animal water intake will be reflected in water release by the animals to their life space as perspiration or urine. A nearly negligibly small increment of water will be contributed by the animals' metabolic processes. Indications are that the animals cannot be trained to urinate and defecate into waste collectors so that it is very likely that such wastes will be released at random within the life space cage. In absence of gravity, there will be no defined "up" direction, and excretions

FIGURE 3-6

VARIATION IN LIFE CELL CARBON DIOXIDE CONCENTRATION
WITH VARIATION IN ANIMAL OXYGEN USE RATE
CARBON DIOXIDE REMOVAL THROUGH PERMSELECTIVE MEMBRANE



RATIO OF ANIMAL METABOLIC OXYGEN USE TO NOMINAL
BOTH ANIMALS SIMULTANEOUSLY

9-3-ENR1F CARBON DIOXIDE IN LIFE SPACE ATMOSPHERE, PERCENT

will probably be ejected at some velocity which will cause the wastes to impinge upon that portion of the cage structure lying in the path.

Under these conditions, water in the wastes will have to be removed by evaporation. The mode of atmospheric dehumidification will then establish the life cell relative humidity or conversely, choice of life cell humidity level will establish the scale of the moisture removal collection. For water vapor removal, analogous to removal of contaminants, two general approaches are available: (1) use of chemical absorbents such as lithium chloride or silica gel; or secondly, (2) use of a water permeable membrane to allow diffusion outward to space. The quantity of water to be removed in 180 days is 53 pounds, a great deal more than the quantity of other contaminants requiring removal.

3.2.3.1 Humidity Control by Absorption

Several chemical water absorbents are available which might be used for life cell atmosphere dehumidification but their water uptake capability is limited. Water absorptive capacities, pounds of water per pound of chemical are given below for the more suitable absorptive chemicals:

	<u>Capacity</u>	
	<u>Nominal 30% RH</u>	<u>Saturation 80% RH</u>
Silica Gel	0.15	0.4
Lithium Chloride	2.0	4
Calcium Chloride	1.2	3.4
Calcium Sulfate	0.066	0.09
Activated Alumina	0.075	0.13

Of these chemicals, only lithium chloride has a desirable high level of absorptivity and also a non-caking nature

facilitating its use. Silica gel would be competitive only under circumstances where its capacity for easy regeneration can be utilized. Calcium chloride "cakes" badly when wet and calcium sulfate and activated alumina have too little absorptive capacity to be useful. Since 53 pounds of total water needs to be absorbed over 180 days, about 27 pounds of lithium chloride absorbent would serve to maintain low humidity over the 180 day mission. Any small increase (20% - 50%) of the water release or mission duration would only push up the water loading on the chemical and produce a somewhat higher relative humidity but still below saturation.

3.2.3.2 Humidity Control by Permeable Membrane

Plastic membranes, not only of silicone rubber but also of cellulose materials (acetates, nitrates, butyrates) are highly preferentially moisture permeable. Moisture permeabilities of some of these materials are as follows. Units are grams of moisture permeation per day for 30% relative humidity into a vacuum per square inch area for a 1/1000 inch thick film.

<u>Material</u>	<u>Permeability</u>
Silicone rubber	0.5 grams
Cellulose acetate	0.144 grams
Cellulose Nitrate	0.115 grams

Of these films, one can easily secure tough, pinhole free sheets or tubes of the cellulose acetate or nitrate whereas as noted earlier the silicone rubber sheets of 0.001 inch thickness are fragile and apt to be porous with pin holes. Since the animal releases about 135 grams/day of water, one can, from the quotient of this by the membrane permeabilities, compute membrane areas required for water vapor removal which are as follows:

Silicone rubber	270 sq. in.
Cellulose acetate	960 sq. in.
Cellulose Nitrate	1150 sq. in.

The air impermeability of the cellulose plastics would mean that these would have to be used in conjunction with one of the "controlled leak" atmosphere flushing techniques for maintenance of the proper life cell oxygen to nitrogen ratio. As noted earlier, the silicone rubber membrane is also permeable to normal atmosphere gases and could (if pinhole free) serve to stabilize the ratio of oxygen to nitrogen in the life space

Experimental tests have verified the feasibility of selective water removal through membranes of cellulose, acetate, or nitrate and the availability of these leak-free material makes the construction of membrane type water removal device feasible immediately. Such a device would occupy about the same space as a chemical water removal device using lithium chloride but weigh far less inasmuch as one could replace the 27 pounds of chemical with about 1000 square inches of film suitably supported. A detailed summary of some test results on such films is given in Appendix B.

3.3 Atmospheric Circulation

The above discussions have established that the animals release carbon dioxide, water, and other contaminants which must be removed either by passing the gases through chemical absorbers or over permeable membranes through which impurities may escape. In either instance it follows that life cell gases must be circulated to bring the impurity concentrated air to the removal device. In the absence of circulation, large impurity concentration differences would arise since atmospheric convection does not occur in gravity free space; i.e., convection in gravity atmospheric environments arising from differences of gravitational pull on cool dense gases with respect to hot, less dense gases.

The circulation requirement is then fixed by the necessity for transporting polluted atmospheric gases through purifiers to effect removal of impurities as fast as such impurities are formed. The amount of impurity removed per unit time by a purifier is measured by the product of the total gas flow rate through the purifier by the concentration change within the purifier. For an efficient chemical absorber, all impurity is removed and the concentration change is equal to the initial concentration; for diffusion membrane techniques of impurity removal, the rate of impurity flow through the membrane is proportional to the local impurity concentration so that the membrane removal devices remove a proportional part of the incoming impurity.

The required flow rates, then, vary with the level at which it is desired to keep humidity or carbon dioxide concentration and with the removal technique. A flow rate of 21 cubic feet per hour is required to maintain the life cell at a 50% relative humidity for normal animal water use with membrane water removal. A slightly smaller flow may suffice initially for water removal by a chemical bed, however, such beds may deteriorate (loadup) with use and the same 21 cubic feet ventilating flow use would appear advisable. Flow system pressure drops are likely to approximate 10 inches of water. The total power required for air circulation is only 0.0005 horsepower.

Three simple means of providing this air circulation are as follows:

- (1) Electric power
- (2) Compressed gas power
- (3) Animal work power

3.3.1 Gas Circulation by Electric Power

The use of an electrically powered pump appears feasible and can probably be met using existing pulsating diaphragm type pumps similar to those used to aerate aquaria. Use of the diaphragm type pump prevents any atmospheric contamination by lubricants, and the devices can be operated by small amounts of alternating current produced by a transistorized inverter. In such small scale devices, efficiencies tend to be low; the inverter efficiency will be between 50-70%, the motor efficiency around 50%, and the pump efficiency around 50% so that approximately three watts electric power drain would be required continuously. One must also face the problem of electric motor reliability.

3.3.2 Gas Circulation by Compressed Gas Power

If the atmospheric supply gases can be provided from a pressurized source at 100 pounds per square inch or higher, this flow can be used to promote the required circulation of the life cell gases. The probable required make-up gas flow is around 0.5 pounds per day, making available a theoretical horsepower of 0.0006. Efficiency of practical devices at this low power level would be only around 25% so that the energy of the stored gas would suffice only to supplement the flow produced by other means. Since flow rate and pressure drops are related, this power level could maintain the circulation level at half the rate desired to maintain low carbon dioxide and humidity level. It would serve as a desirable back-up to any other mode of air circulation.

3.3.3 Gas Circulation by Animal Work

Since it is desired to have the animals perform "work" prior to rewarding them with food, the animal's muscular capability is potentially available to power the air circulation device. The release of carbon dioxide and urine by the animals

is probably related to their activity and thus only low levels of air circulation might be needed during animal inactivity. This low level air circulation might be provided by the energy of the makeup gas discussed above which would provide half the desired maximum flow and would suffice during periods of low animal activity. The animals work capability with respect to man can probably be estimated from the respective rates of oxygen metabolism. Two animals will metabolize about 20 liters of oxygen per day, the same amount as metabolized normally by a man in an hour. These two animals probably have 1/24th horsepower so about 1/400th horsepower could be produced over a sustained period by two monkeys. The animals contribution as noted earlier could be supplemented by circulation produced by addition of the makeup gases and therefore would not have to be continuous.

3.4 Waste Management

Since squirrel monkeys apparently cannot be trained in "sanitary habits" a severe waste collection problem is apparent. Some pertinent observations are:

(a) The wastes expelled in a gravity free space will be projected undeviated in the direction expelled until they impinge on the life cell or cage structure. If the surface on which they impinge is unyielding, the materials will splatter.

(b) In the absence of gravity, particles and droplets of waste will be held only by surface tension.

(c) The animals will probably tend to take whatever attitude is permitted by the cage when they defecate. Since defecation usually involves muscular contraction, the animals may prefer to "anchor" themselves to the cage during this period and one may (hopefully) selectively orient the animals during this period by making the floor (side of cage toward fecal trap) of material which the animals legs can grasp comfortably, and by making other surfaces relatively uncomfortable to hold. One needs to observe that in the absence of constraints and gravity, the animals in the absence of gravity will tend to propel themselves like rockets through ejection of wastes.

(d) Allowance must be made for the possibility that "down" may occasionally be reversed during the early period of near-weightlessness, while post-injection maneuvers such as transposition are in progress.

The use of graded porosity fiberglass mats appears to offer the best fecal collection system in conjunction with animal orientation techniques discussed above. The porosity of the fecal trap needs to be "graded" with upper layers of relative high porosity and with succeeding layers of decreasing porosity so as to prevent blocking of the top surface of the trap by a thin film

of dry feces and to permit efficient use of the entire fecal trap volume. About 12 pounds of feces will be generated in 180 days by two animals, and with dry fecal density about 13 pounds per cubic foot, one will need about one cubic foot volume for the trap, shaped to occupy the entire area under the animal life space.

Considerable incrustation can probably be tolerated on the cage walls, at the work station, and on the conical inner surface "above" the cage. It must not be allowed to obscure the television camera view, though, or to impair illumination. To prevent such blockage, a "view cleaner" is visualized near the cone apex, shielding both the camera lens and the cage light source from fecal deposition. It would consist of a traveling strip of transparent plastic that would continually (or periodically) present a view clean surface to the field of view.

Feces build-up on the weighing device poses no great problem in mass measurement accuracy since weight can be determined as part of each operation, but care must be taken to assure adequate clearance for the required motions.

It should not be difficult to secure air velocities great enough to exert a significant air drag force to slowly remove such particles from the life space atmosphere. This flow velocity will serve to change the air in the life cell once every 3 to 5 minutes and thereby help to remove particles in the life space atmosphere.

3.5 Feeding

At the present time there are two types of food widely in use in laboratory work with the squirrel monkey: liquid and solid. The liquid food now under test at Naval Aerospace Medical Institute is the so-called Schwartz Diet which is 50% water. The solid food is a pressed, formed cylindrical pellet. The liquid

diet is presently under test and the results are not fully satisfactory. In this phase of the study the emphasis has been on the solid food diet, since the liquid food dispensing system is similar to the water system and can be handled in that phase of the study. It is understood that the CIBA Pharmaceutical Company diet might be an acceptable alternate to the liquid diet.

We are informed that the liquid food consumption of the squirrel monkey is approximately 45 cc/day and 30 gm/day for solid food. The water intake is around 50 cc/day in both the liquid and solid food diets. In Table 4 a comparison is made between the weight and volume of liquid and food diets. Both the liquid diet and water storage, transfer, and dispensing systems are similar in weight and volume. The liquid diet requires less volume for storage than the solid food, and does not require a mechanical feeder, but it presents a corrosion and dispenser clogging problem.

Samples of the CIBA Pharmaceutical Company 75 mg. whole diet have been secured to assist in the design of possible packaging techniques, along with a paralleled investigation to determine if a monkey feeder for a space mission was commercially available. This investigation disclosed one unit which is built by Inventive Engineers, Inc., but it is designed for chimpanzees and not squirrel monkeys. The manufacturer of this unit feels it can be modified but only to the extent of 20,000 pellets total capacity. The mission requirements as stated in Table 5 is 80,000 total, therefore, this is not adequate. The investigation into packaging techniques for the 75 mg pellets has led us to consider a rectangular and a cylindrical tape package scheme as most feasible.

The rectangular tape is made of .003 mylar ribbon with an 0.2" thick sponge rubber facing (Figure 3-7). Holes 0.150 in. diameter are punched in the tape at 0.300" between center, and

the pellets are inserted into the holes. The pellets being 0.190" in diameter will thus be held in place and will not rub against each other.

The tube packaging configuration is pictured in Figure 3-8. The tube is made of PVC type 0.005" thick and 0.750" wide. The pellets are loaded in place on the tape, the tape is then drawn through a forming die which wraps the PVC around the pellets to form the tube. The PVC is then heat-sealed and the excess material is cut off. The completed tube is then rolled on to the storage reels. This type of plastic is used because it is flexible, can be heat sealed, and is moisture proof.

TABLE 4

Monkey Food and Water Requirements

<u>Type of Food</u>	<u>Daily</u>	<u>180 Days</u>	<u>Contingency</u>	<u>Total</u>	<u>Weight</u>	<u>Volume</u>
Liquid food	45 cc	8100 cc	900 cc	9000 cc	23 lbs.	0.32 ft. ³
Solid food	30 gms.	5400 gms.	540 gms.	3940 gms.		
75 mg pellet	400	72,000	7200	79,200	13 lbs.	0.50 ft. ³
190 mg pellet	160	28,500	2850	31,350	13 lbs.	0.50 ft. ³
Water	50 cc	9000 cc	900 cc	9900 cc	22 lbs.	0.38 ft. ³

(NOTE: If no units appear after numbers, number designates pellets)

TABLE 5

Pellet Food Storage Requirements

<u>Size</u>	<u>Number of Pellets</u>	<u>Type of Package</u>	<u>Width of Reel</u>	<u>OD of Reel</u>	<u>Volume</u>
75 mg. pellet	72,000	Tube	6"	12.0"	0.4 ft. ³
" "	72,000	"	12"	9.5"	0.5 ft. ³
* " "	82,000	"	11"	9.5"	0.45 ft. ³
" "	72,000	Ribbon	6"	14.0"	0.46 ft. ³
" "	72,000	"	12"	9.5"	0.5 ft. ³
* " "	82,000	"	12"	10.5"	0.6 ft. ³

* 75 mg. wafer	82,000	Flat type	12"	8.5"	0.4 ft. ³
" "	72,000	" "	6"	10.5"	0.29 ft. ³
190 mg. pellet	28,500	Tube	6"	11.5"	0.36 ft. ³
" "	28,500	"	12"	7.5"	0.31 ft. ³

(* indicates redundant dispenser units)

3.5.1 Food Storage Containers

Each of the two solid food storage containers, as envisioned, store approximately 81,000 pellets for the redundant dispenser configuration. This configuration is designed to insure adequate food to the monkey if one dispenser fails to operate. The containers and delivery chutes could be of welded aluminum alloy construction to insure the integrity of the pressure system.

On each container there could be a high pressure nitrogen bottle with a regulator to maintain the pressure at the pressure of the life cell. The reason for using nitrogen as the pressurizing gas is to maintain the vitamin values at a desirable level. CIBA have stated that the vitamin "C" in pellets will deteriorate in about 3 months in a dry partial oxygen atmosphere but will remain viable for about 6 months in a dry oxygen free atmosphere. The pressurized storage system also will prevent migration of life cell gas with its moisture into the stored food.

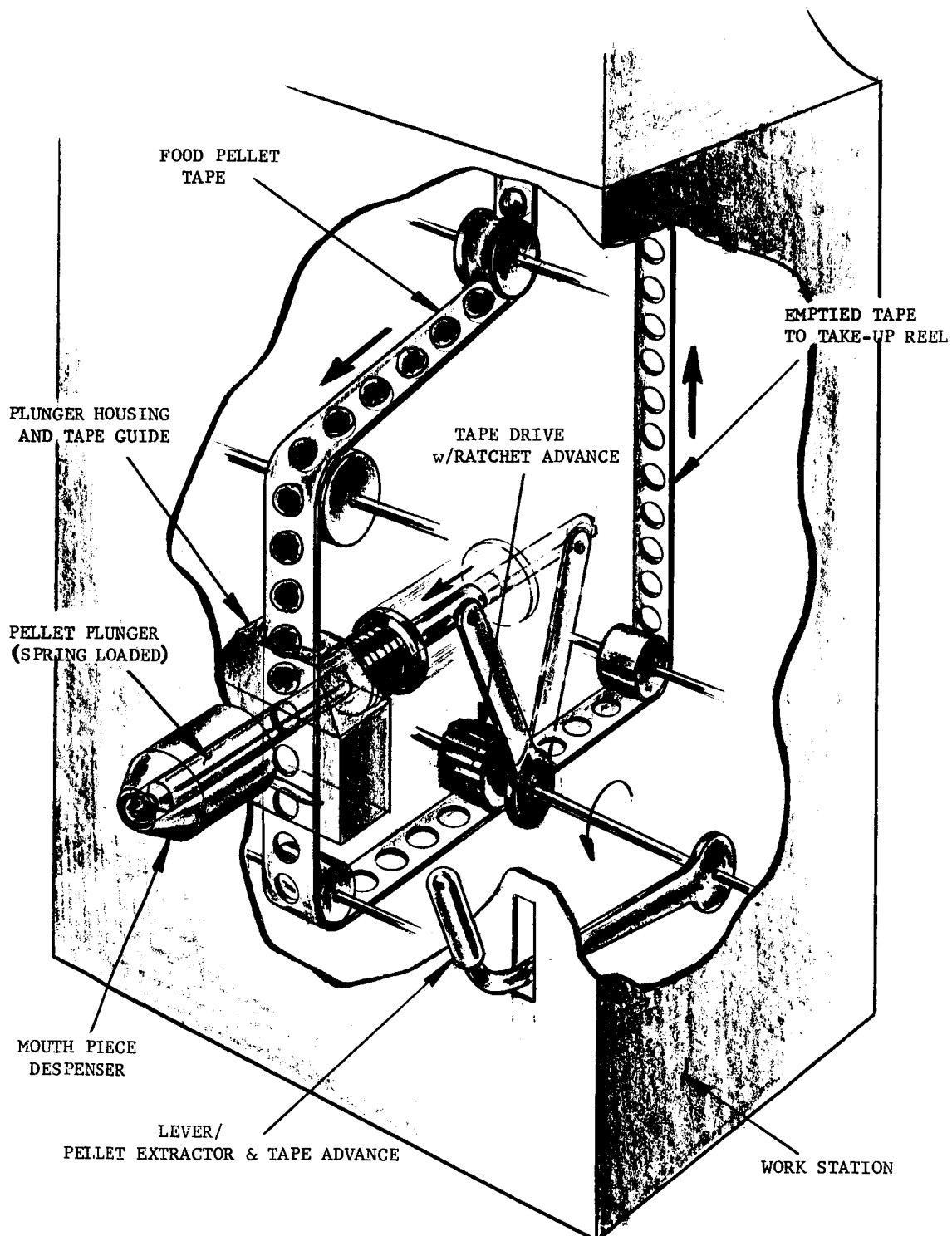
The pellets stored in the casing type configuration would be packaged in a nitrogen atmosphere and those in the tape configuration would be subject to the atmosphere in the storage container. Both types of pellet holders would be wound on spools similar to those used in winding wire. The spools would be loaded with the pellet filled tapes during the pellet packaging operation. The spool assemblies would be mounted on ball bearing assemblies to reduce the force required to advance the food since the monkey may supply the power to dispense and advance his own food. The drive

mechanism at the dispensers would supply the pulling force required to unroll the tapes from the storage spools. The expended pellet casings would be stored on a spring loaded spool in the storage container.

3.5.2 Food Dispensers

A dispenser for a so-called casing type of packaging is shown in Figure 3-8. This unit is part of the work station and could receive its power for operation from the monkey operating the work handle. As shown in Figure 3-8, the food pellets enter the top of the station and are fed into a casing guide which brings the casing past the cutter blades which cut the casing in half. The pellets enter the tube leading to the dispenser and the casing is pulled by the tape driven gears which are used to advance the food to the dispenser. The casing is then sent back to the take-up reel in the storage container for storage. The mouthpiece portion of the dispenser consists of a Kel-F tube which has a lip switch and thermister mounted in it. The pellets would be expelled through a hole in the center of the mouthpiece into the monkey's mouth.

A dispenser for the tape type of package is illustrated in Figure 3-7. This dispenser is an alternate to the casing type design. It is powered in a similar manner but has a different pellet extractor mechanism. The pellets enter the top of the unit and are guided to the extractor mechanism by a teflon lined tube. The position of the pellets would be controlled by an electric eye to insure the proper alignment of the pellet in front of the extractor when it is activated so to inject a pellet into the monkey's mouth. The mylar backing for the foam is similar to the 16 mm movie film and the advancing mechanism for the tape is similar, so that there is a positive displacement of the tape at all times. The emptied tape could be stored in the take-up reels similar to that in the



FOOD DISPENSING UNIT
(FLAT TYPE TAPE)

FIGURE 3-7

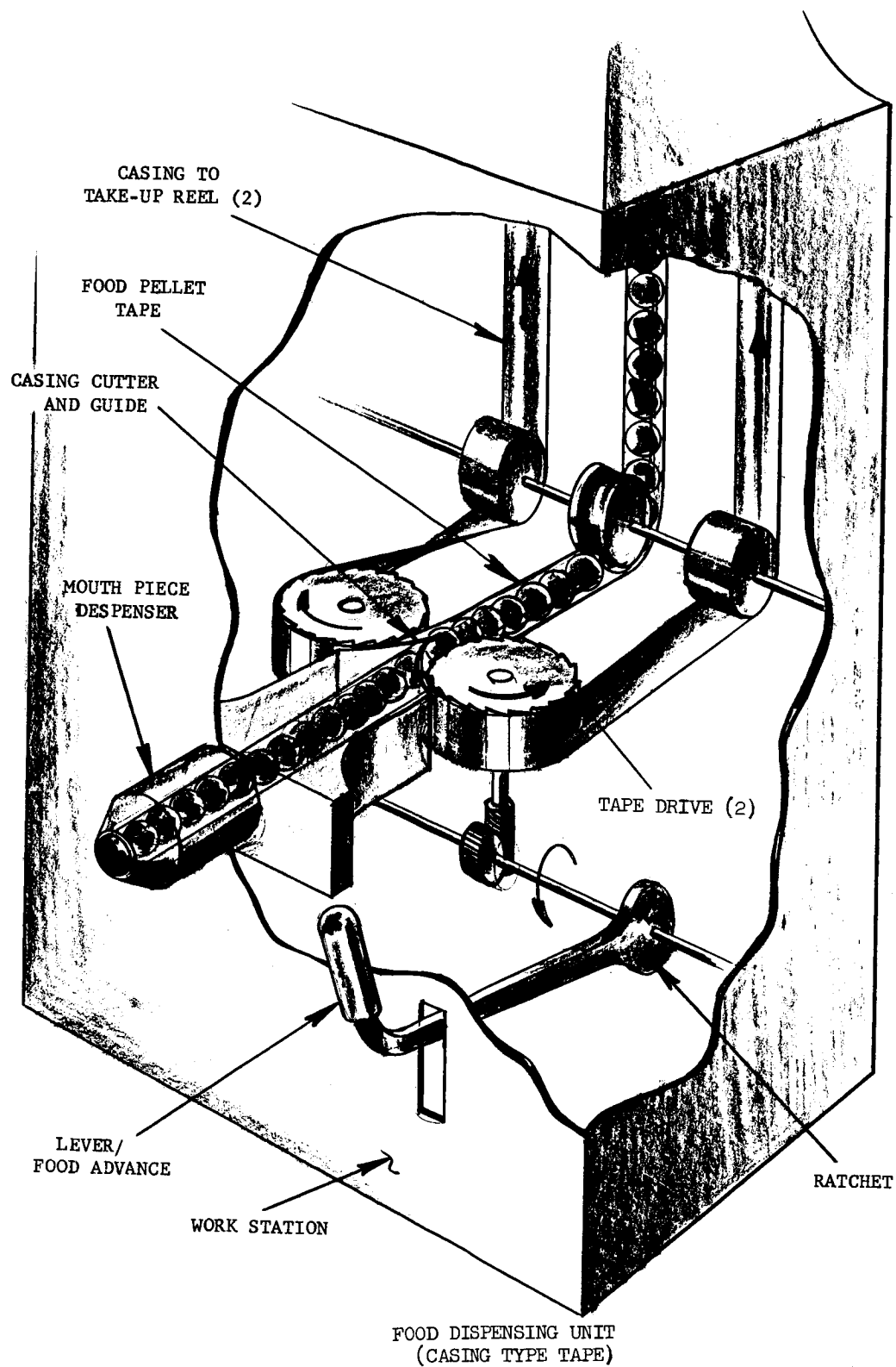


FIGURE 3-8

casing method with one change. Since the major volume of the tape is foam, the foam is compressed by a roller during take-up to reduce its height from 0.200" to .010". Again the mouthpiece of the dispenser would consist of a Kel-F tube with a lip switch and thermistor mounted in it. The pellets would be ejected through the center of the mouthpiece into the monkey's mouth.

Both types of solid food and also the water dispensers envisioned here could be powered by the monkey doing work at the work station. The work performed by the monkey would be transformed into potential energy in a spring mechanism. Upon selecting which dispenser he wishes to use, he would close his mouth over that mouth piece and lip switch. The closure of the lip switch releases the dispensers mechanism and dispenses the food. Upon making his selection, the other units should be disarmed and inoperative at this time. Upon the completion of this feeding one dispenser mechanism would be unloaded and two still loaded. When the monkey operated the work station the next time, he would wind up the spring in the unloaded unit, thereby reloading that unit. This procedure is suggested to minimize the work required from the monkey at any one time.

An additional good packaging technique that may be feasible is the one now being used by NASA Ames for chimpanzee studies. It is a flat pellet, the shape of a wafer 0.2" x 0.2", and can be placed on a mylar tape which has a non-toxic adhesive spread on it to hold the pellets. This technique was developed by Inventive Engineers, Inc., and is now in production.

Table 5 indicates some of the parameters involved in the different configurations of packaging, the number of pellets of different size and are of required storage containers. The single unit indicates no redundancy is considered in the system and

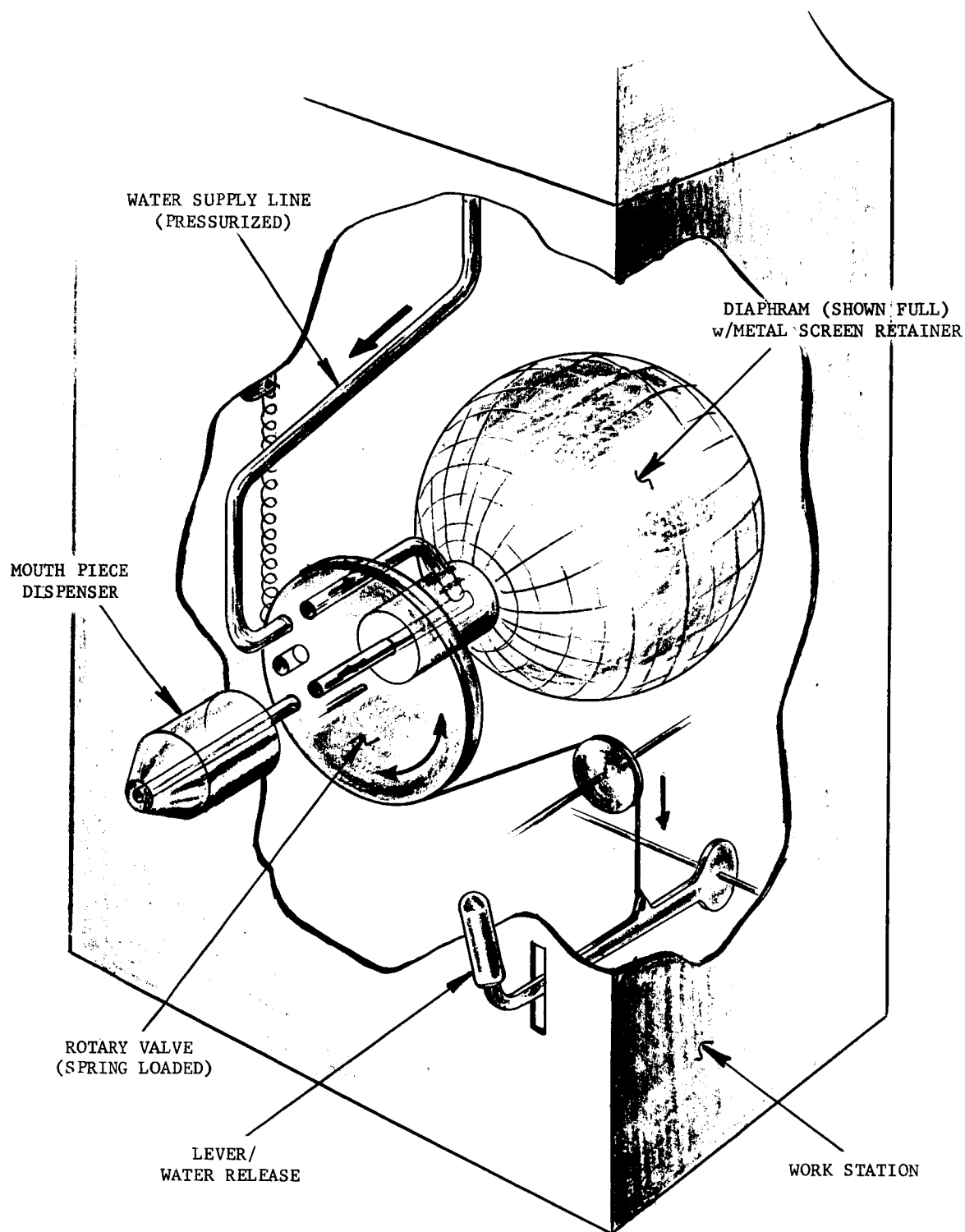
a dual unit indicates a redundant system is assumed which will supply upwards of 300 pellets a day to the monkey if one unit fails early in the mission.

3.5.3 Water System

The water system for the monkey as envisioned contains three main sections; the storage tank with its pressure bladder, transfer piping, and the dispenser. The water consumption of each 540 gram squirrel monkey is approximately 50 cc per day (Figure 3-9) or 9000 cc for the entire 180 day mission including a 10% contingency. In discussions with NAMI personnel it was concurred that a control water supply for all experiments and flight test should be established along with the central food supply.

The water storage tank shown in Figure 3-10 is of stainless steel construction with a volume of 0.4 ft.³. In the zero g environment, the water system must be pressurized to insure positive displacement of the water to the dispensers. This may be accomplished by means of a balloon type bladder. There is a manifold inside the tank that will insure against the bladder blocking off the water flow. The tank would be filled with water, the bladder assembly then inserted and charged with nitrogen. As the water is consumed by the monkey, the bladder will expand to maintain a relatively constant pressure within the system.

Insofar as the water storage tanks are stored outside the life cell area, it will be necessary to design thermal control for the water system. It is desirable to deliver the water to the primate at his normal environmental temperature. The area surrounding the tank is subject to temperature changes, during each orbit, therefore, the lines and tanks may require insulation and temperature control. To insure against leakage there should be a



WATER DISPENSER SYSTEM

FIGURE 3-9

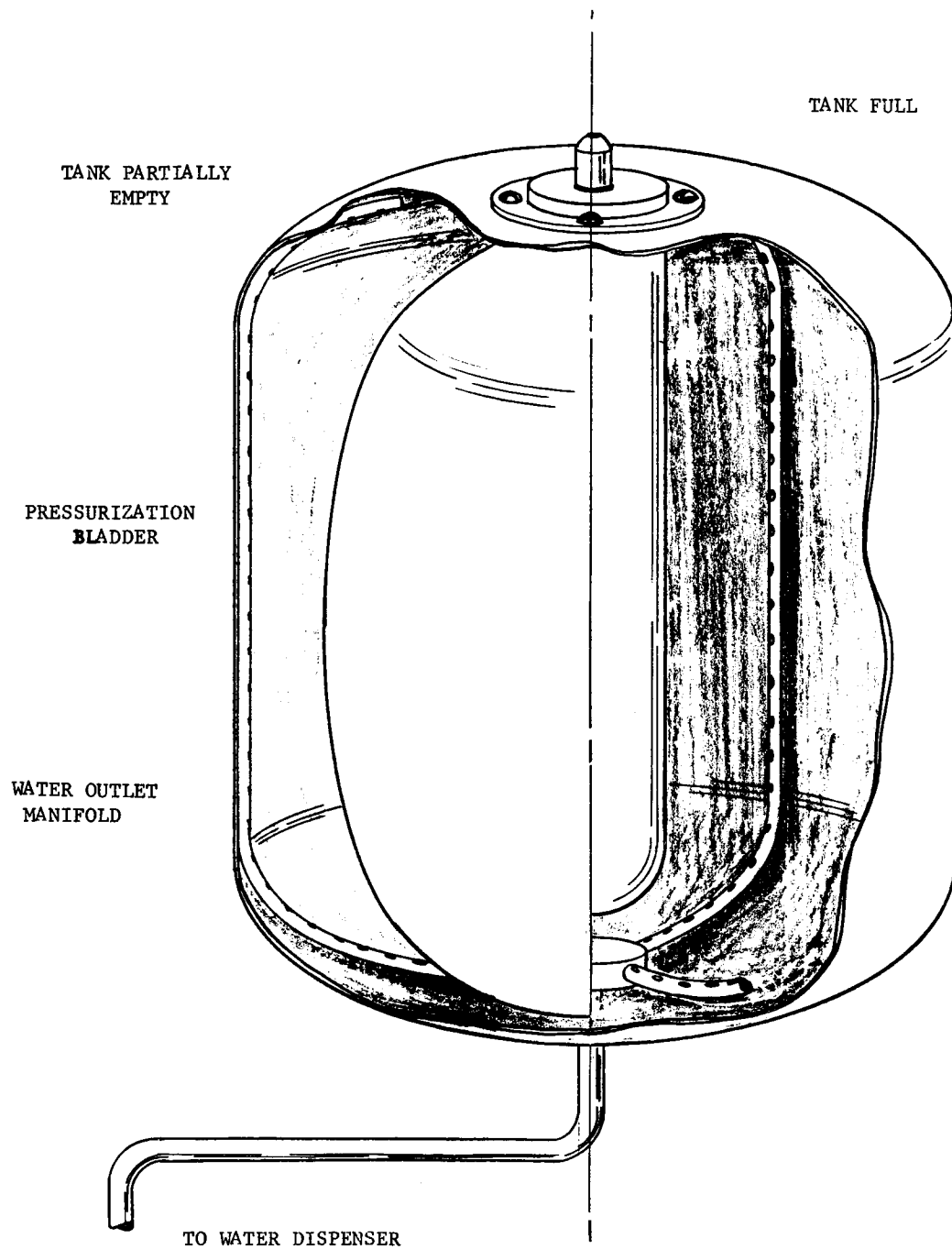


FIGURE 3-10

minimum of joints outside the life cell area, because the tanks and piping are in a vacuum environment. In all cases, the piping would be made of stainless steel with highly reliable couplings.

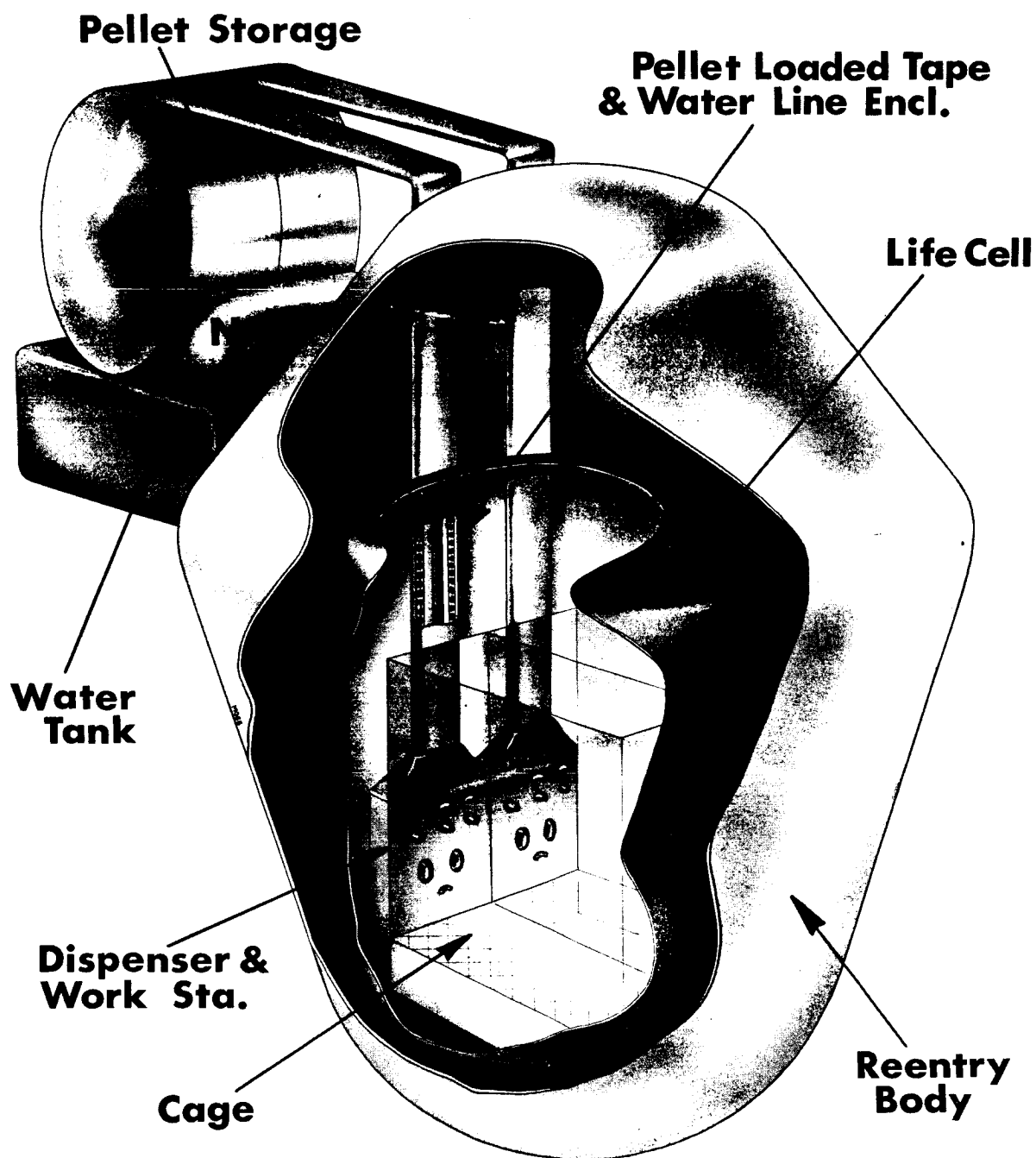
The water dispenser shown in Figure 3-10 would be part of the work station and would be mounted between the two food ports. This unit consists of a two-way rotary valve, a spring load operating mechanism, a mouthpiece with the lip switch, and a latex bladder inside a screen retainer.

In its normal position, the rotary valve is connected to the water storage supply. The water under pressure flows into the latex bladder expanding it against the screen retainer at which time the water flow will stop. When the monkey closes the lip switch on the mouthpiece, the rotary valve rotates to the dispensing position, which permits the life cell pressure to deflate the expanded bladder which then forces the water out of the dispenser and into the monkey's mouth. Upon removing his mouth from the dispenser, the rotary valve rotates to the "fill" position by means of a spring mechanism. The volume of the water dispensed each time is a function of the size of the diaphragm and screen retainer. It is also possible to have the position of the screen retainer movable to increase or decrease the volume allowed to be filled by the diaphragm during filling, thereby controlling the amount of water at each dispensing.

An artists concept of a possible feeding, watering, and life cell configuration which would be compatible with existing, already developed orbit re-entry hardware, is shown pictorially in Figure 3-11.

3.5.4 Medication

Due to the unusual stresses to which the subjects in this experiment will be exposed it is not unlikely that conditions



FEEDING AND WATER SYSTEM

FIGURE 3-11

may develop in which it is desired to administer medication, either of preventive or corrective nature.

Thus it may be desirable to have a corrective medication unit incorporated in the water system at the dispenser to correct for possible inflight sickness such as diarrhea or constipation. This system could be a bank of vials which could be broken on ground command to inject corrective medicine into the water system. Likewise, it would also be possible to place a preventive medication unit with, or in place of, the corrective unit. The preventive medication unit could be programmed to inject medication at a regular interval during the mission.

Regular or preventive medication could also be administered by treating selected food pellets with the desired medicine. The subjects would then receive low level treatment as a regular part of their diet.

Each of the tanks would have separate piping systems but would have a command manifold at a point just ahead of the medication units. This would permit a margin of redundancy without a complete additional system.

3.6 Work Stations

The work station which has been mentioned previously would be mounted in the cage area at a sufficient distance from the social area to avoid social contact at the work station. The work station configuration shown as in Figure 3-11 consists of two "U" shaped work handles, an indicator to show the monkey when the work station can be operated, and three dispensers, two of which are solid food and one water. Each dispenser has an indicator which when activated indicates it is ready for operation. These indicators are a flag type and an audio signal. This is to conserve power and to increase reliability over lamp type indicators.

Two work handles are required in case the EKG and pulse rate monitoring is to be obtained during the work cycle from sensors mounted in the handles. If these two functions can be monitored by a different technique, a single work handle will be sufficient. The repeated back-and-forth operation of a single handle for reward is more natural than the sustained pull of two handles simultaneously. An added advantage of the one-handled work station would be that useful mechanical work may be thus obtained from the monkey which can be used to advance and dispense his own food and water and perhaps accomplish other mechanical functions.

3.6.1 Work and Feeding Schedule

To initiate the work and feeding schedule, the monkey must first have a successful mass measurement. Upon completion of this measurement, an audio and visual indication would then be given to the monkey that the work station is activated. The monkey would then be given an indication of the type of work task he is required to perform. This is controlled from the ground through the task logic circuit. Successful completion of his task is indicated by a flag indicator at the dispensers. At this point, the monkey has a choice of solid food or water, but not both. To activate the dispenser, the monkey closes his mouth over the dispenser and lip switch. At this point, his choice of reward is injected into his mouth. When food or water is obtained at the dispensing port, the other ports are disarmed. The monkey can perform a preselected number of work-feeder cycles before he must return to the mass measurement station to reactivate the feeder station.

3.6.2 Monitoring

The monitoring of the work effort and task requirements would be controlled and recorded in the task logic unit. This unit controls and records the animal's performance for the task. A counter unit records the number of food and water dispensing for each dispenser on a regular basis and can be obtained by ground command.

3.6.3 Mass Measurement Device

The mass measurement unit would consist of a box into which the monkey will back himself. The box would be constructed in such a manner that the monkey is held as rigid as possible to insure an accurate measurement. A dual balance spring arrangement will hold the box in equilibrium. The box is deflected to initiate the measurement and released by a solenoid. A mass determination is made by measuring the period of oscillation. While it is recognized that a highly accurate measurement of the mass of the monkeys would be very difficult while in orbit, it is felt that an accuracy adequate to determine the basic physiological condition of the monkeys will not be unreasonable. Techniques can be developed and refined from careful, thorough ground based studies prior to design of the detailed instrumentation.

3.7 Mechanical Configuration

The life support package would be an aluminum pressure vessel approximately 24 inches diameter by 36 inches long, of which a 20 inch long segment would be allocated to living space. This space would be further divided along a diameter into two cages, one for each specimen. The lower floor of each cage would be constructed of 0.062 inch diameter stainless steel wire on 0.5 inch centers, while the top could be constructed of a much smaller

wire (approximately 0.010") on 0.75 inch centers with an interlocking mesh. The solid divider wall between the two cages would contain a social window measuring approximately 6 inches by 8 inches with four 0.060 inch diameter wires on 1 inch centers. The outside walls of the cage are solid material. The activity of the specimens would be monitored by a TV camera located at one end of the pressure vessel.

At the opposite end of the vessel and outside the "floor" of the cages would be a fiberglas mat of graded porosity used to collect both feces and urine. Movement of these materials would be aided by the circulation of air through the cages and the mat.

The work stations (feeders/waterers) should be sufficiently far from the social area to avoid social contact while at the work cycle. All food supplies would be stored outside the living space in inert gas pressurized containers. Water would also be stored in a similar manner and forced into the work station by a pressurized bladder.

The gas mixture for the living space atmosphere could be stored either as a compressed gas mixture in externally mounted vessels, or as a cryogenic mixture in vessels pressurized to maintain the gasses in the supercritical state. If stored pressurized at approximately 3000 psid conventional valves, reducers, and pressure regulation, all of which would be mounted within the living space pressure vessel could be used.

The mass measurement station is mounted as far from the social area as possible. This unit may be mounted inside the living area, but should be as reliable a mechanism as possible. It is desirable to have this station arranged so that the work panel is visible from the station.

4.0 PHYSIOLOGICAL DATA ACQUISITION AND INSTRUMENTATION

Instrumentation will provide monitoring of variables which relate to the physiological condition of the subjects. The design will accommodate two squirrel monkey subjects, each weighing approximately 540 grams. The system will be designed for a 6-month mission to be preceded by pre-launch checkout. During the 6-month experiment, no adjustments and modifications (other than those which can be made via the command system) can be made. The subjects are not to be restrained by harnesses and/or wires, and are not to be encumbered by harnessed instrument packages.

Several variables are to be monitored, and must be accommodated by the instrumentation system. Some of these are basically physiological variables; others relate to overt activity of the subjects and to conditions existing in the life support system.

Discussions which follow will describe proposals for monitoring heartrate, respiration rate, body temperature, mass, gross activity, food consumption, water consumption and work panel activity.

4.1 Physiological Monitoring Components

4.1.1 General Considerations

System components which are considered to possess characteristics which offer greatest promise of applicability to this experiment are described below. The majority of the discussion is devoted to these devices. In addition, other devices which have been considered and which appear to hold less promise, yet which may be found to merit consideration as the system design proceeds, are mentioned.

The term "components" refers to those devices which are utilized in combination in the systems which are described in Section 4.4.1. Components are described separately here so that additional detail may be furnished without encumbrance of the description of the complete system.

The fact is recognized that there are many problems associated with utilization of implanted instrumentation components. Nevertheless, use of implants is felt to be greatly superior because of the preponderance of problems which exist when other techniques are utilized for a mission this long in duration. Also, the experiment is to be conducted under a zero gravity condition. It is expected that this condition will impose many hardships upon instrumentation because of floating debris and waste products, and it is felt that utilization of implants would greatly reduce the deterioration of sensing mechanisms as a result of such foreign matter.

The use of implants should reduce also the susceptibility of the system to failure because of changes in the behavior of the animals. While effects on the performance of implanted systems due to changing behavior can be expected, it is not likely that these changes will pose as great a threat to the success of the experiment as would the same changes in behavior in systems not using implants. It is expected that it will not be possible to predict behavior of these subjects under prolonged zero-gravity conditions. It follows that instrumentation should be designed so as to be subject in a minimal way to possible changes in behavior patterns.

The respiration rate instrumentation may be cited as an example of this. A thermistor probe detector, properly designed, would probably be a satisfactory sensor. The thermistor could be placed somewhere near where the animal's nostrils could be expected to be. The most logical choices would likely be near the work panel or the "massing" station where the subject will be trained to go in performing the prescribed work schedule. Design of these systems are greatly complicated, however, by the fact that a subject in zero gravity conditions may be oriented in any position relative to the bottom of the cage. The area monitored by the sensor

would need to be large enough to operate when the subject was in any position. Also, the animal may possibly be "massed" in a position other than those which are considered normal in an environment where no gravity exists. While it is true that the mechanical design of the cages can be made to force the animal to assume certain positions, there are a great number of possibilities for deviations.

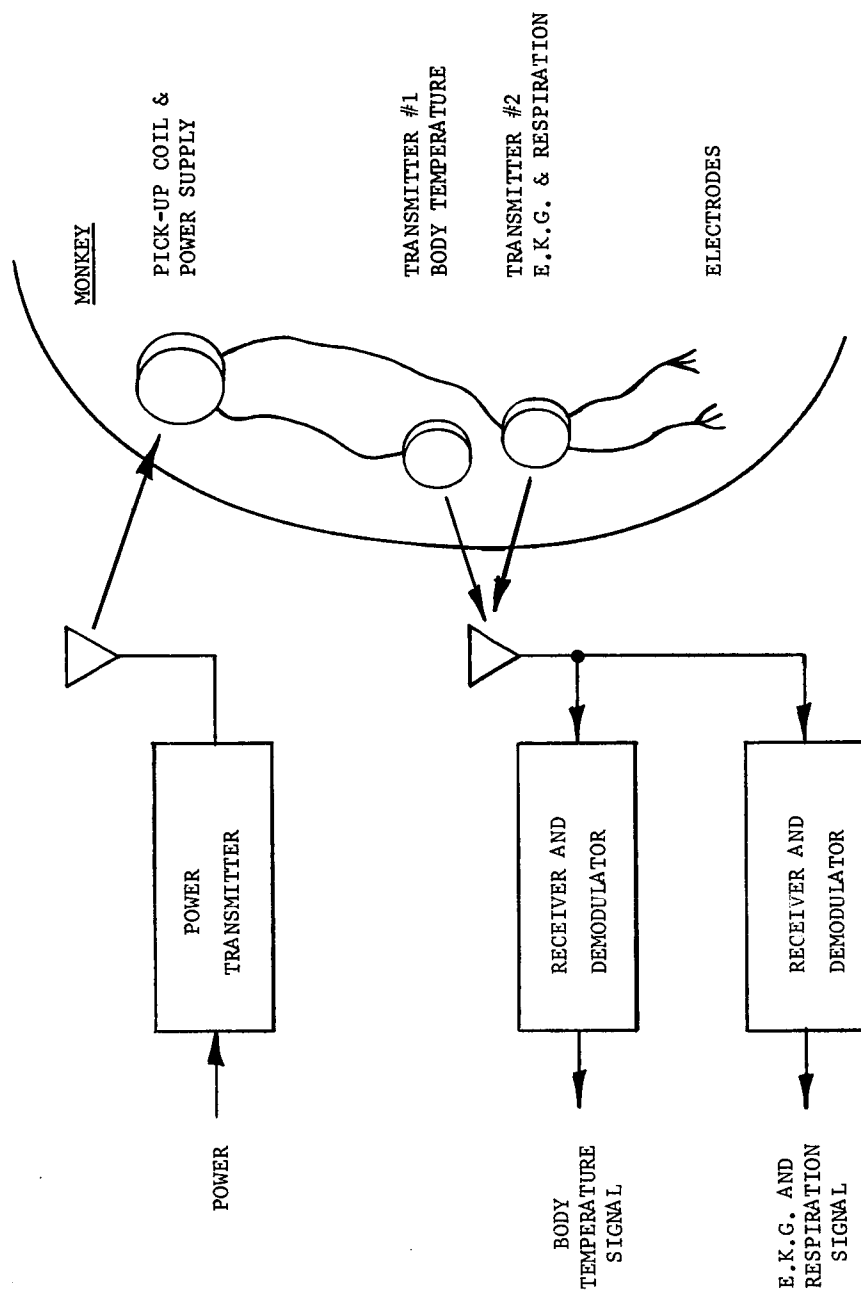
This illustration is presented to provide insight into the reasoning regarding the use of implantable devices. It is believed that the state of the art is such that utilization of such systems will provide reasonable promise of success of the experiment so far as instrumentation is concerned.

4.1.1.1 Passive Implanted Components

As used here, passive component is defined as one which utilizes power applied from an external source. The passive telemetry system utilizes a power source external to the animal to power the implanted transmitters. As illustrated in Figure 4-1, power is typically transmitted to a receiver power supply within the animal at a frequency of 1 megacycle. The power supply converts this energy, and in turn, powers one or more transmitters operating at a frequency of approximately 100 megacycles. Physiological signals modulate the transmitter.

This system has distinct advantages over active implants. The most obvious is that the battery is eliminated, and with it is eliminated the possibility that the battery will be discharged prematurely. This reduces, to a great degree, restrictions on the time period between initial surgery and launch. Surgery for implanting the transmitters could be done well in advance of the launch with negligible compromise of the useful life of the system after initiation of the experiment. Another advantage of the passive system is that the danger of tissue damage due to minute leakage of battery vapors (e.g., mercury vapors) is also eliminated.

FIGURE 4-1



PASSIVE TELEMETERING COMPONENTS

FIGURE 4-1

The major disadvantages of this system are the added complexity of the instrumentation and their inefficiency (in terms of watts of power which must be provided by the satellite power supply to gather the physiological data). An example of such a passive, biotelemetry system is that which has been developed by Dr. W. S. Ko at the Department of Electrical Engineering at the Case Institute of Technology. Each transmitter is approximately the size of an aspirin tablet. Two transmitters per monkey would be required for this experiment. The power supply is approximately 1 cm. in diameter and a few millimeters thick.

4.1.1.2 Active Implanted Components

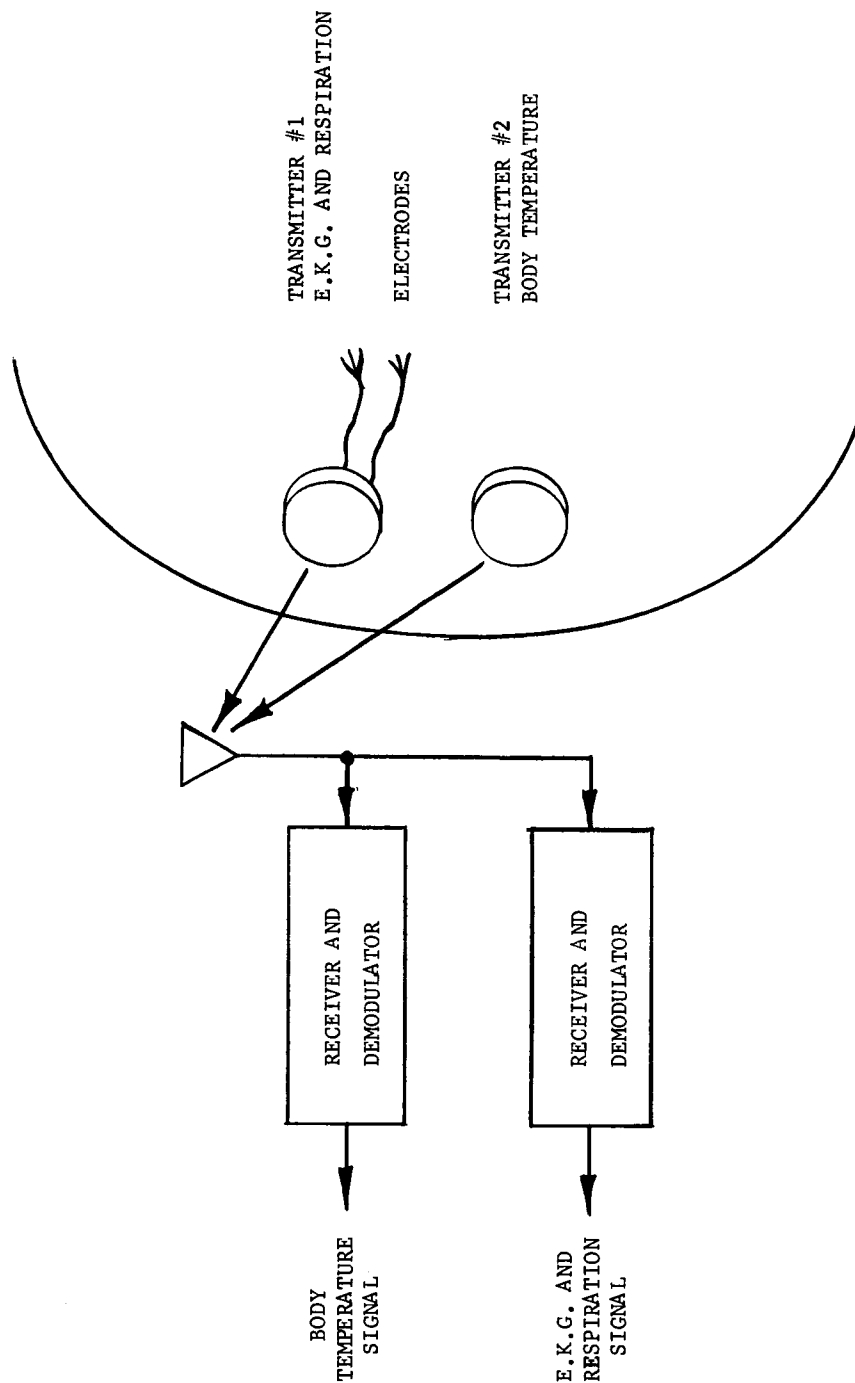
An active system (Figure 4-2) is one in which the implanted telemetering transmitters are powered by batteries packaged within the unit. Although limits in battery life impose restrictions on these components, this disadvantage is at least partially offset by the simplicity of the system utilizing these transmitters. An example of this type of transmitter is the unit developed by Gordon J. Deboo and Thomas B. Fryer at NASA's Ames Research Center. Their temperature transmitter has an acceptable resolution and a life of approximately nine months. The unit is approximately 0.7 inch in diameter by 0.22 inch high. A companion EKG transmitter has a life of only one month, but it is believed that with the incorporation of a larger battery and some circuit modifications, battery life may be extended to beyond six months. These units transmit continuously.

4.1.1.3 Other Implanted Components

Several other possibilities exist for implantable transmitters.

1. Development of a biotelemetry transmitter which is powered by batteries but which can be switched on and off by a remote transmitter should be feasible with state of the art techniques. The transmitter power required for such a unit would be

FIGURE 4-2



ACTIVE TELEMETERING COMPONENTS

FIGURE 4-2

much less than that of the passive system described in 4.4.2.1, and the disadvantage of the limited lifetime of the active circuit is eliminated. Although there is no knowledge that such a system has been developed, there seems no reason that it could not be.

2. Another system which may be feasible is the battery-operated transmitter using several subcarriers. Mr. R. M. Goodwin at the Biomedical Instrumentation Laboratory of the Franklin Institute is currently developing such a system under NASA Contract NSR 39-005-018. He expects that this transmitter will have two or three channels, weigh four grams, and last from five to eight months. Volume of the unit is expected to be two or three cubic centimeters.

All of the heartrate transmitters described utilize the amplified EKG signal to modulate the transmitter carrier. A cuff has been developed by the Life Science Group, Martin Marietta Company, which surrounds the aorta. A strain gage in the cuff senses expansions of this artery, and yields an electrical signal which is well correlated with blood pressure. Provided the strain gage outputs are sufficiently large, this device could be used with the body temperature transmitter discussed previously. Such a combination of existing systems would minimize development effort, and would provide a long-life heartrate implant.

4.2 Non-Implanted Instrumentation Components

Although implantable probes seem preferred and have been discussed first, it seems possible to obtain sufficient physiological data utilizing non-implanted sensors.

4.2.1 Recording From Work Station Sensors

A technique which appears to offer promise of providing heartrate information without implants utilizes the work panel handles as EKG electrodes. An investigation into the electrical characteristics of this EKG signal would need to be made to determine if usable data could be obtained in this manner, especially when the electrodes are contaminated. It is expected that the existence of artifacts may tend to make this technique unattractive.

4.2.2 Other Techniques

Several other techniques which should be investigated are discussed below. Utilization of any of these methods allows one work handle to be eliminated. A work panel with only one handle would require that the monkey perform simpler basic tasks. It would also permit a design in which work done by the monkey (in repeated operation of the handle) would be used to perform useful functions in the capsule.

The development of a suspension and electronics system to obtain ballistocardiographic information with a single apparatus seems possible. This would be done in conjunction with determination of the monkey's mass.

Development of an audio system which would take advantage of the low ambient sound levels existing in an orbiting vehicle is another possibility. A microphone-amplifier system would be used to detect heart sounds or other sounds related to cardiac functions.

Incorporation of a microphone in the mass-determining apparatus where it would contact the monkey and pick up sounds made by the heart.

Incorporation of an optical plethysmograph in the "massing" box might also be employed.

4.2.3 Respiration Rate Instrumentation

Two alternative methods (both untested) are proposed for the determination of respiration rate without the use of implants.

1. A temperature-sensitive device (most likely a thermistor) would be mounted on the work panel or in the mass measurement apparatus. This sensor would detect the temperature differences between expired and inspired (or ambient) air.

2. A microphone might be mounted (in a fashion similar to that described for the thermistor described above) to detect audible signals related to respiration. Also, the microphone-amplifier system

described in the section on heartrate determination might also be used to detect noises originating in the respiratory tract.

4.2.4 Body Temperature Measurement

Only one technique for determining body temperature without implants is proposed here. Since spouts and/or nozzles are to be used for dispensing food and water, the food spout might be equipped with a thermally insulated temperature sensor which has low thermal mass. The sensor will come into intimate contact with the wet surface of the tongue and mouth interior. When the monkey eats, it should provide a sufficiently accurate measurement of body temperature.

4.3 Mass Measurement

The resonant frequency of a mass and spring network varies inversely as the square root of the mass. A technique utilizing this principal is proposed as a means of determining the mass of the animal. In an ideal network, a rigid mass is assumed. Obviously, a small monkey does not represent such a rigid mass, and it is expected that artifacts will be generated by motion of the monkey's head and tail relative to the body. Two solutions to this problem are proposed.

It is believed that the monkey can be trained (as part of his working procedure) to back into a box whose sides fit snugly against the subject's body. The box would then be moved to an off-center position, and when released, would oscillate in side-to-side harmonic motion of approximately one cycle-per-second. It is realized that the monkey's head, unrestrained, will wobble and cause errors in the measurement, but it is believed that sufficient experience can be gained so that allowance can be made for some of the larger errors. The monkey can probably be alternatively trained to hug a pole which is then set into motion along the axis of the pole in a fashion similar to the way the massing box is set in motion. The most severe problems in this case are expected to

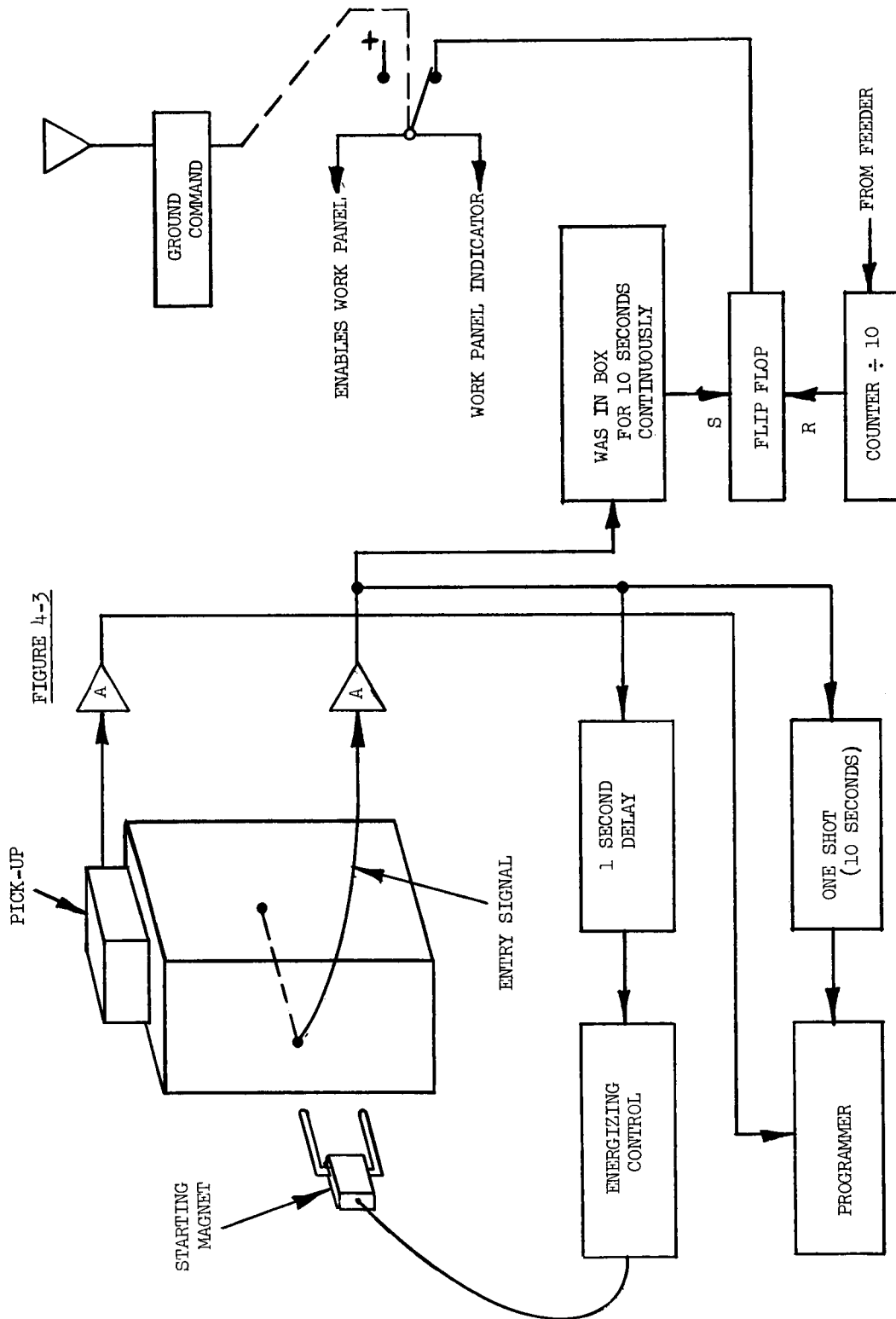
arise as a result of the unpredictability of the location of the monkey's tail, and the difficulty of training the monkey to hug the pole as part of the normal work routine.

In either of these designs (or variations thereof which may evolve after studies of the behavior of these monkeys) the apparatus is deflected and set into motion by an electromagnet. An accelerometer or other sensor senses the motion (.03 g's Peds). The output signal is amplified and the output supplied to the recorder. The information (relating to mass) in the exponentially damped sine wave is presented for analysis at a ground station. This technique reduces the severity of errors caused by movement of the monkey while the measurement is being made. The empty apparatus would be set into motion periodically to establish zero mass measurements necessary largely because of the expected feces build-up.

Figure 4-3 illustrates the instrumentation of the "massing" apparatus. The monkey must stay in contact with the apparatus for at least 10 seconds before the work panel is energized to allow the monkey a prescribed number of feedings. The capability of eliminating this procedure from the work schedule by ground is incorporated into the system so that the monkey will not starve should he refuse to perform his work schedule.

4.4 Related Data Instrumentation

Several other parameters are measured continuously. Four-lamp photo cell arrangements are positioned (equally spaced) along the length of each cage. The light sources are positioned on the partition, and are common to both cages. The interruption of any of the four light beams by a monkey advances an air activity counter. A cumulative count is transferred to a tape recorder at regular intervals, but the counters are never reset. This system has the capacity for counting approximately two days of normal activity without a repetition of register condition. Another counter accumulates real time information. It is advanced at one minute intervals and reset daily. It's count is transferred to the tape



"MASSING" STATION INSTRUMENTATION

FIGURE 4-3

recorder along with other data to indicate the time at which the measurements were made.

The total counts of feedings, waterings, and lever pulls are stored in other counters and are handled in a manner identical to that in which clock and activity counts are processed.

4.4.1 Systems Design

System designs described in this section are recommended as representing the most feasible compromises of the many possibilities available. It is realized that because of considerations which are not now apparent, techniques other than those listed here may need to be utilized. These system designs will be re-evaluated as the design progresses, as the needs of the experiment become more clearly defined, and as experience is gained with animal subjects of the type to be utilized in the actual experiment.

These systems reflect consideration of several basic ground rules which the Laboratory proposes to follow in this endeavor. Both of the systems discussed here and that which utilize implants are similar in these respects.

(a) These systems utilize components which currently exist as described here or which can be designed and constructed as combinations of state of the art technologies.

(b) The systems utilize data storage and playback techniques and devices. Storage is necessary because data must be acquired relating to conditions and activities which exist and occur when the spacecraft is not in communication with the ground station(s) associated with this program.

(c) Analog (rather than digital) data storage techniques are proposed. While either type of system could be designed with essentially equal promise of success, the alternative of using digital storage techniques would require considerably more data processing aboard the spacecraft. The analog system also has an advantage in that it provides to experimenters and analysts on the ground data in as basic a form as possible. The presentation of waveforms with reasonable fidelity will permit the analyst to exercise judgement

in evaluation of data. Such evaluations could not be performed highly-automated by on-board and ground-based analysis equipment which, at best, could be designed to have but limited adaptive and adjustment capability. It is expected also that the ability to preserve records of the outputs of physiological sensors will prove to be very helpful in interpretations of changes which may develop in the analysis as the experiment progresses.

The analog system should prove to be sufficient because data will not be obtained in such great quantity as to require automation of data processing. (The digital system would most likely lend itself more readily to automated analyses.) In the interest of simplification of the ground system, provision has not been made in this proposal for special formatting of data. Such provision could be made should partial automation (by computer or special equipment) be deemed desirable as the development progresses.

A digital system would likely be considerably more complex than the analog system shown here. Attendant with such an increase in complexity are possible losses in reliability and increases in size and power consumption.

(d) These systems utilize standard r.f. telemetry links to transmit data from the spacecraft to earth.

(e) Command systems are utilized to perform switching, control, and command functions which cannot be readily instrumented. The decision to perform some of these commands can be made only after human judgement of considerable depth has been exercised. Some of these commands (such as the command to utilize different system components) would normally be employed only if data should indicate abnormal operation of on-board systems. Other commands may be utilized more frequently, e.g., the command to dispense medicines to the subjects aboard the spacecraft.

(f) Although the diagrams provided as part of this proposal do not illustrate in detail provisions for redundancy in the systems, it is recognized that such provisions should be made.

Some of these provisions which have been made for utilization of redundant units and for switching of units are illustrated in the diagrams and in the discussions. One illustration can be cited in the passive system, in which provision has been made for obtaining data even though the monkey does not - for some reason - go to the "massing" station. It would be undesirable if the life cell was instrumented only if the subject first goes to the "massing" station. Although every effort will be made to insure that the monkey will initiate the feeding cycle at the station, it is conceivable that the monkey may find a way to by-pass this activity. As the system is illustrated here, only data relating to the mass of the animal will be lost in the event the animal does not go to the "massing" station. Provision has been made so that data can be obtained at the expense of greater power utilization.

Somewhat less reliable data would be expected in this mode of operation because greater distances exist between the pickup and transmitting loops, and because there is greater opportunity for unfavorable alignment of these loops relative to each other. An effort will be made to design these systems so that the best compromise between system efficiency and non-directivity is provided.

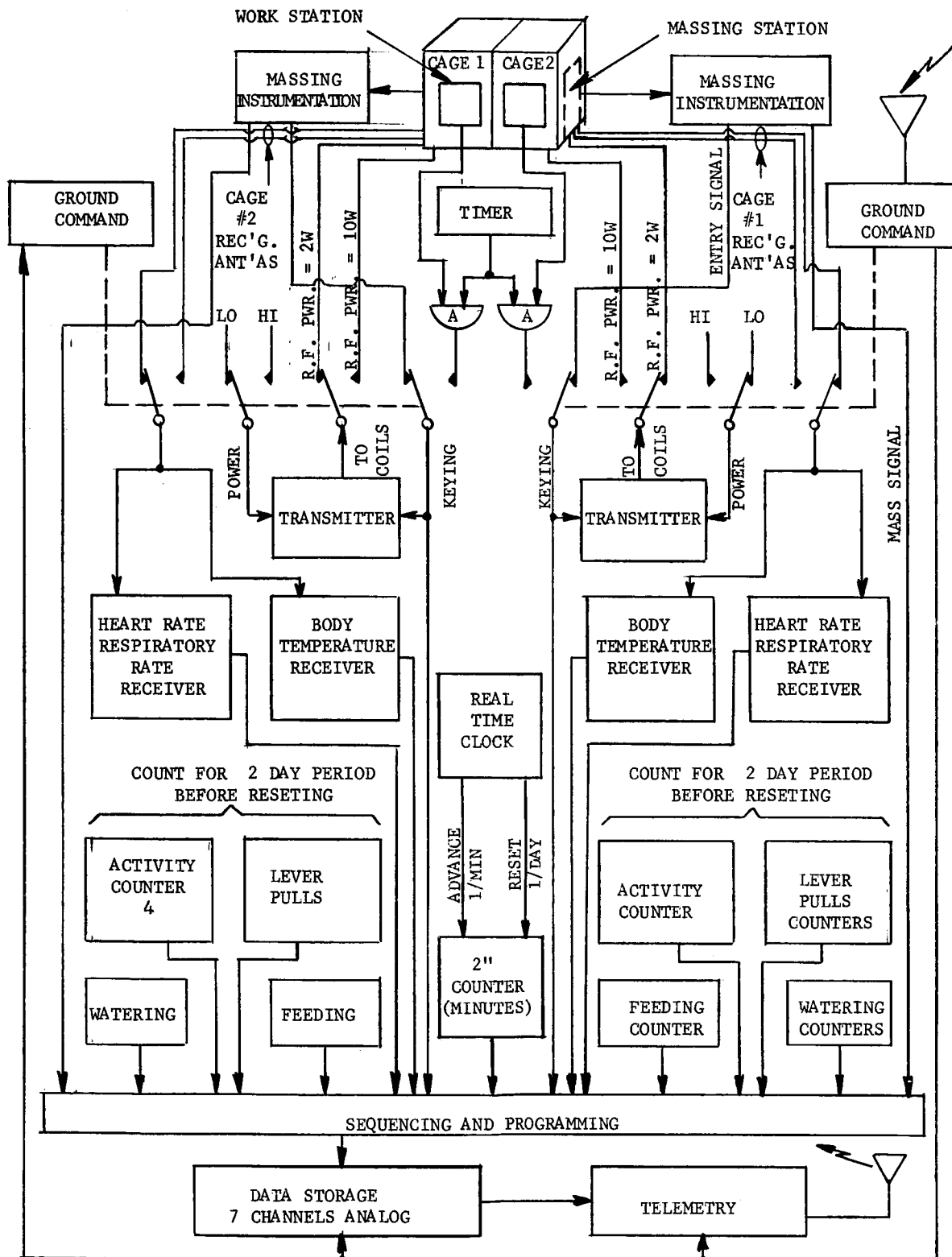
A meaningful analysis of system design can be made only after the initiation of the program, and after study of typical subjects and their behavior.

4.4.2 Systems Using Implanted Components

4.4.2.1 Passive Component System

Figure 4-4 is a block diagram of a system which utilizes passive instrumentation components. While the mass of the monkey is being determined, the close proximity of the implanted power supply and power transmitter facilitates operation with modest power consumption. All physiological measurements in the normal mode of operation are made while the monkey is being "massed". The signal indicating the initiation by the monkey of the massing phase

of the schedule initiates action in the data acquisition system. Several channels of data are recorded simultaneously on a seven-channel, FM magnetic tape recorder. Data are stored, and at a later time, are transmitted to a ground station. Existing passive biotelemetry EKG transmitters have a frequency response capable of handling a respiration signal (presumably caused by slight movements of the electrodes) super-imposed upon the electrocardiogram. Other channels on the tape recorder store body temperature, motion (or acceleration) of the "massing" apparatus, and digital information from several sources. The block diagram shows these sources as counters containing information about real time, activity, food consumption and water consumption, and work output. The counters are sufficiently large to accumulate data for a few days without repeating any reading. The data in these counters are recorded after being shifted serially to one channel of the magnetic tape recorder. Another set of receiving and transmitting antennas are available for use in an emergency mode. If one of the animals forgets or refuses to use the "massing" apparatus, the emergency mode of operation can be initiated by ground command. In this mode, a higher power transmitter is used. This facilitates data collection no matter where, in the cage, the monkey is situated, provided the plane of the receiver coil in the monkey is roughly parallel to the plane of the transmitting antenna. To offer a better probability that this orientation will exist, acquisition is initiated by the first pull on the work lever during every hour. This period can be modified by ground command. Presumably, after study of the animal activity at the work panel, the orientation of the monkey (and, hence, the receiving coil) can be predicted. Not depicted in Figure 4-4, but certainly feasible, are ground-controlled substitutions or switching of some major sections of the system.



DATA ACQUISITION AND HANDLING
(PASSIVE BIOMEDICAL TELEMETRY TECHNIQUES)

FIGURE 4-4

4.4.2.2 Active Component System

The system using the active telemetering components (Figure 4-5) is very similar to that using the passive components. The major difference is the elimination of the power transmitters and their associated components. This system does not depend upon utilization by the monkey of the "massing" apparatus to initiate accumulation of the other physiological data. Rather, the implanted transmitters operate continuously, and the receivers are energized and data collected at regular intervals as determined by the programmer. Heart rate, respiration rate, and body temperature and activity counts (see Section 4.3.2.1) are recorded periodically. The mass data are recorded when required. Time restrictions may be placed on mass data recording.

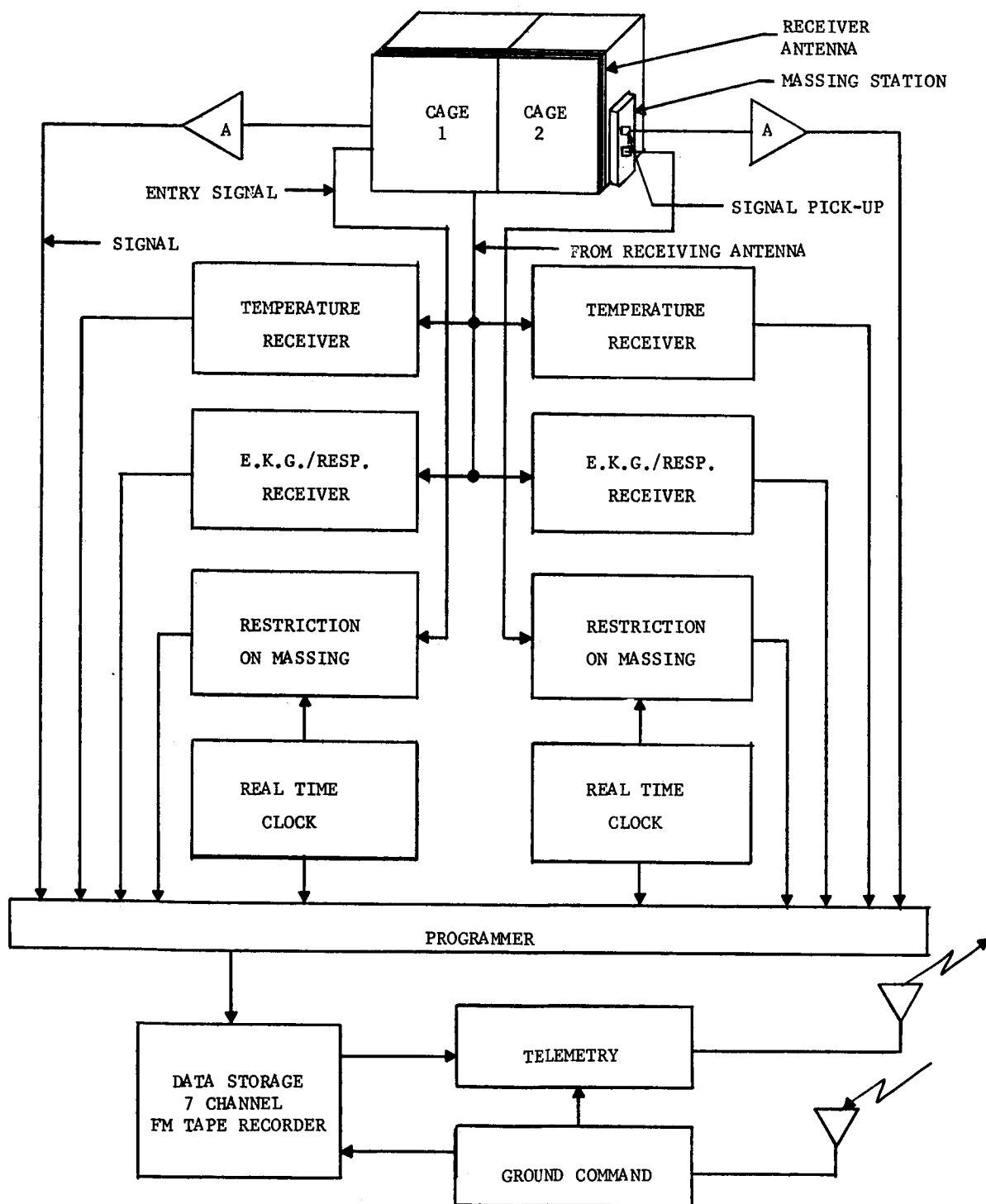
4.4.3 Systems Using Non-Implanted Components

This system must necessarily be discussed in general terms. It must accept many possible transducer inputs. Moreover, depending upon the location of the transducer being used, the time of initiation of the data recording will vary.

The block diagram illustrating this system (Figure 4-6) shows various timing inputs to a programmer which connects the correct transducers to an FM tape recorder which stores the data for later transmission to a ground station. For example, if the work handles were used as EKG electrodes, the heartrate information would be taken throughout the first 10-second pull each hour.

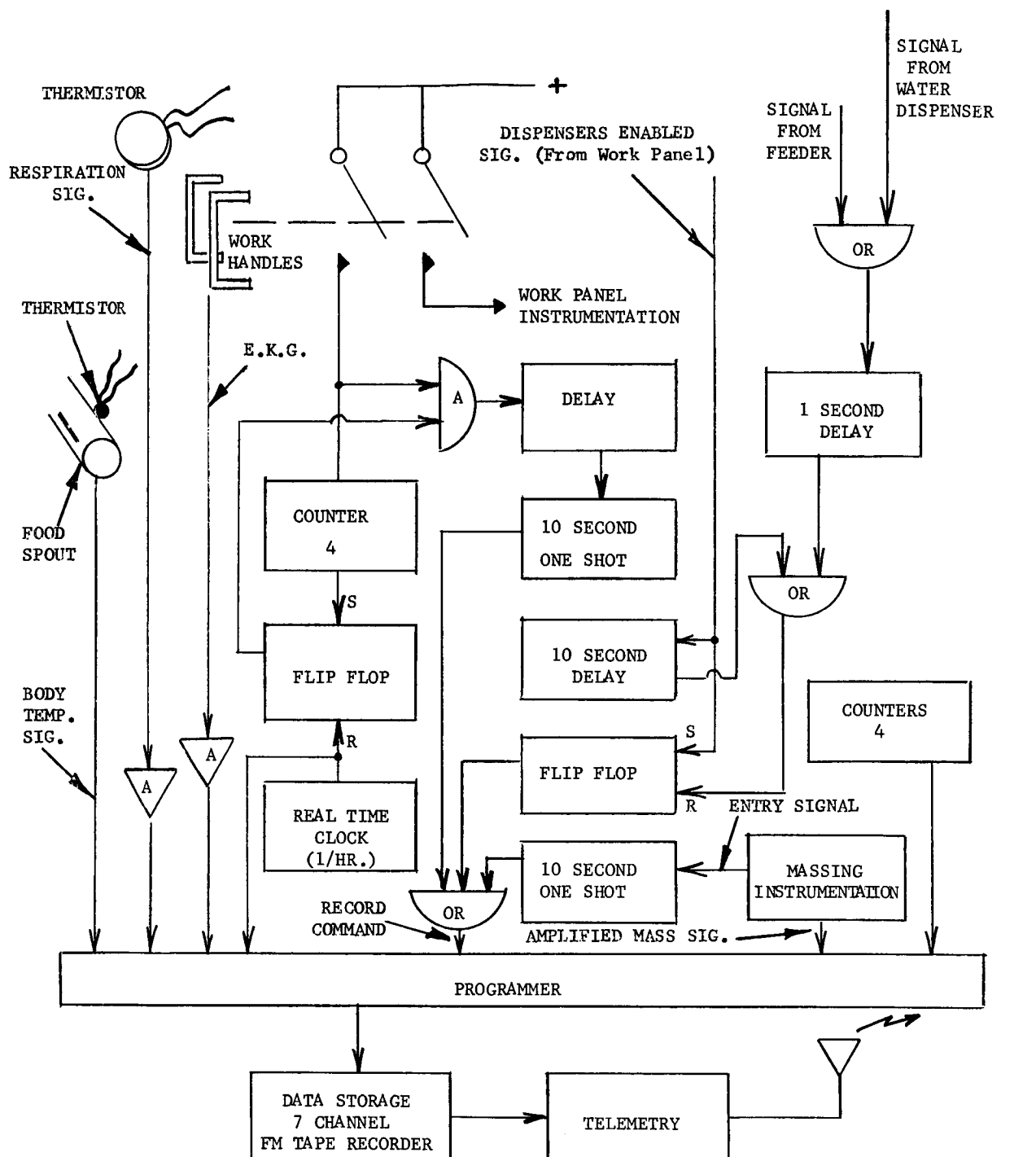
If a microphone was used to determine heartrate, then either a one-hour clock or the massing apparatus would determine the timing at the data acquisition.

For body temperature measurement, the food spout thermistor output might be recorded for 10 seconds after the dispenser light comes on. (It is assumed that having worked for food, the monkey will go to get it within ten seconds.) The massing information would be recorded as in the other systems. The digital counts are transferred to tape storage at approximately one hour intervals.



DATA ACQUISITION AND HANDLING
(ACTIVE BIOMEDICAL TELEMETRY TECHNIQUES)

FIGURE 4-5



NOTE Instrumentation for one cage only shown. Other cage identical.

DATA ACQUISITION AND HANDLING
(NO IMPLANTS USED)

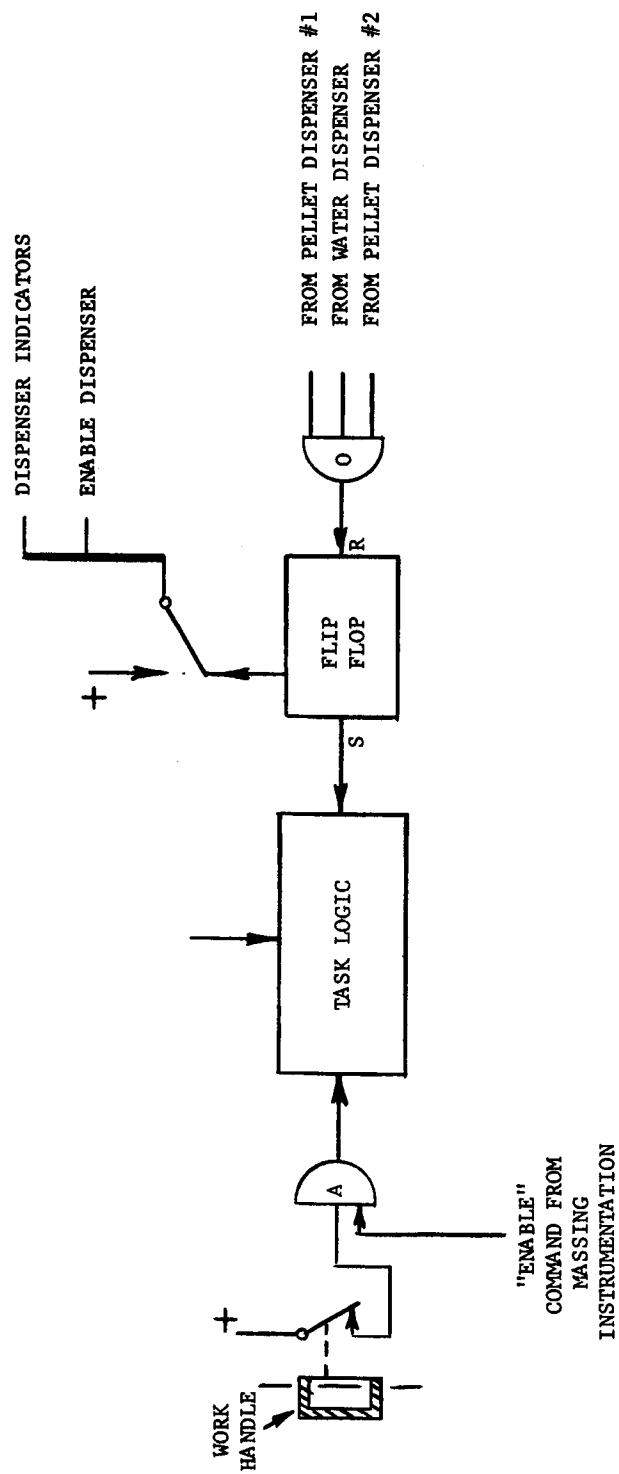
FIGURE 4-6

4.5 Work Panel Instrumentation

The amount of work required from the monkey would be controlled by the experimenter via telemetry and would be effected in the satellite by the task logic unit (Figure 4-7). This unit would monitor the quantity of food and water dispensed, the number of pulls the monkey has performed and the number of operations between "massing" measurements. These work levels would be set by ground command to vary the number of pulls required or the duration of the pulls necessary to obtain a reward. This work cycle must, of course, exceed the minimum necessary to reload the dispensing mechanisms (See Section 3.5.3).

The task logic unit would receive a signal from the mass measurement control and unlock the work station and then give the monkey an indication that the station was ready for operation. The monkey would then perform the desired task in order to obtain his reward. Upon completing the task, a flip flop will unlock the dispensers, and operate the indicators and permit the lip switch on the dispenser to release the food or water. With the completion of the required number of feedings, the task logic unit would disable the work station which would then signal the monkey that he must then initiate the next cycle of measurements.

FIGURE 4-7



WORK STATION INSTRUMENTATION

FIGURE 4-7

4.6 Television

A general requirement has been stated for television coverage of the monkeys, to monitor their behavior and general condition. It is understood that the TV coverage should include the entire cage floor plus the work station. In the absence of specific requirements for resolution, contrasts, frame rate, and duration of each observation, and in view of the probable limitations in bandwidth, ground coverage, and field of view, an effort was made to rough out some reasonable definition of performance. A parallel effort was initiated to ascertain the availability of suitable cameras, but time did not permit a thorough search.

However, it has been determined that an intensive effort has been put into the development of small television cameras, and that such a unit will probably fit at the top of the life space as here envisioned and that its field of view would include the entire cage volume with exception of a small portion of the upper corners.

The following performance requirements are tentatively suggested:

Resolution: 100 x 100 lines.

Contrast: Equivalent to 8 gray scale steps.

Frame rate: Six per second.

Duration: Continuous

Field of view: Up to 90 degrees.

Based on the foregoing, the picture element rate would be 60,000 per second with a bandwidth of perhaps 400 kc, which roughly matches the LEM television transmission capability. Even higher bandwidths could be accommodated without much difficulty within the estimated power and antenna limitations, on a continuous basis. Continuity of ground reception by the MSFN would be better than 50 percent for the low inclination orbits (which appear most likely) making the need for on-board tape recording rather doubtful.

The required illumination can readily be provided and maintained with a few watts of electrical power, and the possible contingency of a deliberate day-night cycle could be accommodated within the dynamic range of available camera tubes, providing a small amount of light is provided during the "night" periods.

APPENDIX A

EMERGENCY CALL DOWN

5.0 INTRODUCTION

The basic experimental philosophy is to reduce disturbing factors in the zero g experiment to the smallest possible values. Since any animal sickness or distress introduces variables which can blur the zero g experiment data and since the death of an animal drastically interferes with the amount of data recoverable, it is evidently advantageous to be able to terminate the experiment and recover the monkeys when there is indication of lasting trouble. The greatest interest here is in the occurrence of such premature recovery requirement during phase III, while the experimental package is in orbit by itself.

Under these conditions it would be out of the question to use a Saturn booster and an Apollo flight for this recovery alone. Recovery by means of a well controlled re-entry procedure for the animal capsule is the method of choice. The entire recovery time may well take less than a day. It would start with the ground monitor detecting some sudden or gradual physiological or engineering difficulty which is not correctable. A difficulty which would result in the death of both subjects prior to the scheduled orbital rendezvous would seriously compromise the entire experiment.

The decision must then be made specifying the call-down orbit and initiating any recovery force deployment. By careful selection of the call-down orbit and retrofire point and the vacuum descent trajectory the location of the capsule on impact can be made accurately such that only a few hours need lapse between the decision to recover and actual manned retrieval of the landed monkeys. This minimizes the life support problem and the danger to the monkeys and puts the burden of accuracy on the retrofire parameters.

Since recovery system developments are time consuming and costly, it would be most desirable to be able to adopt an already proven system for this application. From the present incomplete analysis such an adaptation seems possible.

The problems of impact zone selection, recovery force deployment and timing are extremely important in successful recovery but cannot be adequately studied at this time; there are thus three main considerations to be covered in this appendix:

- (a) Stabilization and orientation for retrofire.
- (b) Retrofire parameters.
- (c) Life support until recovery.

If all these are shown to be feasible as required for a recovery time of less than six hours then the benefits of such recovery become available and greatly enhance the chances of mission success.

5.1 Stabilization and Orientation

Since the requirement for emergency call-down might come late in the six-month orbital experiment, the initiation, orientation, and stabilization techniques selected must be assured operable after such a prolonged orbital flight. The usual approaches involve active orientation and stabilization techniques. There is little experience with these active control procedures for accomplishing recovery after so long a time and there are obvious questions relative to the expected reliability of such approaches for this mission. It is, therefore, necessary to apply techniques with higher inherent reliability under these conditions. For these reasons, passive or semipassive orientation and stabilization techniques have been sought and examined for their applicability. Three such techniques are described below. Any of these techniques can be shown, overall, to be suitable. The method of choice can be found only after a detailed engineering study which includes thermal management, power system design, antenna configuration and other factors. These and other subsystems are complexly linked to the choice of orientation and stabilization control system employed.

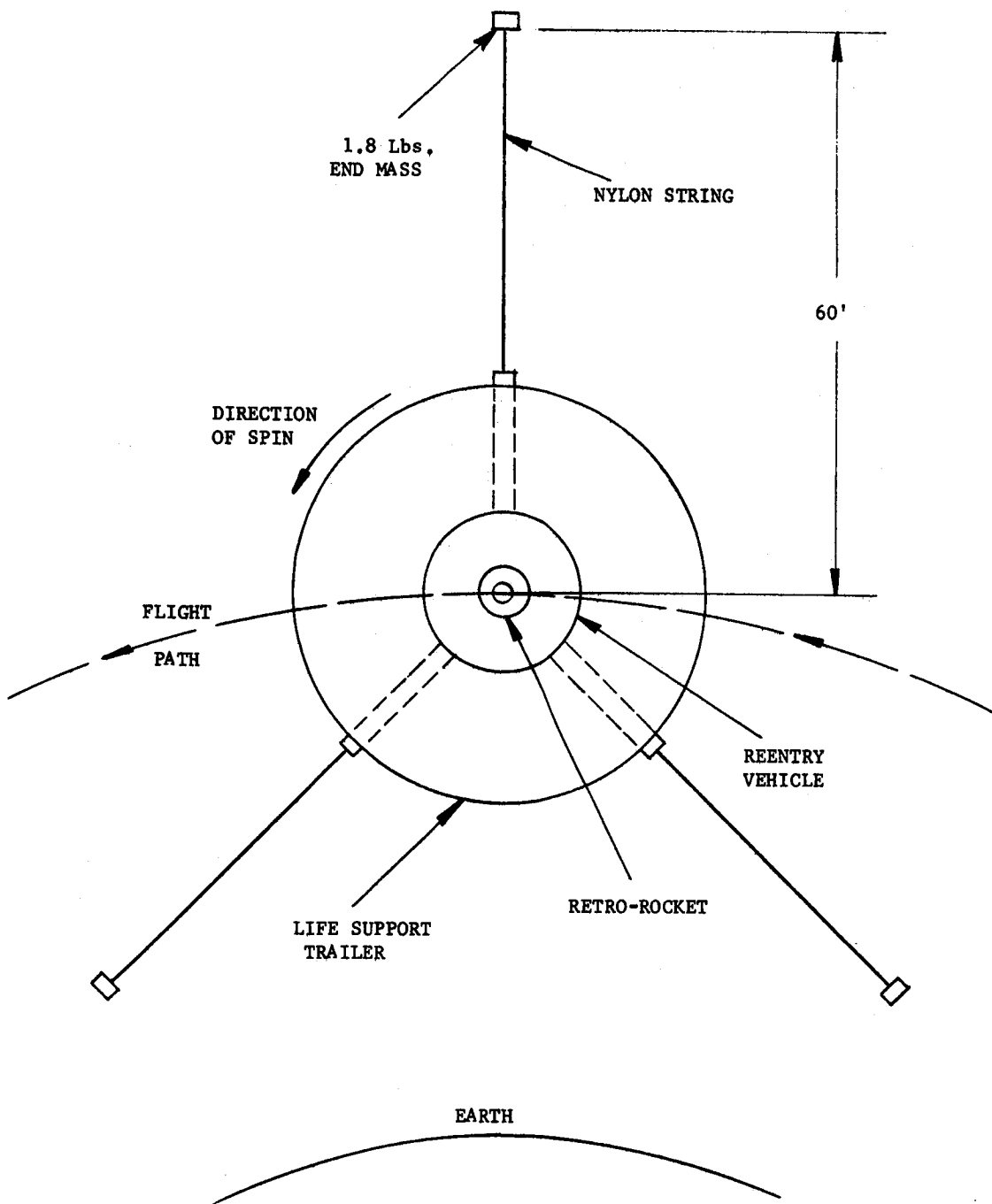
A passive or semi-passive stabilization and orientation system must rely on the environmental phenomena available in orbit such as the gravity gradient, forces aerodynamic drag, or the earth's magnetic field.

5.1.1 Ground Controlled Magnetic Stabilization and Orientation

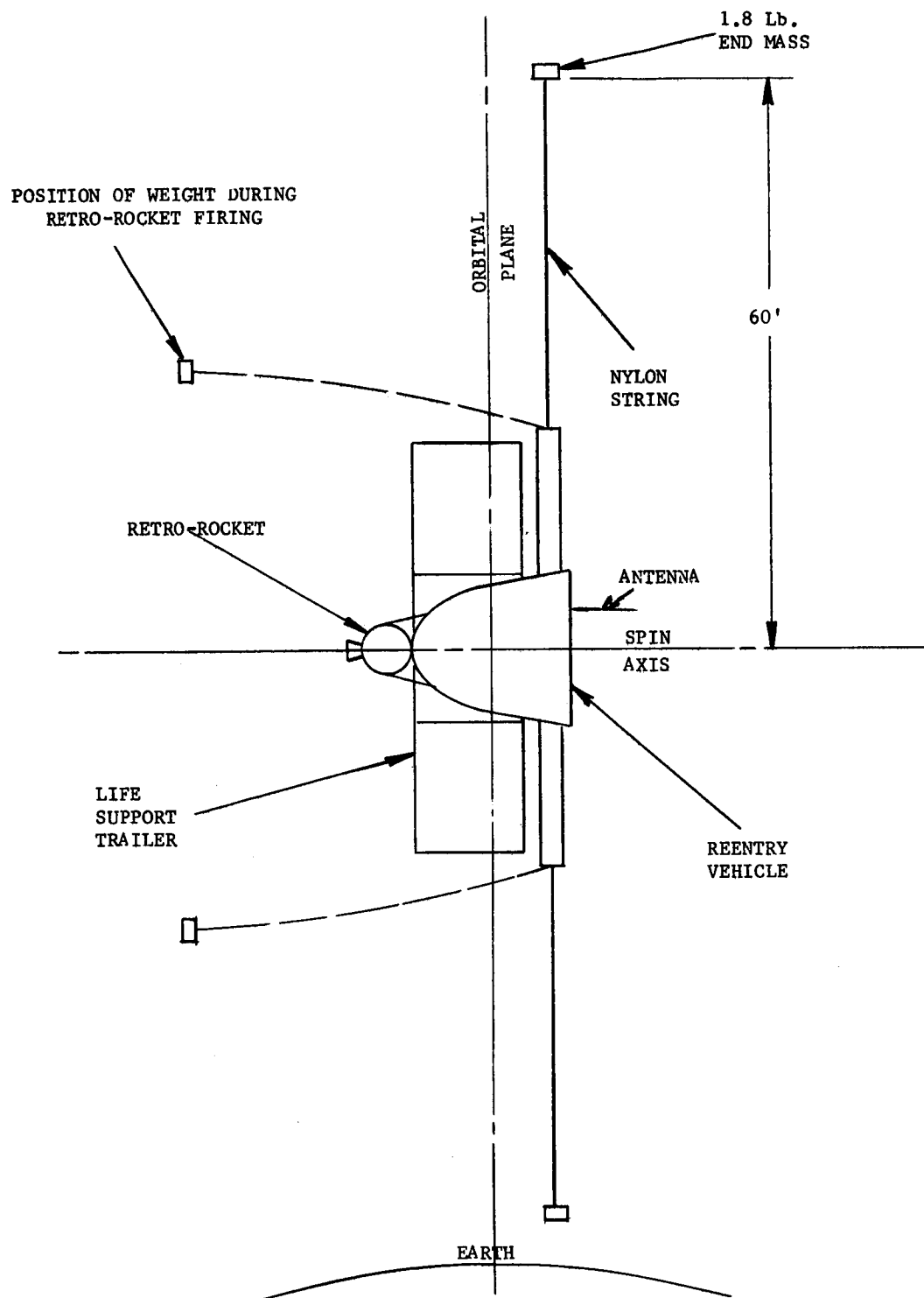
Satellites have been successfully stabilized and oriented utilizing the earth's magnetic field. In effect, magnets on board the satellite are energized in such a manner with respect to the earth's

field that they function as a rotor in this field and spin the satellite. The rate of spin can be controlled from the ground by means of these magnets. The addition of a controllable magnet on the longitudinal axis provides a ground controlled yaw torque which can be used for two purposes; to orient the satellite optimally for temperature or solar cell power generation, and to orient it for re-entry alignment. This scheme uses centrifugal orientation forces generated by ultra slow spin of geometrically extended structures. Such spin rates are compatible with the "zero" g requirements of the experiment and are far below physiologically detectible angular acceleration rates. A simple spin maintenance technique utilizing only electronic switching would assure the maintenance of adequate centrifugal forces. A unique design for the extended structures, shown in Figure 5.1.1-1, would provide for inertial stabilization during retro rocket firing. The alignment error at the initiation of retro rocket firing would be of the order of ± 2 or 3 degrees.

Typical design parameters for this configuration would be spin axis moment-of-inertia of 600 slug feet which would cause the monkeys to experience a force of 3×10^{-7} g if they were 1 foot radial distance from the spin axis. This g level should be negligible for any biological experiment. The moment-of-inertia would be obtained from three 1.8 pound masses which would be located at the end of a 60-foot nylon cord. Figure 5.1.1-2 shows a view of the spin stabilized satellite as seen in a plane perpendicular to the orbit. As is the case with the DME-A satellite recently designed by the Applied Physics Laboratory and now operating in orbit, this satellite would have a ground controllable spin axis orientation as well as spin rate. It is expected that one would normally operate the satellite by causing the spin axis to be normal to the orbit plane, then using a stub antenna, shown in Figure 5.1.1-2, to obtain a perpendicular-shaped antenna pattern which will provide signal strength that is improved over an isotropic radiator by approximately 1 to 3 db. This system also provides a controlled orientation of the spacecraft relative to the sun



VIEW OF SPIN STABILIZED SATELLITE
IN THE ORBITAL PLANE
FIGURE 5.1.1-1



SPIN STABILIZED SATELLITE AS SEEN
PERPENDICULAR TO ORBITAL PLANE

FIGURE 5.1.1-2

and relative to the earth so that one generates controlled and predictable electric power from the spacecraft's solar cells and also the thermal design is considerably simplified by having a predictable attitude.

When it is decided that recovery should be made, the satellite spin axis will be moved into the orbit plane and the retro-rocket will be fired when the spin axis is approximately 35 degrees relative to the local vertical. Immediately prior to retro-rocket firing, the support section which houses most of the life support system, would be separated from the re-entry capsule. When the retro-rocket fires, the nylon cords will be forced backward and toward the satellite's spin axis. This will result in spinning the spacecraft up to 3 rpm. This will tend to counteract the thrust misalignment of the retro rocket, and if the burning time is sufficiently long (perhaps a minute) the uncertainties in magnitude and direction of the velocity reactor can probably be held within tolerable limits. Under the acceleration of approximately 1 g which the retro rocket will produce, the force on the nylon cords will only be 1.8 pounds, which is a simple requirement to meet since this material is exceedingly strong in tension. Potential problems of cord tangling and burn-through are recognized, and must be studied more thoroughly before the practicability of this scheme can be varified. The induced spin rate of 3 rpm during the firing of the retro rocket which the monkeys will experience produces an acceleration force of only 3×10^{-3} g at a distance of 1 foot from the spin axis. This again should be a negligible acceleration. However, the finite spin rate of 3 rpm; i.e. one rotation in 20 seconds may have some physiological effect on the monkeys, which should be evaluated if this system is to be utilized. Since the monkeys will experience this rotation rate for about one minute and since the accelerations produced by rotation are very small compared to those resulting from firing of the retro rocket, it is probable that the experiment will not be impaired by the increased spin rate resulting from this maneuver.

After the retro-rocket firing is completed, the nylon strings will resume their prior position and promptly decrease the satellite's spin rate. Upon re-entry the strings will burn away.

5.1.2 Three-Axis Gravity Gradient Stabilization

The use of the earth's gravity gradient to stabilize a cylindrical or dumbbell shaped satellite along the vertical is a familiar method. However, gravity gradient can be used to stabilize a satellite in three axes.

If we have a rigid body of arbitrary mass distribution indicated by three sets of orthogonal dumbbells as shown in Figure 5.1.2-2, because of gravity-gradient and centrifugal forces, this body will tend to align itself so that the axis of minimum moment of inertia will seek the vertical, the axis of intermediate moment will stabilize in the orbital plane and the maximum inertia axis will be oriented perpendicular to the orbital plane. If we take the vertical direction as the Z-axis, the direction of forward motion as the X-axis, and the Y-axis so as to form an orthogonal set, the torque in the pitch (X-Z) plane can be readily shown to be (for small angular displacements from the equilibrium position)

$$\tau_p = 3 \omega_0^2 (I_x - I_z) \theta \quad (1)$$

wherein θ is the pitch angle.

Furthermore, if displaced a small angle ϕ off the vertical in the roll (Y-Z) plane, the net torque acting upon this body will be given by

$$\tau_r = 4 \omega_0^2 (I_y - I_z) \phi \quad (2)$$

and if the X dumbbell is displaced a small angle ψ from the orbital plane there will be a yaw (X-Y) stabilization torque due to centrifugal force that is given by

$$\tau_y = \omega_0^2 (I_y - I_x) \psi \quad (3)$$

where I_x = moment of inertia of the body about the X-axis,
 I_y = moment of inertia of the body about the Y-axis,
 I_z = moment of inertia of the body about the Z-axis,
and ω_0 = orbital mean motion (radians/sec).

The equations listed above are completely adequate for most considerations of passive gravity-gradient stabilization.

One then obtains for the equations of motion

$$I_y \frac{d^2 \theta}{dt^2} + 3 \omega_0^2 (I_x - I_z) \theta = 0 \quad (4)$$

$$I_x \frac{d^2 \phi}{dt^2} + \omega_0 \dot{\psi} [I_x + I_z - I_y] + 4 \omega_0^2 (I_y - I_z) \phi = 0 \quad (5)$$

$$I_z \frac{d^2 \psi}{dt^2} - \omega_0 \dot{\phi} [I_x + I_z - I_y] + \omega_0^2 (I_y - I_x) \psi = 0 \quad (6)$$

From these differential equations one can easily obtain the uncoupled natural periods of liberation in the pitch, roll, and yaw planes as follows:

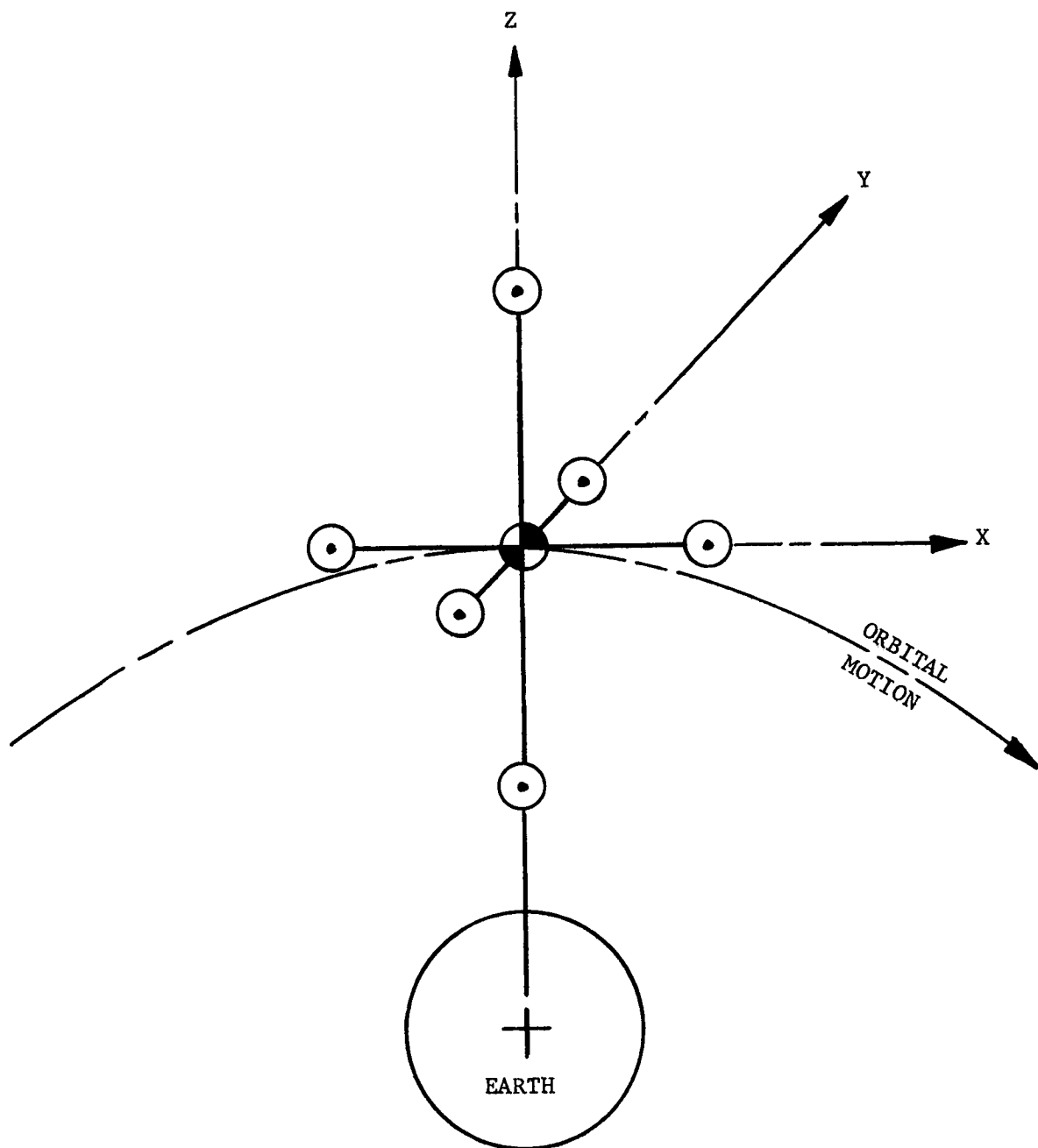
$$T_p = T_o [3 (I_x - I_z) / I_y]^{-1/2} \quad (7)$$

$$T_r = T_o [4 (I_y - I_z) / I_x]^{-1/2} \quad (8)$$

$$T_y = T_o [(I_y - I_x) / I_z]^{-1/2} \quad (9)$$

where T_o = Orbital period of the satellite.

Substitution of typical numbers that are achievable for satellite moments of inertia which are within a factor of 2 from our re-entry package readily indicate that the restoring torques are exceedingly small and the natural periods of liberation are exceedingly long. Consider a satellite which has the configuration shown in Figures 5.1.2-1, with +Z and -Z boom lengths of 100 feet, +X and -X boom lengths of 40 feet, and



STABILIZATION FOR A SATELLITE OF ARBITRARY
MOMENT OF INERTIA DISTRIBUTION

Fig. 5.1.2-1

+Y and -Y boom lengths of 20 feet, all with end masses of 0.1 slug (3.2 pounds). Then for a satellite orbiting at 600 nautical miles altitude ($\omega_o = 10^{-3}$ radians/sec) we get the following torques:

$$\tau_p = 0.873 \times 10^{-4} \text{ ft-lbs/degree}$$

$$\tau_r = 1.375 \times 10^{-4} \text{ ft-lbs/degree}$$

$$\tau_y = 0.052 \times 10^{-4} \text{ ft-lbs/degree}$$

Although these torques are exceedingly small, when they are applied in the frictionless environment of space, they are able to readily stabilize bodies that are hundreds of feet long. It is however necessary to realize how small these torques really are and to take care in the satellite design to eliminate any other sources of torque that might disturb this real but delicate balance.

The natural frequencies of libration for the "typical" satellite configuration described above are:

$$T_p = 0.63 T_o = 66.7 \text{ minutes}$$

$$T_r = 0.54 T_o = 57.2 \text{ minutes}$$

$$T_y = 1.06 T_o = 112.1 \text{ minutes}$$

The fact that these natural periods of libration are exceedingly long compared to most terrestrial devices makes it difficult to damp rapidly from large initial amplitudes. However, in our case the satellite can actually be initially placed in the right orientation with the astronaut available to monitor this action. The astronaut could effectively position it within as small an error as possible so that its axes are aligned with the vertical, the orbital plane, and the perpendicular to the orbital plane. This would be done after observing the deployment of the booms as shown in Figure 5.1.2-2.

Any remaining oscillations can be reduced to ± 3 to 5 degrees by means of magnetic damping.

This completely passive stabilization mode, which depends only on the deployment of the booms, would make the satellite available at all times for initiation of the call-down sequence.

The spacecraft will be aerodynamically stable in its initially placed yaw orientation, thereby minimizing the possibility of reversal due to some unanticipated perturbation.

5.1.3 Gyroscopic and Gravity Gradient Stabilization

The ambiguity in yaw presented in a three axis gravity gradient stabilized satellite can also be overcome by using a small constant speed rotor as follows:

The satellite is stabilized along a vertical axis by means of the gravity gradient utilizing a mass extended on a boom. In the yaw axis, stabilization is achieved by means of a small rotating mass. Such a mass exerts a restoring torque on the satellite until the rotor spin angular momentum vector is parallel to the orbital angular momentum vector.

A digital simulation run was made for a satellite of the general characteristics of the recovery capsule. The run was a transient run in which the rotor angular velocity increased quadratically from zero to full speed over five orbits. To demonstrate preferred yaw stability, the initial yaw angle was such that the rotor spin and orbital angular momentum vectors were anti-parallel. This run also illustrated the behavior of the spacecraft under large angular deflections and the effective time constant of the system. The results show that the satellite had been stabilized in yaw to $\pm 20^\circ$ within the five orbits during which time the rotor had been brought up to speed. Libration motion would be damped by dissipation of energy through a passive eddy current damper.

Steady state simulation results gave the following maximum libration amplitudes:

<u>Angle</u>	<u>Bounds on amplitude (degrees)</u>
Pitch	-.40 to 1.3
Roll	-1.1 to .4
Yaw	-.63 to .66

5.2 Retrofire Parameters

To achieve the desired disorbiting trajectory, it is necessary to assure the proper orientation of the reentry body and its retro-rocket.

Only the life cell, with its re-entry protection and recovery aids, would be recovered. This is primarily to assure an acceptably predictable descent trajectory, since the retro-rocket would develop a fixed total impulse while the total mass of the complete experiment package would decrease with time, as consumables are used and lost overboard. These weight changes could be estimated and continually updated, of course, by monitoring food, water and gas consumption, but they also would change the optimal thrust axis orientation, thereby adding another variable that cannot conveniently be controlled. The life cell weight of perhaps 350 pounds (including heat shield) would, however, be affected only by the accumulation of dry feces and changes in the animals' weight, involving a percentage variation of less than five percent over the entire mission. Overall mass variation during this same period might approach thirty percent, though, with a corresponding effect on the deflecting velocity change and ultimately on the impact prediction accuracy. Other parameters would also be affected, notably the entry angle (which affects heat shield performance) and the maximum deceleration during re-entry.

Additionally, deboosting of the entire package would require a much larger retro-rocket and heat shield. The range to impact and the range error are largely governed by the magnitude and direction of the deflecting velocity change. Figure (5.2-1) illustrates the magnitude of these effects for a 300 n. mile circular orbit. For each magnitude of the velocity change a different thrust orientation angle yields a minimum total range to impact, at which condition the flatness of the curve shows that impact accuracy is scarcely affected by small angular errors.

RANGE TO IMPACT
VS.
MAGNITUDE AND DIRECTION
OF VELOCITY CHANGE FOR
300 N.MI. CIRCULAR ORBIT

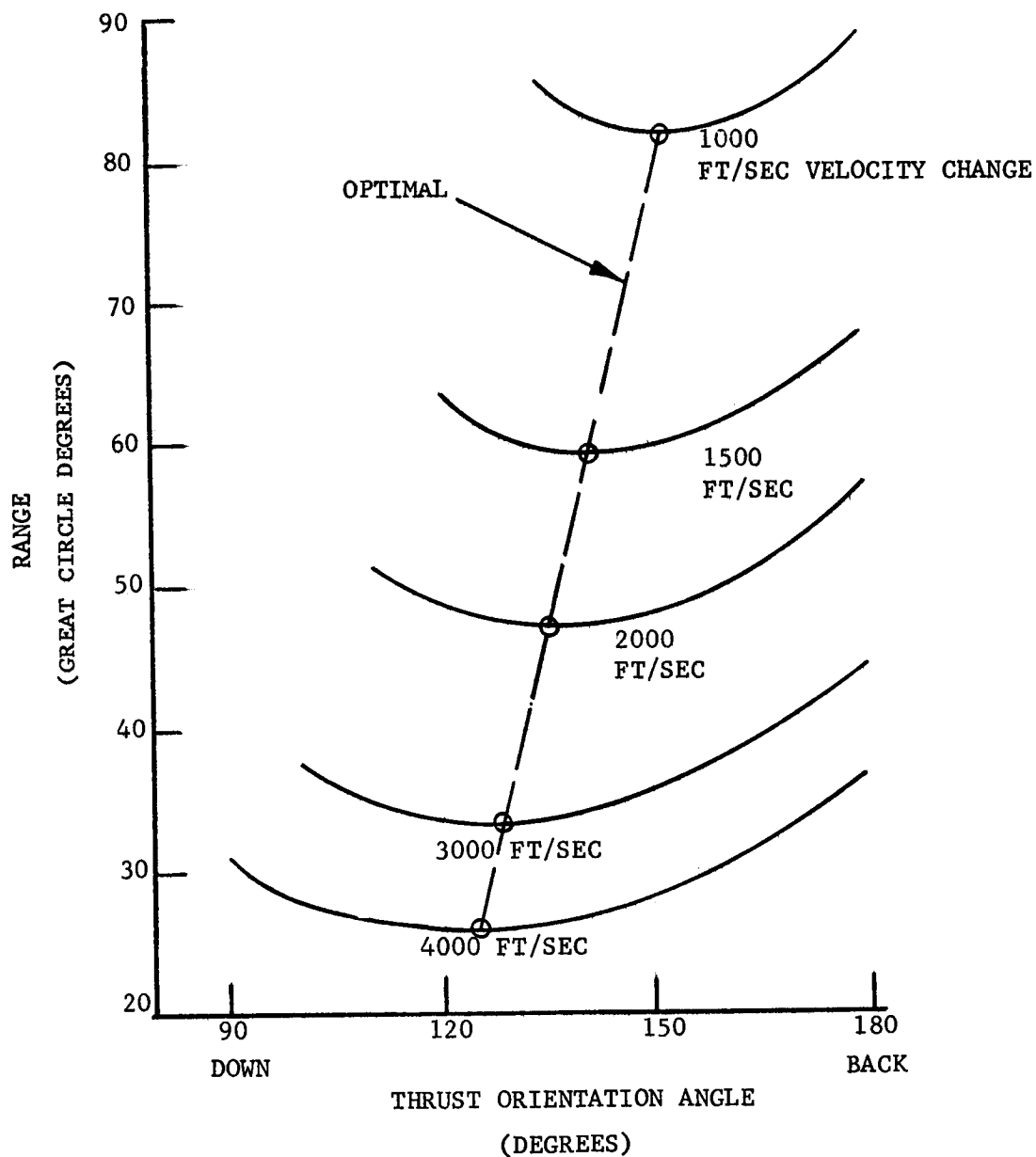


Figure 5.2-1

Figures (5.2-2) and (5.2-3) indicate the overall trend in atmospheric entry conditions. The first one, Figure (5.2-2) gives the atmospheric entry angle versus altitude for optimal thrust orientation, and the second, Figure (5.2-3) shows the peak deceleration the animals will have to withstand versus the altitude for optimum thrust orientation.

An acceptable retro-rocket for the 3-axis gravitationally stabilized spacecraft might be the Langley-developed 4.75 KS 4431, which is also designated as SPIA Unit 365. It would burn for roughly five seconds, producing a maximum acceleration of about 15 g's and a deflecting velocity change of approximately 2000 feet per second. With proper allowance for tolerance build-ups this would yield an along track uncertainty of perhaps 50 nautical miles. Suitable motors for the other stabilization concept may also exist, but no research has been done. The motor thrust would be directed as shown in Figure 5.2-4 to prevent dislodgment of the trapped feces. Its sense may either be up, as shown, for the "apogee route", or down for a direct descent.. Both trajectories would yield equivalent re-entry conditions and impact accuracies.

5.2.1 Re-entry Protection

The existing forebody which has been developed for the Biosatellite project appears in general compatible with the life cell shown in Figures 5.21-1, 5.21-2, and 5.21-3. Its heat shield (modified if required) would offer adequate thermal protection during re-entry since the orbital altitude, entry angle, and vehicle weight are roughly comparable. The illustrated life cell, with a cage height of 27 inches, would project considerably beyond its after end, requiring a special afterbody which would call for additional analysis and testing. Reducing cage height to the minimum acceptable value of 15 inches would greatly relieve any potential thermal or aerodynamic stability problems. A superficial examination also indicates that the existing separation mechanism would be suitable in this application.

5.2.2 Retardation

The existing sequence and devices used to retard the Biosatellite after re-entry appear applicable for use in this problem, although the axially mounted TV camera favors the use of annular packaging and

ATMOSPHERIC ENTRY ANGLE
VS.
ALTITUDE FOR OPTIMAL THRUST ORIENTATION

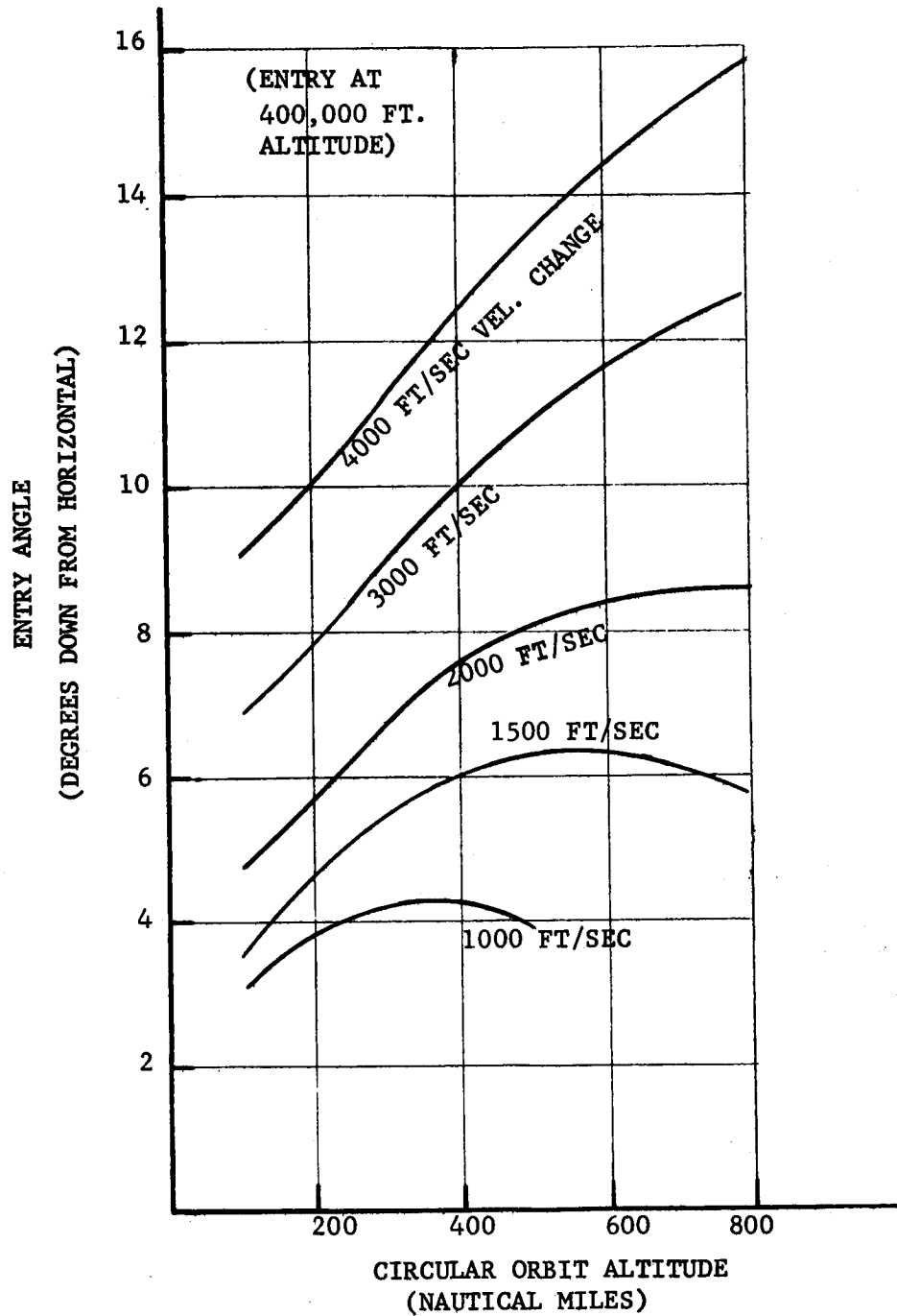


Figure 5.2-2

PEAK DECELERATION DURING REENTRY
VS.
ALTITUDE FOR OPTIMAL THRUST ORIENTATION

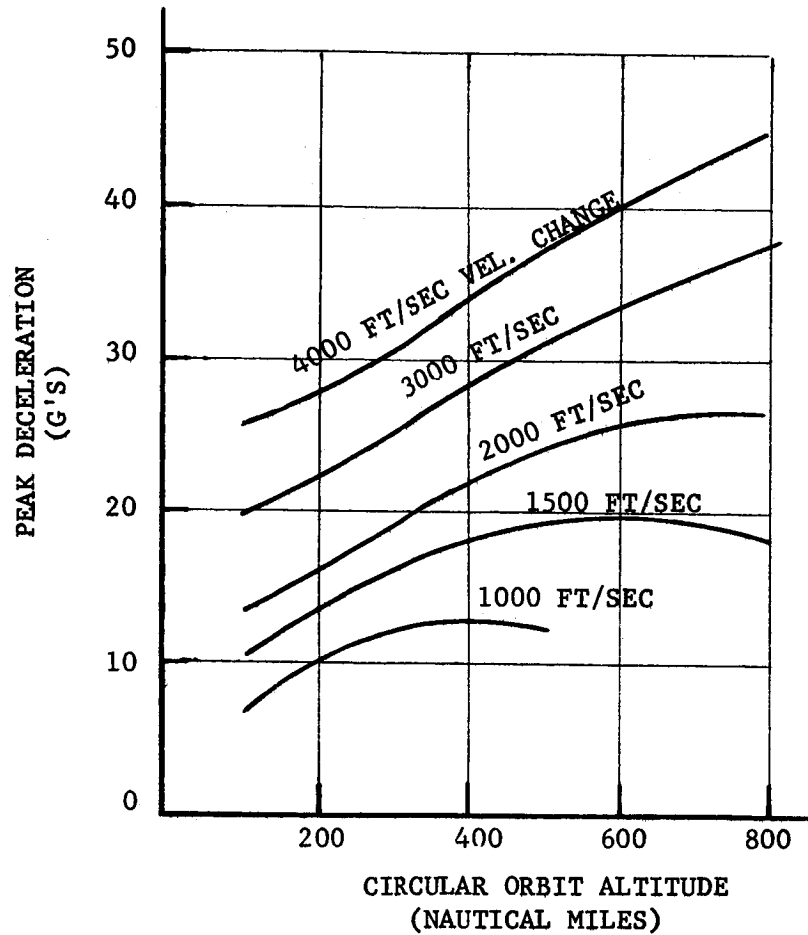
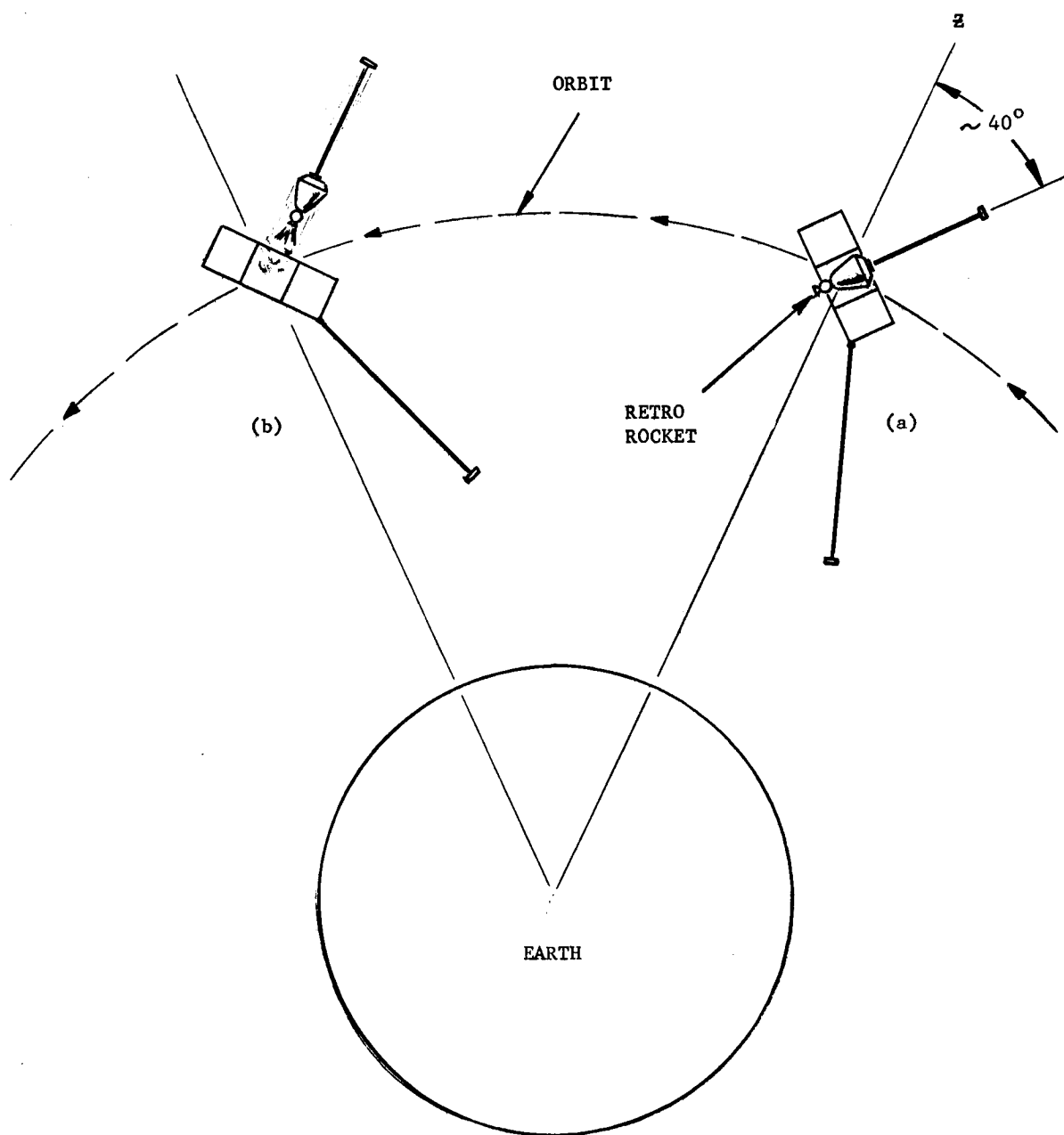
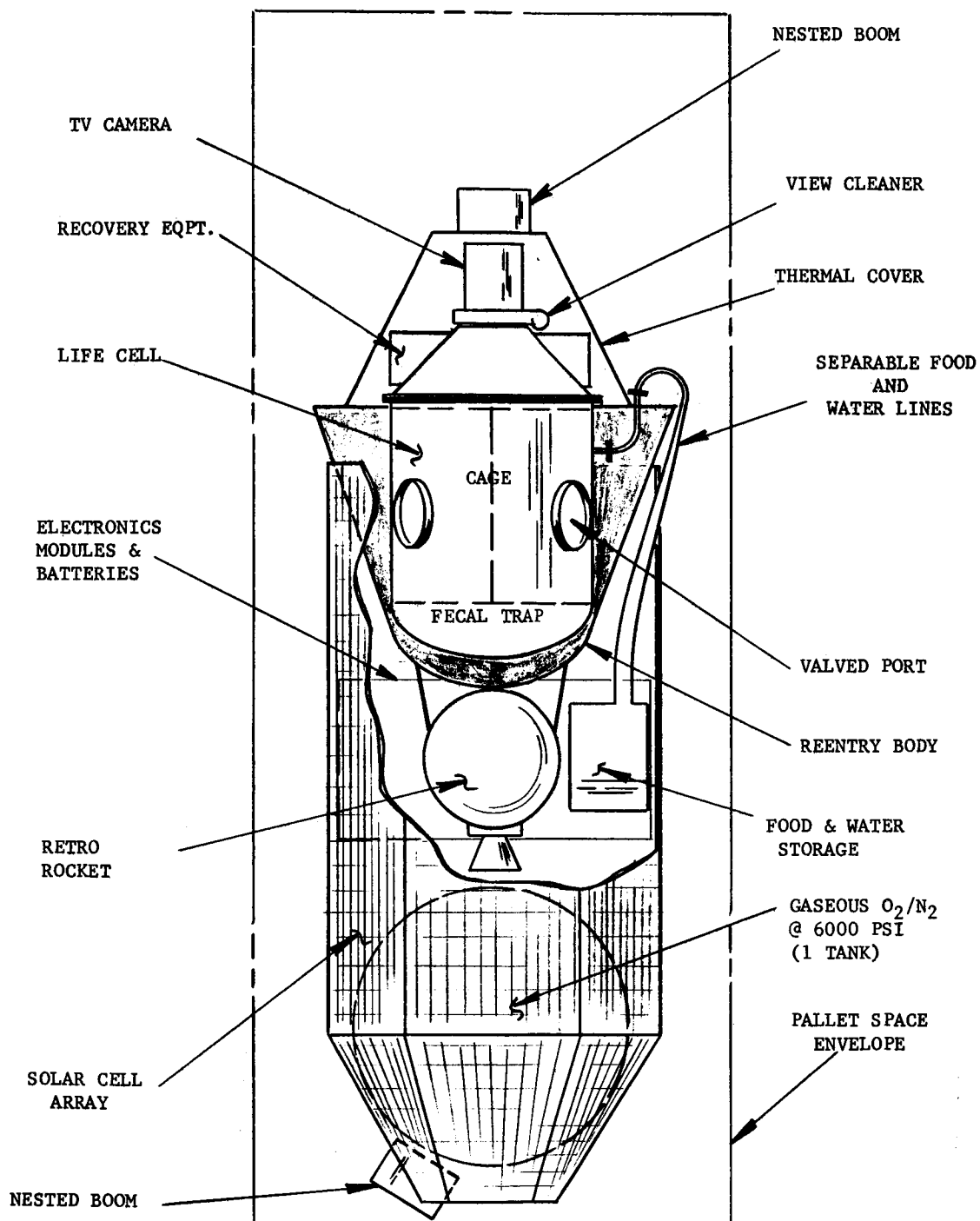


FIGURE 5.2-3



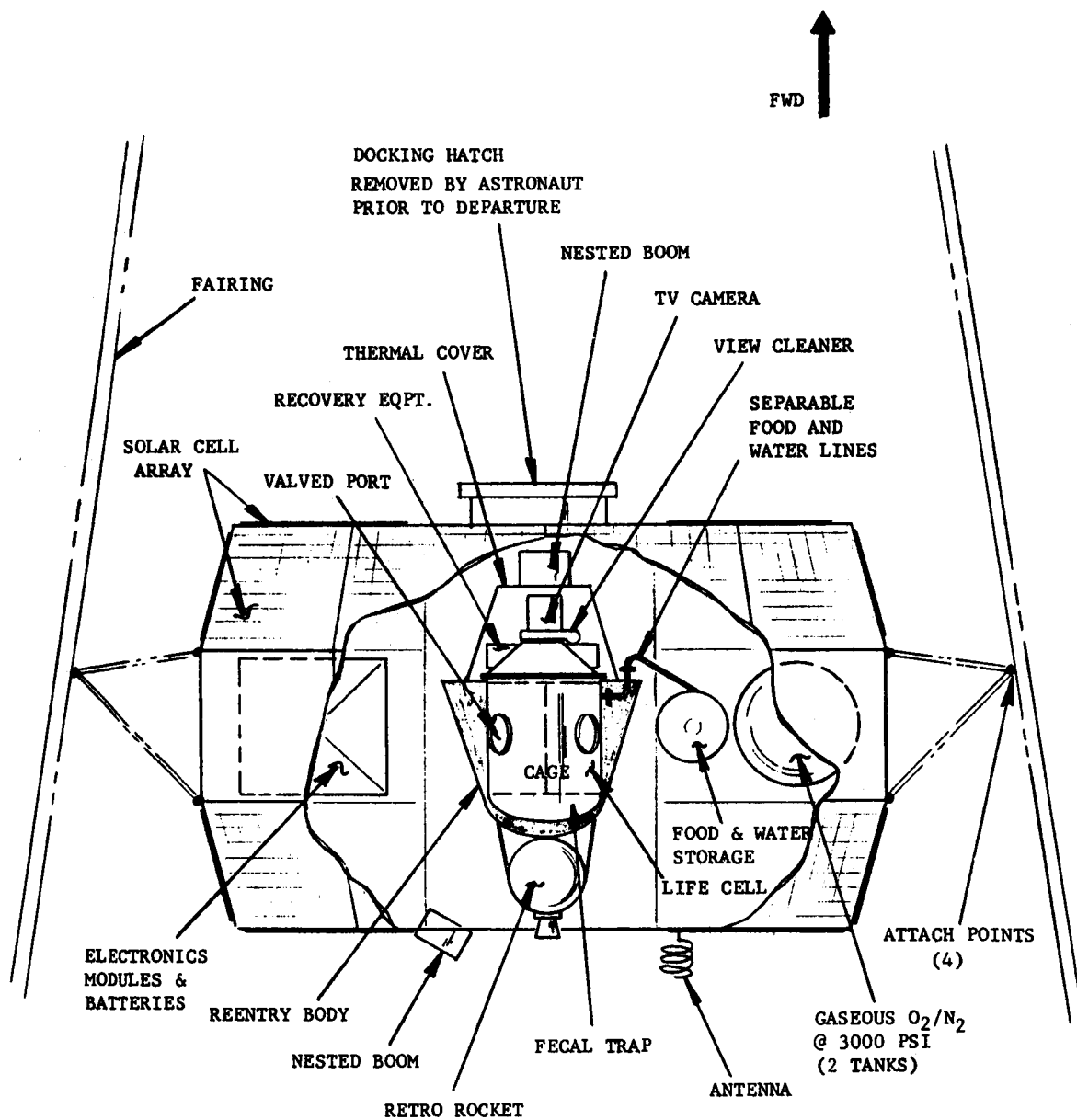
THRUST AXIS ORIENTATION
AND STABILIZATION

FIGURE 5.2-4



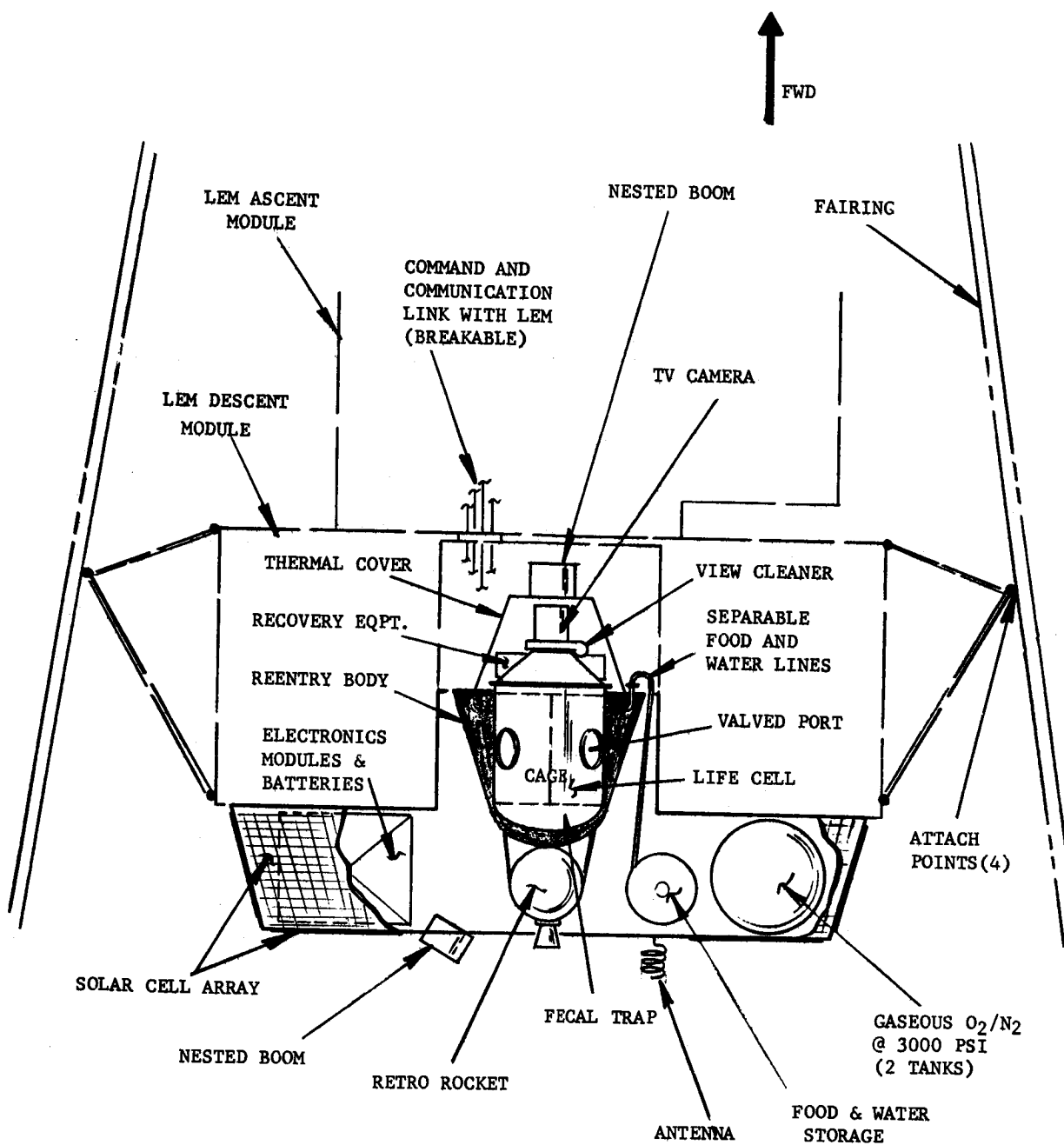
PALLET PASSENGER

FIGURE 5.2.1-1



LEM SUBSTITUTE

FIGURE 5.2.1-2



LEM COMPANION
FIGURE 5.2.1-3

a ringsail parachute. It is probable that the air snatch feature would be eliminated in order to avoid the expense of prolonged periods of aircraft readiness.

5.2.3 Recovery

Either land or water impact would be technically feasible, but the wide variety of possible orbits and mission profiles make the problem of land recovery extremely nebulous at this time. The problems of water recovery are much less sensitive to such considerations, and thoroughly proven techniques are available, therefore this mode appears preferable. Hopefully several factors would conspire to hold the recovery operations to an appropriately modest level, namely;

- (a) The impact footprint would be quite small;
- (b) Recovery opportunities need not occur more often than once a day;
- (c) The assurance of live recovery can be somewhat lower (although still quite high) than for a manned vehicle.

5.3 Life Support of the Primates During Re-entry and Recovery

The total time to recovery from the initiation of call-down is taken to be 6 hours. This figure is reasonable in view of the selection of orbits available so that the earth surface impact point can be selected to favor quick recovery. Beyond six hours the atmosphere control must be modified to keep CO₂ accumulation under control. This last can be done if study indicates that the recovery time can be greater than six hours. It should be remembered that call down has been initiated because of some emergency so that prompt recovery becomes a matter of greater importance.

The four phases of life support considered here are:

- (1) Atmosphere supply
- (2) Water supply
- (3) Physical protection
- (4) Sealing food and water lines

5.3.1 Atmosphere Supply

The life space volume of the satellite life cell itself contains over 9000 cubic inches (5.2 cubic feet) volume of atmosphere at a

nominal 14.7 pounds per square inch pressure. Subsequent to deorbit, the life cell would be returned to sea level atmospheric pressure in at most 45 minutes, after which loss of life cell atmospheric gases would cease except for the purging effect of the addition of fresh atmospheric gas. It is anticipated that the life cell package would be recovered within six hours at most from start of deorbit and animals removed at this time. The reentry life cell gas supply must then provide for these two conditions:

- (1) Replenish any atmospheric gases lost to space during deorbit period of at most 45 minutes.
- (2) Provide additional life cell gases for up to 5-1/4 more hours to maintain an adequate oxygen concentration in the life cell, and to purge carbon dioxide if needed to sustain life until recovery.

If design considerations indicate that the makeup gas added during recovery be of the minimal volume, pure oxygen can be used to advantage, otherwise it is proposed to add replenishment atmospheric gases of the same oxygen-nitrogen composition as used in orbit.

The normal rate of supply of 0.455 pounds per day mixed 32½% oxygen - 67½% nitrogen would require only 0.114 pound during the six hour period. The whole gas supply will weigh one pound. A reducing valve to produce a fixed flow through an orifice will weigh an additional half pound. During reentry and recovery, this supply would add atmospheric gases at a constant rate. The constant pressure control for life cell space would act to vent the life cell to maintain constancy of pressure and would thus produce a large vent opening as the reentry took place and the life cell gases were vented to atmospheric pressure instead of space.

The addition of life support atmosphere at a constant rate will result in a partial purging of life cell gases at this rate, producing a partial elimination of the carbon dioxide generated by the animals. The rate of build-up of carbon dioxide will be slow because of the large life cell volume.

The equation below for carbon dioxide balance for the life cell states that the molal rate of carbon dioxide accumulation (molal volumes

times rate of change of molal concentration) equals the excess of carbon dioxide generation over elimination by purging. The 9000 cubic inch life cell volume is 6.5 gram molal (22.4 liter) volumes

$$6.5 \frac{dC_{CO_2}}{dt} = 0.0238 - 0.264 C_{CO_2}$$

This equation gives as the value of concentrate, C_{CO_2} for CO_2 , after a time t from deorbit, with C_0 as the initial concentrate.

$$C_{CO_2} = 0.091 \left[1 - (1 - 11 C_0) e^{-\frac{t}{25}} \right]$$

Thus at the end of six hours the life cell carbon dioxide concentration (with 0.5% initial concentration) will be only 2½% for average animal metabolic level during this period. The 2½% carbon dioxide level has been tolerated safely for longer periods than this by human subjects.

One could reduce the required quantity of supply gas from 0.115 pound to a third (.04 pound) through use of a pure oxygen makeup atmosphere added at one third the rate previously used for makeup gas. One would not wish to do without the addition of a makeup gas completely to avoid the possibility of atmospheric loss during reentry through otherwise uncompensated leaks. The life cell atmosphere includes about 6½ gram moles of gas of which about a quarter is oxygen amounting to about 50 grams. Since the two animals only consume 0.91 gram per hour, only a 2% drop in oxygen concentration would occur per hour and the animals would survive about four hours without gas addition. Addition of the oxygen at the suggested rate (0.04 pound/six hours) will result in addition of a slight excess of oxygen over metabolism. Since the weight of the required controls will not be affected, the oxygen only replenishment system appears to weigh about one pound total (gas, gas cylinder and regulator) reflecting only a small (½ pound) net weight saving. Carbon dioxide build-up rate will be only slightly greater due to the lesser purge rate (2.7%).

The dimensions of the life space assumed are:

24" in diameter

36" long

20" of length living space

The atmospheric supply system proposed for life support during reentry and recovery consists of a 15 cubic inch air bottle pressurized to 1800 pounds per square inch; a deorbit activated release valve, and a small reducing valve to produce approximately 30 pounds per square inch regulated pressure upon the flow metering orifice.

In the reentry and recovery phase of the mission the primate must be supplied water within six hours or dehydration may set in. The primate can withstand a couple of days without food, but not water. The normal water consumption of the primate in orbit is 20 cc per day, but during recovery this consumption may be higher. A liquid supply for the recovery phase will supply sufficient sugar-water mixture for two days and have a capacity of 100 cc. The secondary liquid supply may be mounted in the life cell area adjacent to the dispensers and can be connected in parallel with the main water line. The secondary supply is isolated during the orbital phase of the mission by a check valve, which is kept closed by the water pressure of the main supply.

During the separation phase, the explosive valve will shear and seal the water transfer line at the interface of the reentry body and the support section. At this point the secondary liquid supply will be available for the supply of fluid to the primate. This is accomplished when the primate begins to consume the fluid from the dispenser. The loss of line pressure during the dispenser bladder filling procedure opens the check valve and permits the secondary supply pressurization to provide for the water supply.

There are no requirements for electrical power to operate the water system in the recovery phase. Upon separation the task logic circuit will be disabled since there is no longer a requirement for mass measurements and the pellet dispensing. The indicator over the water dispenser will remain in the go position and the indicator over the food dispenser in

the no-go position. This does not require additional electrical power. For the monkey to obtain the sugar water solution he must operate the work station sufficiently to actuate the liquid dispenser. The dispenser will operate on the ground in the same manner as in orbit.

5.3.2 Sealing Food and Water Lines to Life Cell

The transfer lines from the support section to the life cell must be disconnected for reentry. To insure that these disconnects are accomplished with a high degree of confidence, the use of pyrotechnic disconnects is dictated. The water lines would be constructed of stainless steel and the pellet transfer chutes made of teflon lined aluminum tube. The disconnect for the water line would be a valve using an explosive charge to seal the water line and shearing off the tube above the seal. The pellet transfer chute would be sheared by a cable cutter type shearing unit which seals off the end of the tube leading to the life cell.

Most explosive actuated shearing mechanisms are designed to specific requirements and are not standard stock items. Therefore the exact configuration is not known but the technique of manufacturing these items is presently available.

5.3.3 Physical Support of Primate

During normal flight and reentry the floor of the cage is always considered the down direction and the direction of the thrust axis. When the capsule reenters the earth atmosphere there is a maximum force of 15 g's applied to the primate. This force should not present an undue strain on the primate, since testing has shown that they can withstand a much larger force than 100 g's.

It is expected that the primates will orient themselves in such a way on the cage floor so as to withstand the forces of reentry, therefore the cage floor must be of sufficient strength to support this load. The presently suggested weight of the primate is approximately 540 grams or 1.2 pounds which when under a retrofire or reentry force of 20 g's would be a 24 pound force spread over an area of four square inches.

The presently proposed cage configuration calls for a floor constructed of 0.064" diameter stainless steel rod spaced 0.500" between centers and running at right angles and having interwoven mesh. The maximum distance between external support for the floor mesh is six inches in each direction. It may be desirable to substitute a non-metallic mesh material if electronic implants are used in this experiment. This would be required to permit the transmission of electronic signals into and out of the cage. The strength of lexan type material will be within the requirements of the above loading during retrofire and offer the dielectric properties desired. The proper selection of the non-metallic material must be made to insure that the monkey cannot eat through the cage and that it will not be damaged by urine and feces being deposited on it.

APPENDIX B

EVALUATION OF THIN FILMS

6.0 INTRODUCTION

The use of a selectively permeable membrane to expel water from a biosatellite atmosphere without an intolerable loss of air is sufficiently attractive to merit thought about preliminary design. While the manufacturers of the various films under consideration have reported their permeabilities, the procedures by which these data were obtained bear little similarity to the conditions under which the films would be used. A series of experiments was therefore carried out to compare available films under environments they might later encounter.

We might look upon the process by which water is removed from the air stream as taking place by three steps, one after the other. First, the water molecule must impinge upon the film and it is likely that some will bounce off rather than be absorbed. Second, the water molecule will diffuse into the film, generally flowing toward points of lower water concentration. Third, water molecules reaching the "downstream" surface will mostly re-evaporate from that surface unless impeded by water re-entering that surface from the opposite direction. This counterflow won't occur from a vacuum and it can be minimized without a vacuum if a dry gas is swept across the surface. We, therefore, must perform two sets of measurements: one, to find an effective flow rate for the sweeping gas in the downstream side and, after that is found, to find the optimum flow rate of moist air across the membrane on the upstream side.

Because a film which leaks appreciable amounts of air must be rejected on that score alone, leakage was measured before any other tests were made. In this test, the membrane was subjected to half-atmosphere differential air pressure and the amount of air passing through was measured by water displacement.

6.1 Experimental Procedure

The test cell, Figure 6.1-1, consisted of two plastic rings with the test film placed between them, and two plastic cover plates, making a two-chambered cylinder with the film separating the chambers.

The film was supported by a dacron mat and wire screen. Each chamber was fitted with two hose connections for admission and exit of the flowing gases. The gas flowing through the "upstream" compartment was air which had been saturated with water vapor by bubbling through water; its pressure was fixed by a regulator at the source, its flow rate regulated and measured, and its relative humidity before and after passing across the film measured by wet-bulb thermometers. The gas flowing through the "downstream" compartment was helium which had been dried by anhydrous calcium sulfate; its pressure was regulated to a half-atmosphere less than the upstream air pressure; its flow rate was regulated and measured. After the helium has passed across the film, it was passed through a weighed absorption tube filled with anhydrous calcium sulfate where the moisture picked up from the film was deposited. The amount of water absorbed in the tube in a fixed period of time, usually an hour, served as the basis upon which film efficacy was judged.

6.2 Results

Two sets of water permeation curves were obtained: the "downstream" curves (Figure 6.2-3, 6.2-3, 6.2-5) where the helium flow rate was varied while the moist air flow through the "upstream" chamber was held at a high constant rate and the "upstream" curves (Figures 6.2-2, 6.2-4, 6.2-6) where the rate of moist air flow was varied, while the helium flow sweeping the "downstream" side was held at a high constant rate. Both types of curves appear to approach asymptotes but at flow rates which may be impracticably high. Tables 6, 7, and 8 show the actual results obtained for regenerated cellophanes and cellulose acetate. Table 9 summarizes the water vapor permeabilities for seven commercially available films; three showed sufficient permeability to water vapor to be of interest: Dupont's 215PD regenerated cellophane and Eastman's cellulose acetate. General Electric's dimethyl siloxane rubber in single 1-mil sheets leaked too much; when doubled to cut down leakage, its permeability was decreased below that of the cellulosic films.

TABLE 6

Dupont 193 PUD-O Regenerated Cellophane (0.001" thick)

DETERMINATION OF WATER VAPOR PERMEABILITY AT VARIOUS AIR FLOW RATES

Upstream (Variable)			Downstream (Constant)	
Relative Humidity	Air Flow		Helium Flow	Water Permeated
Inlet → Outlet	cc/min.		cc/min.	$\text{g} \cdot \text{H}_2\text{O}/\text{mil}/\text{hr}/100\text{in}^2$
-	-	1050	1050	1.944
92% → 77%	500		1050	1.389
92% → 76%	250		1050	0.817
92% → 86%	100		1050	0.372

DETERMINATION OF OPTIMUM DOWNSTREAM FLOW RATE OF HELIUM

Upstream (Constant)			Downstream (Variable)	
Relative Humidity	Air Flow		Helium Flow	Water Permeated
Inlet → Outlet	cc/min.		cc/min.	$\text{g} \cdot \text{H}_2\text{O}/\text{mil}/\text{hr}/100\text{in}^2$
-	-	1050	1050	1.944
95% → 71%	1050		500	1.875
95% → 72%	1050		250	1.809
95% → 69%	1050		100	1.256

Temperature: 23°C

Pressure differential across film: 7.5 psig

TABLE 7

Dupont 215 PD Regenerated Cellophane (0.001" thick)

DETERMINATION OF WATER VAPOR PERMEABILITY AT VARIOUS AIR FLOW RATES

Upstream (Variable)			Downstream (Constant)	
Relative Humidity		Air Flow	Helium Flow	Water Permeated
Inlet → Outlet		cc/min.	cc/min.	$\text{g} \cdot \text{H}_2\text{O} / \text{mil} / \text{hr} / 100\text{in}^2$
-	-	1050	1050	2.252
94% →	70%	750	1050	1.792
-	-	500	1050	1.065
93% →	76%	250	1050	0.940
95% →	87%	100	1050	0.505

DETERMINATION OF OPTIMUM DOWNSTREAM FLOW RATE OF HELIUM

Upstream (Constant)			Downstream (Variable)	
Relative Humidity		Air Flow	Helium Flow	Water Permeated
Inlet → Outlet		cc/min.	cc/min.	$\text{g} \cdot \text{H}_2\text{O} / \text{mil} / \text{hr} / 100\text{in}^2$
-	-	1050	1050	2.252
94% →	69%	1050	750	2.280
-	-	1050	500	2.250
95% →	70%	1050	250	1.673
95% →	71%	1050	100	0.810

Temperature: 23°C

Pressure differential across film: 7.5 psig

TABLE 8

Eastman Cellulose Acetate (0.001" thick)

DETERMINATION OF WATER VAPOR PERMEABILITY AT VARIOUS AIR FLOW RATES

Upstream (Variable)			Downstream (Constant)	
Relative Humidity		Air Flow	Helium Flow	Water Permeated
Inlet → Outlet		cc/min.	cc/min.	$\text{g} \cdot \text{H}_2\text{O} / \text{mil} / \text{hr} / 100 \text{in}^2$
98% → 69%		1050	1050	1.630
97% → 72%		500	1050	1.250
95% → 77%		250	1050	0.885
- → -		100	1050	0.590

DETERMINATION OF OPTIMUM DOWNSTREAM FLOW RATE OF HELIUM

Upstream (Constant)			Downstream (Variable)	
Relative Humidity		Air Flow	Helium Flow	Water Permeated
Inlet → Outlet		cc/min.	cc/min.	$\text{g} \cdot \text{H}_2\text{O} / \text{mil} / \text{hr} / 100 \text{in}^2$
98% → 69%		1050	1050	1.630
96% → 69%		1050	500	1.460
96% → 73%		1050	100	0.820

Temperature: 23°C

Pressure differential across film: 7.5 psig

TABLE 9

SUMMARY OF WATER VAPOR PERMEABILITY OF VARIOUS FILMS

Conditions of the Experiment:

Air leakage: Zero except where noted

Upstream flow: Air

Initial relative humidity: 96-97%

Temperature: 23°C

Pressure: 7.5 psig

Flow rate: 1050 cc/min.

Downstream flow: Helium

Temperature: 23°C

Pressure: Atmospheric

Flow rate: 1050 cc/min.

<u>FILM</u>	<u>THICKNESS</u> <u>Inches</u>	<u>WATER PERMEATED</u> <u>gm H₂O/hr/in²</u>
193 PUD-O Cellophane (Dupont)	0.001	1.944
215 PD Cellophane (Dupont)	0.001	2.252
Cellulose Acetate (Eastman)	0.001	1.630
Dimethyl siloxane rubber (General Electric)	0.002	1.126 *
(2 x 0.001 sheets)		
Dimethyl siloxane rubber (R. E. Darling Co.)	0.010	0.499
Cellulose triacetate (Eastman)	0.005	0.312
Lexan (General Electric)	0.001	0.222

*leakage: 2-3 cc/min.

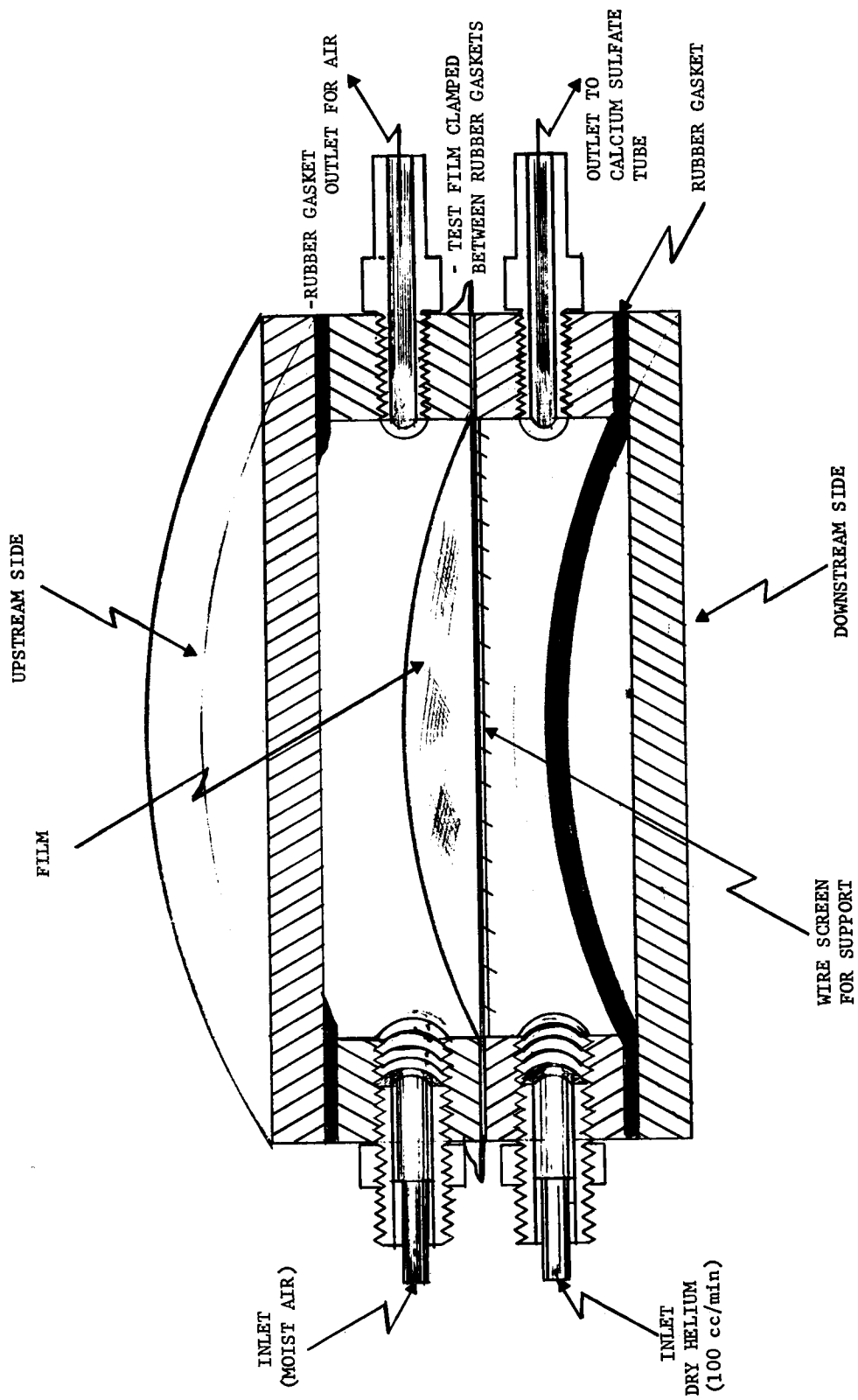


Figure 6.1-1

TEST APPARATUS FOR WATER VAPOR PERMEABILITY

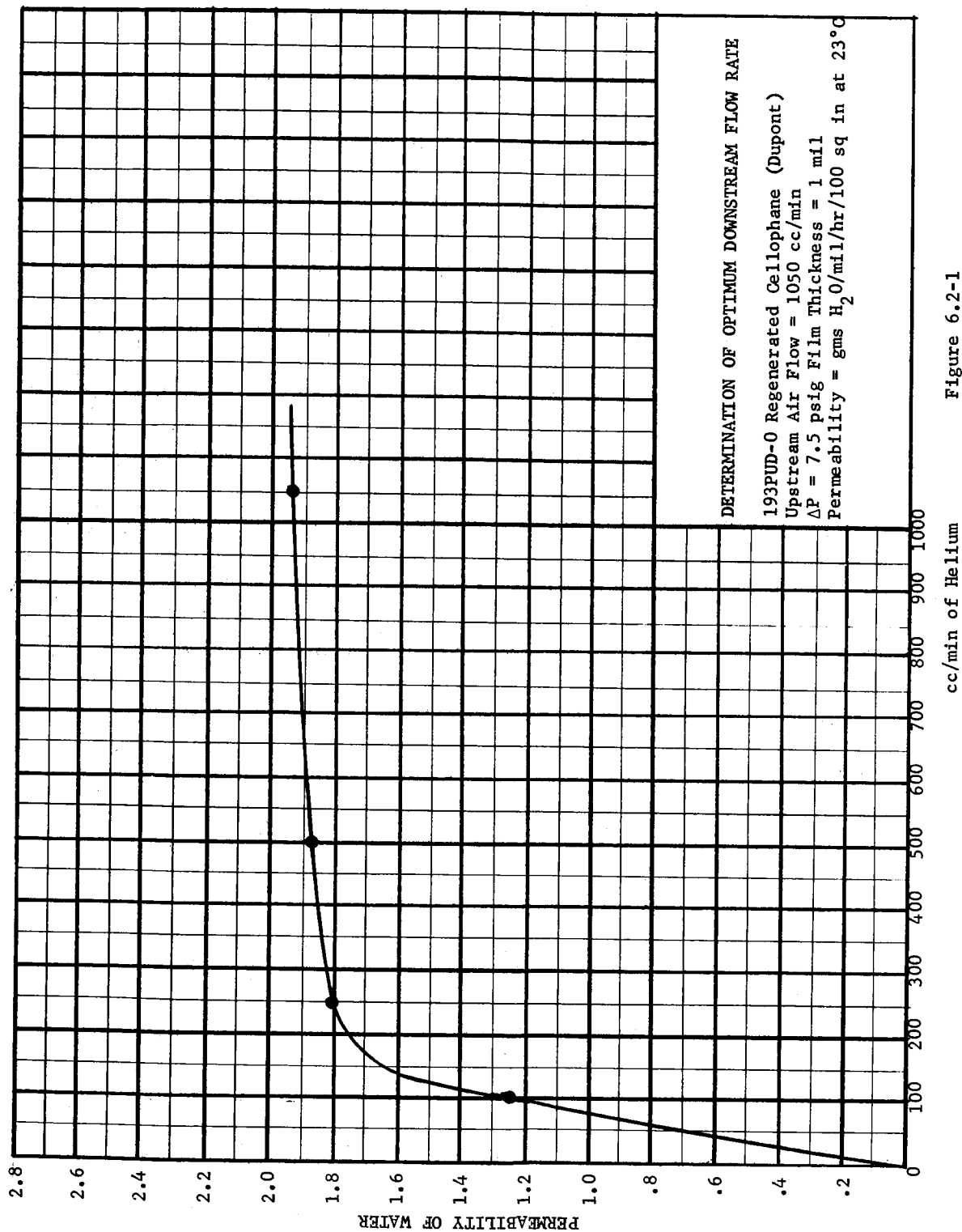


Figure 6.2-1

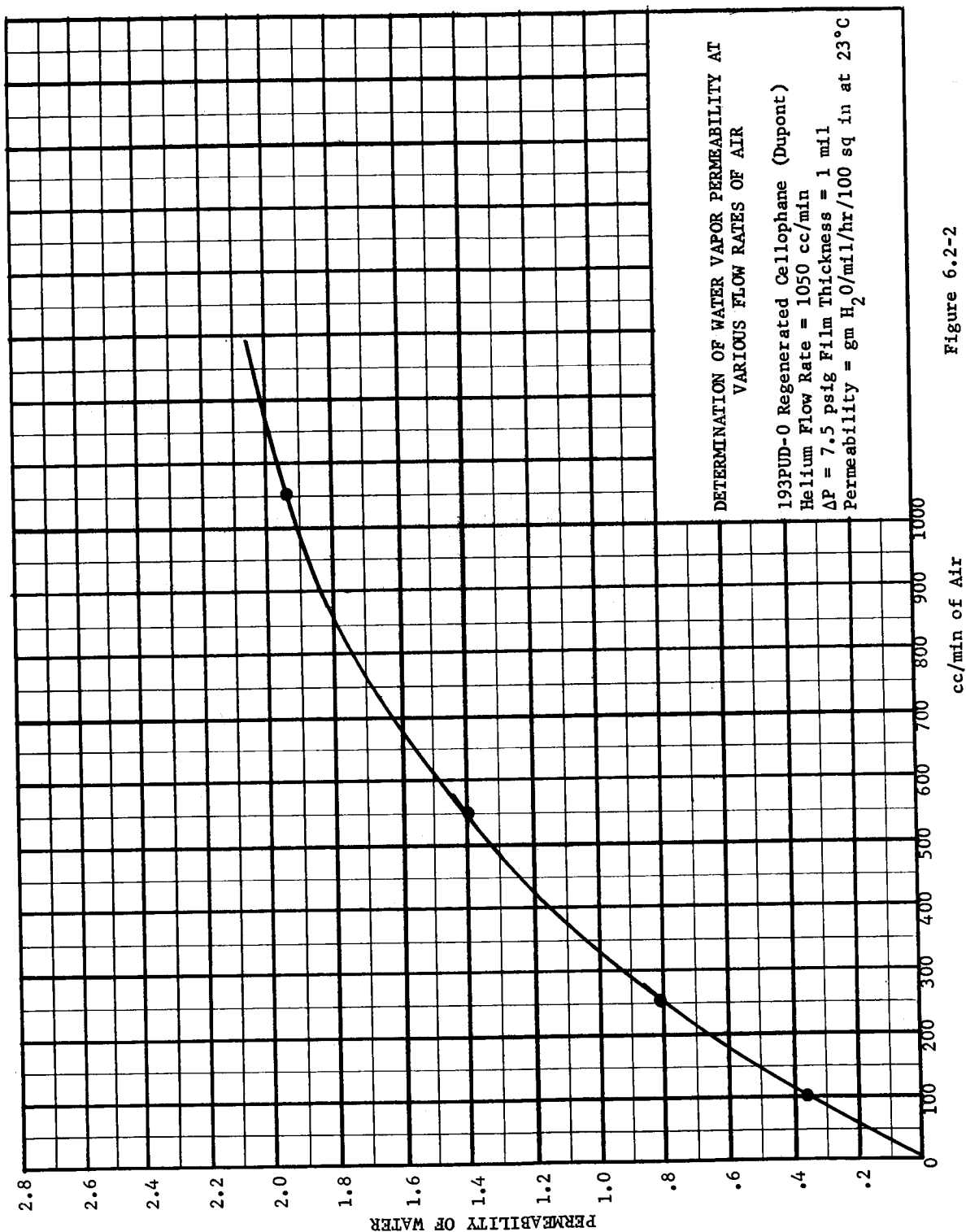


Figure 6.2-2

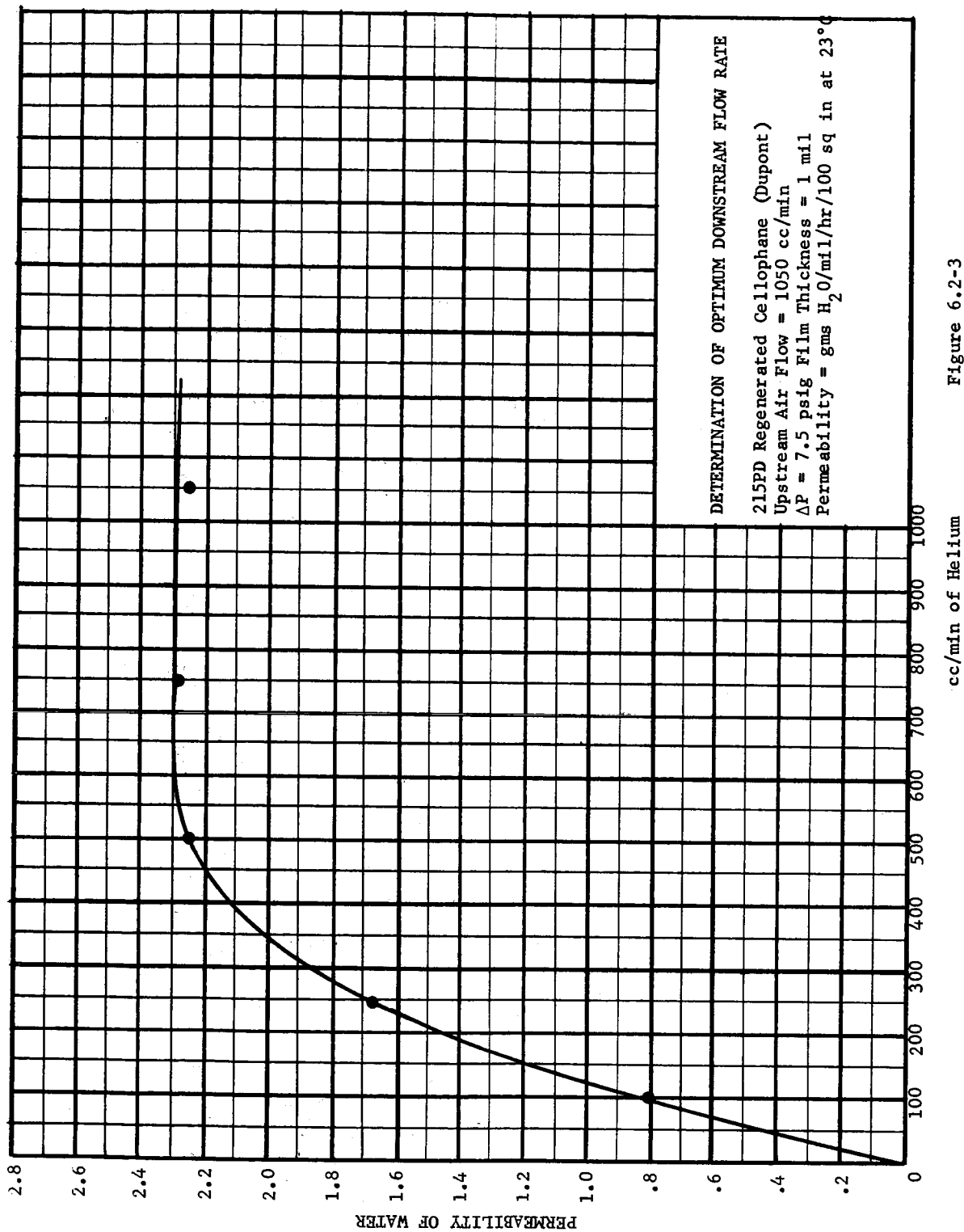


Figure 6.2-3

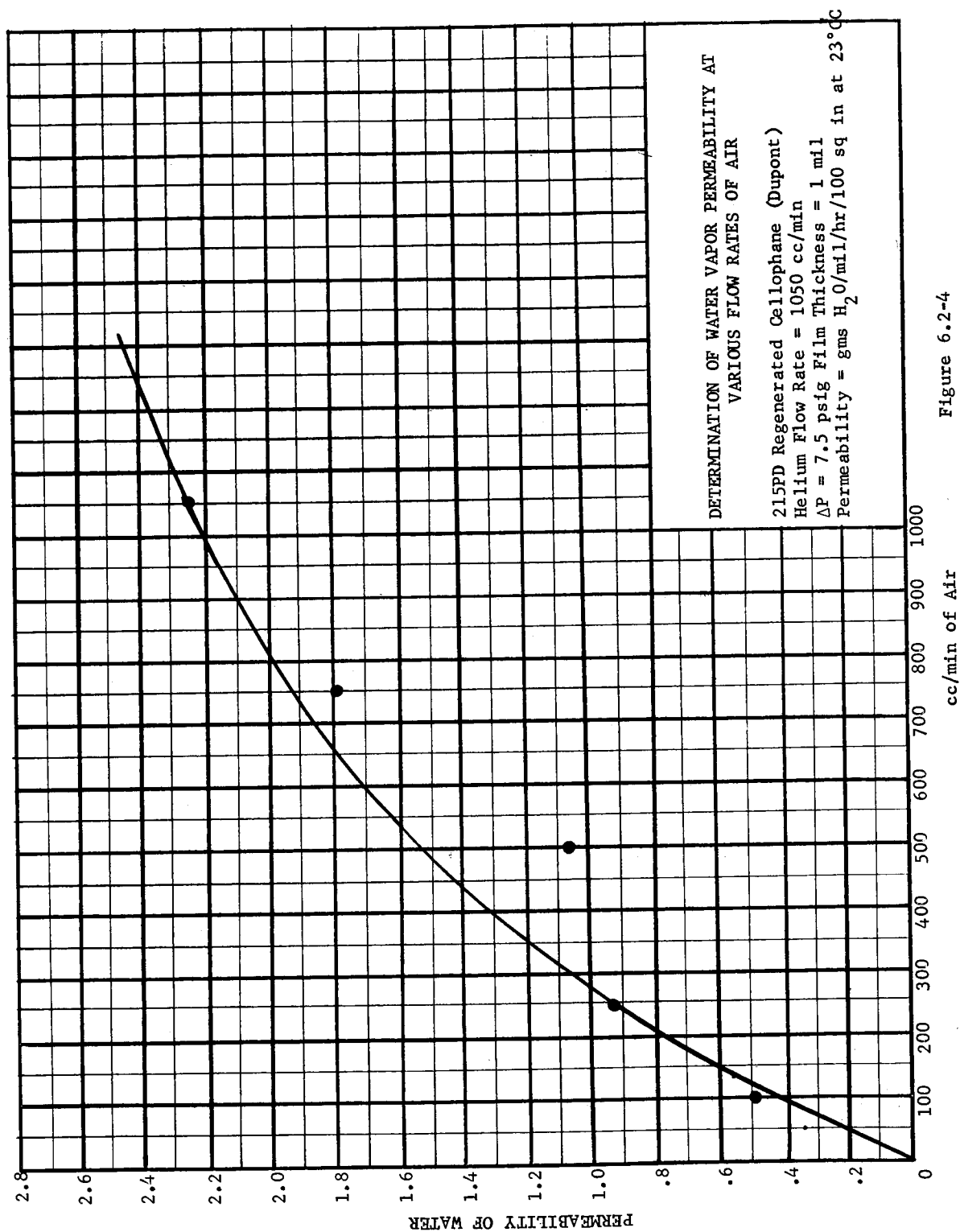


Figure 6.2-4

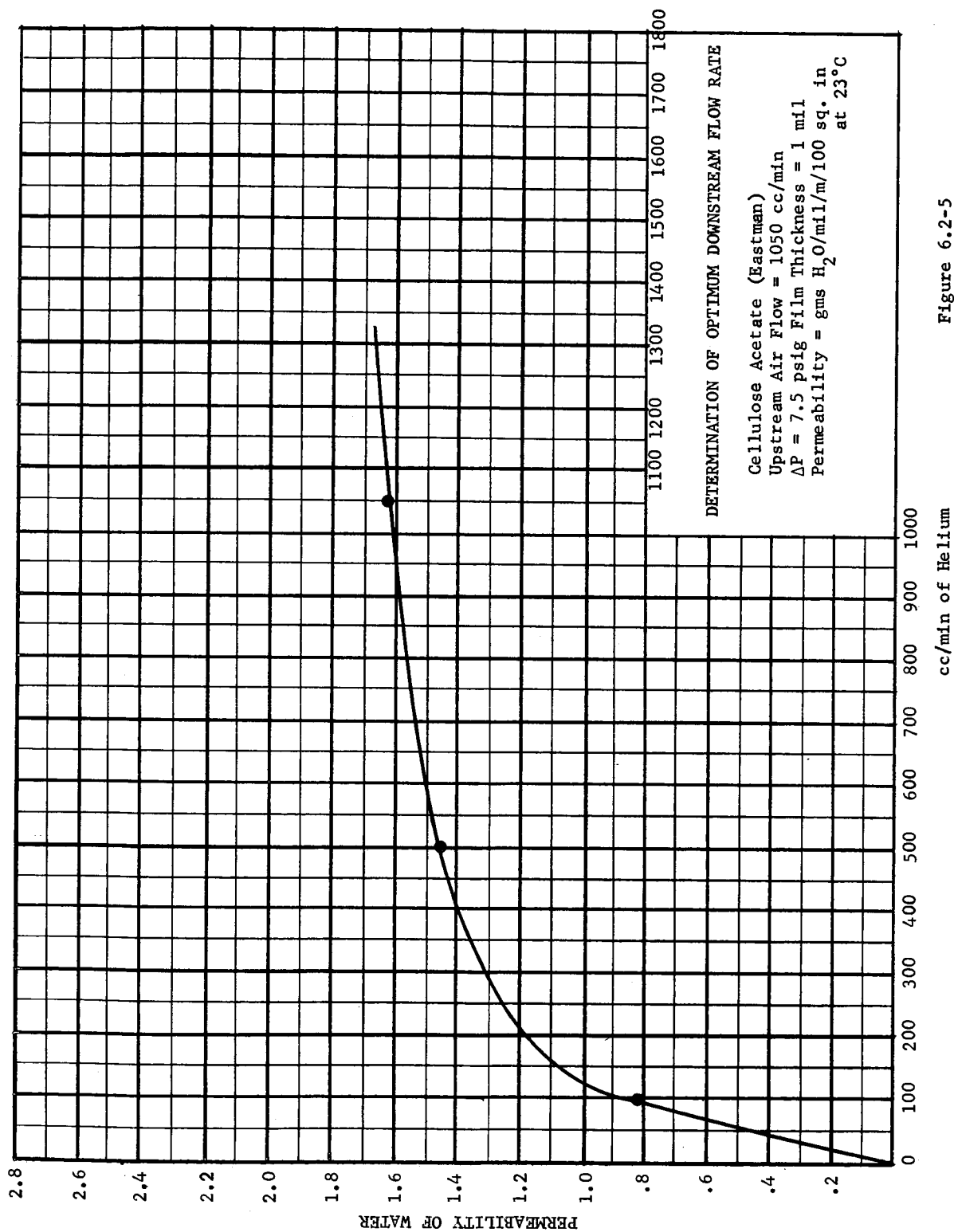


Figure 6.2-5

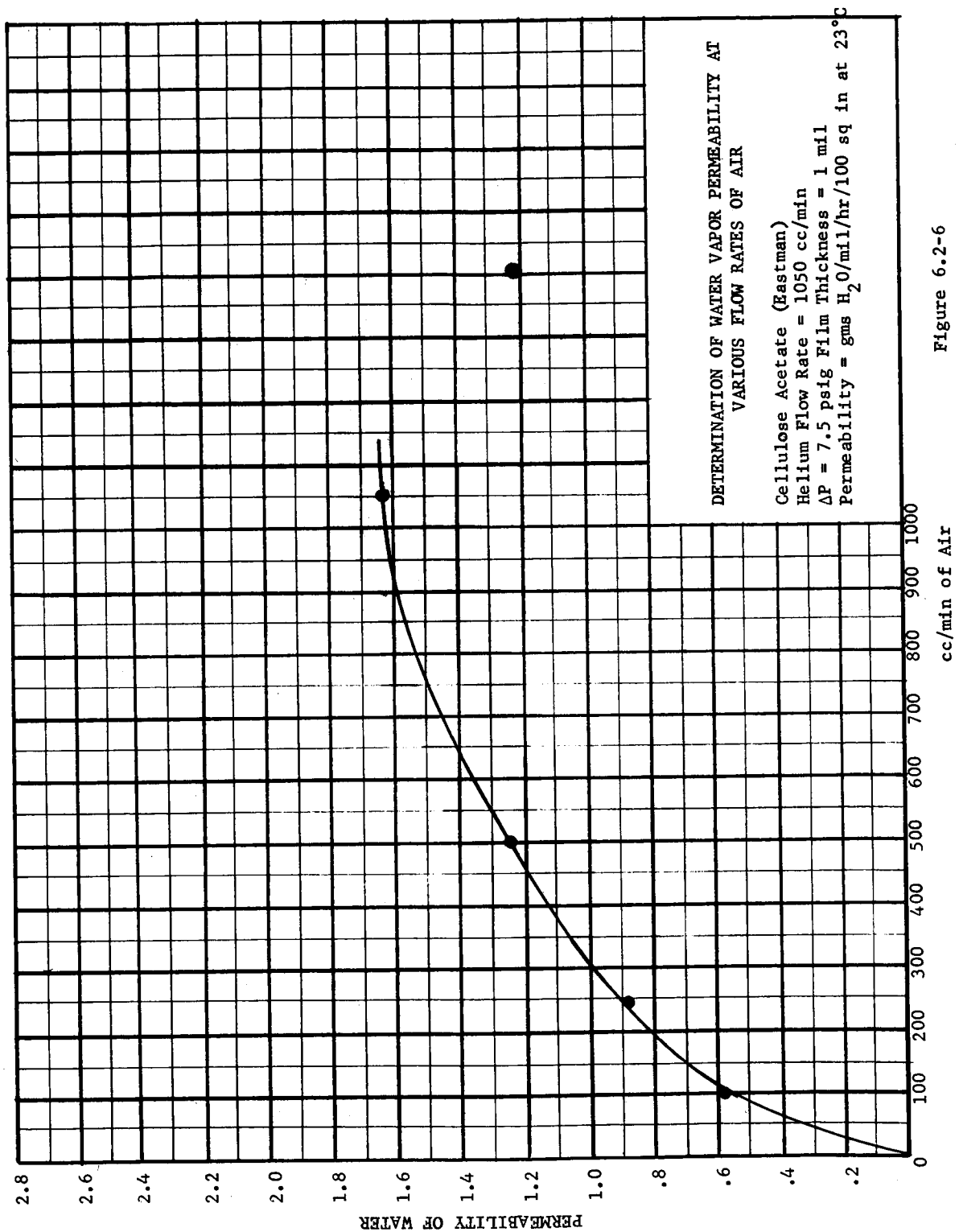


Figure 6.2-6