FINAL REPORT TO

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PART I SCIENTIFIC REPORT

RESEARCH CONTRACT NASA NSR 05-007-158

"PHYSIOLOGY OF CHIMPANZEES IN ORBIT"

JULY 8, 1968 through FEBRUARY 28, 1971

Dr. W. Ross Adey
Space Biology Laboratory
Brain Research Institute
University of California, Los Angeles

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INTRODUCTION

This report is the final progress report of the Physiology of Chimpanzees in Orbit Program. It presents the major achievements and accomplishments of the scientific and engineering team's related efforts. The major sections of the report are shown below:

TABLES

FIGURES

FIGURES (Continued)

FIGURES (Continued)

FIGURES (Continued)

Part One

BEHAVIOR

AND

PHYSIOLOGY

BEHAVIOR AND PHYSIOLOGY

The basic plan for a long term biomedical experiment in space using two highly instrumented chimpanzees, one unrestrained and one restrained in a survival couch, has been described previously in the proposal "Physiology of Chimpanzees in Orbit." This proposal was first submitted to the National Aeronautics and Space Administration June 30, 1967. A more detailed definition of the flight experiment, using the unrestrained animal is given in the interface document of this report. A detailed definition of the flight experiment using the restrained chimpanzee was projected to be submitted in an interface document during fiscal year 1971.

In preparation for a flight in the mid or late 70s we have implemented and pursued a research program to establish (a) efficient and effective behavioral training procedures to assure successful performance by the chimpanzees on the flight tasks and (b) a library of information that will allow critical assessment of the effect of extended weightlessness on the physiology and behavior of the chimpanzee.

I. BEHAVIORAL TRAINING

The procedures for the domestication of the chimpanzees, and for training the animals on primary, matching to successive samples (MSS) and primate environmental control (PEC) behavioral tasks have been developed.

A. DOMESTICATION

Domestication or taming of the young preadolescent chimpanzees is initiated at their arrival at this University and continues throughout their laboratory life. The domestication procedures begin with observations by the Animal Trainers of the chimpanzees during the quarantine period for the purpose of estimating their dominance-submissiveness characteristics, their agility, native resourcefulness, etc. Following the quarantine period the training consists of daily exposure to progressive amounts of handling and gentle restraint. This is followed by obedience training and teaching the animals to accept intensive medical examinations. A specific in house guide to the domestication and taming of these wild animals is included in the appendix of this report.

B. PRIMARY TRAINING AND ADAPTATION TO PARTIAL ISOLATION

Primary training is initiated within the chimpanzee's home cage, midway through his domestication or taming program. The modified home cages are equipped with a primary training panel and a simple button press panel for water on an ad lib basis. In addition, the cage is curtained for visual isolation during the training to initiate an adaptation to isolation programs that will prepare the animals for the isolation of prolonged flight. The training protocol is detailed in the enclosed interface document.

Primary behavioral training is to allow each chimpanzee's food and water intake to be contingent on the button press habit; to build up a strong button press habit that is highly resistant to extinction and interference from extraneous events; to acquaint the animals with the response schedule requirements that are to be used with the PEC tasks, and to serve as a means of manipulating the rate of the button press response to maximize the probability of the "observing response" which is necessary for successful learning of the MSS tasks. Primary training is also to allow early evaluation of collective and idiosyncratic motivational-performance characteristics of each chimpanzee; to investigate behavioral and drug induced stresses; to test efficacy of training techniques; and as a means of beginning early in the animal's laboratory life an adaptation to an isolation program that will adapt the animals for the isolation of a prolonged orbital flight. Prior to the termination of this contract, all chimpanzees in the present colony, both the behaviorally sophisticated and the relatively naive, had begun their primary training. The preliminary results indicated that the animals' performance on the various response schedules accurately reflect their idiosyncratic motivational performance characteristics.

C. MATCHING TO SUCCESSIVE SAMPLE TRAINING

The MSS tasks are a series of easy-to-difficult delayed-matching tasks designed to test the limits of the chimpanzees' performance capabilities. These flight tasks allow evaluation of spatial orientation and locomotion abilities, focused attention or attention span, recent memory and hand-eye coordination. Training of the MSS tasks are initiated upon completion of primary training--first in the home cage environment and then in the sound attenuated and isolated behavioral cage environment. Within the latter setting EEG, EOG, and EMG are taken to allow definition and assessment of the physiological substrates of the orienting response, focused attention, levels of alertness, fatigue and stress, as well as concomitants of recent memory and the decision making processes.

The systematic exploration of the primate brain to find the deep brain recording sites or combination of sites which will yield the most consistent EEG indices of the above has been initiated within the last year by Dr. Samuel Moise, Jr. and Dr. Anatol Costin and is continuing. Development of this study is intimately associated with the development of our computer analysis methods.

Feasibility of the MSS tasks up to the 2 sample, 5 choice task using our outdated computer-programmed procedures had been demonstrated in the two chimpanzees that were candidates for the 30-day systems test. Before termination of the contract, these animals were undergoing training on the flight configured panel within the behavioral booth of the environmental chamber.

D. PRIMATE ENVIRONMENTAL CONTROL TASKS

The operant PEC tasks are a) primate control of houselight intensity or light/dark cycle, b) primate control of ambient temperature, and c) the auditory enrichment task. These tasks are incorporated within the framework of our biorhythm, isolation experiments. The first two tasks give the animal control over the entraining agents of light and temperature. The third task, which will also contribute to our library of circadian and infradian data, is to allow the animal to reduce the isolation contingencies by pushing buttons under various response schedules to hear familiar chimpanzee and animal trainer sounds. Training on these tasks follows primary training and is concomitant with both isolation and the later stages of MSS training. Reduction of staff and financial limitations precluded the commencement of PEC training prior to the termination of this contract.

E. WASTE CONTROL BY "POTTY TRAINING"

Potty training was undertaken as a possible method to complement other methods of waste control proposed in the interface document. Its purpose for the space flight is primarily to allow attainment of periodic samples that would be uncontaminated by urine, water, etc. Three general procedures of potty training were to be evaluated: (a) natural, (b) movie-TV, (c) operant. The natural procedure consisted of replacing the grid floor of the chimp's home cage with a floor with a hole in it. This method would rely on the chimp's inherent motivation to keep his cage free of feces. The natural procedure led to unsatisfactory results. Some animals defecated all over their cages, others defecated in one spot and others shoved their feces out of the cage door onto the floor but not through the hole in the floor. The movie-TV procedure is a method used by our trainers in the past to train chimps for the movie industry to go on the potty and flush it on cue. This method was successful for one chimp and was progressing satisfactorily for four others. A major disadvantage of the movie-TV procedure is that it is animal trainer dependent and somewhat unreliable, i.e. although the animal may defecate on the potty on cue, five minutes later the animal may again defecate wherever it happens to be. The third method, the operant procedure, is to put the chimpanzee's defecation habits in his home cage under stimulus control with the use of operant techniques within the framework of the animal's biorhythmic defecation patterns. The effects of contract termination before completion of apparatus construction precluded the initiation of this latter training procedure.

II. PHYSIOLOGY

A series of studies were performed in our laboratory investigating significant aspects of cyclic biological functions and the effects of stressful events on the physiology and psychology of the chimpanzee. Electrophysiological, biochemical and behavioral variables were investigated. The results were to be compared to those obtained in human experiments in order to show that the chimpanzee could indeed be the surrogate for man in determining the limits of man's endurance and capability to participate in prolonged space travel.

A. EFFECT OF 2-DAY FOOD DEPRIVATION STRESS ON 24-HOUR URINARY EXCRETION VALUES

The study was designed to determine 1) baseline 24-hour urinary excretion values in the young, unrestrained chimpanzee, and 2) changes in urinary values, if any, induced by stress of either 2 initial days of normal diet (control days) and 2 days of food deprivation (stress days), or 2 days of food deprivation followed by 2 days of normal diet (post days). 24-hour urine excretion values were obtained for volume, osmolarity, creatinine, creatine, urea-N, 17-hydroxycorticosteroids (17-OHCS), 3-methoxy-4-hydroxymandelic acid (VMA), calcium and inorganic phosphorus. Analyses of sodium and potassium are still to be performed by use of atomic absorption.

In order of significance, increases due to food deprivation stress were observed for phosphorus, 17-hydroxycorticosteroids, volume, VMA, and creatine with significant decreases in calcium and osmolarity. Highly significant changes were noted for calcium and phosphorus. No significant changes were observed in creatinine values. Starvation results in man showed similar trends.

A manuscript on the above was submitted to the American Journal of Physiology. Title: "Urinary Excretion in Two-Day Food Deprived, Unrestrained Chimpanzees."

Some aspects of the above study (i.e., Ca and P excretion in particular) was reported at the Aerospace Medical Association Meeting in Houston (April, 1971).

B. THE SLEEP CYCLE AND SUBCORTICAL-CORTICAL RELATIONS IN THE UNRESTRAINED CHIMPANZEE

Nocturnal sleep was studied in the young unrestrained chimpanzee in a home cage vivarium environment. A 4-channel biotelemetry system was used to transmit the electrophysiological measures (EEG, EMG, and EOG) for seven consecutive nights from each of three chimpanzees. Visual inspection and computer analysis techniques were used in the description of the sleep cycle and of the physical parameters of the EEG during various stages of the sleep cycle. The data acquired during this investigation has been summarized in previous reports and has contributed to the preparation of the following manuscripts: "Telemetry studies of sleep in the unrestrained chimpanzee" (McNew *et al*, 1968); "Sleep of unrestrained chimpanzee: cortical and subcortical recordings" (Freemon *et al*, 1970); "On the problem of bias in error rate estimation for discriminant analysis" (Larson *et al*, 1970); "The sleep cycle and subcortical-cortical relations in the chimpanzee" (McNew *et al*, in press); and "A test of sleep staging systems in the unrestrained chimpanzee" (Larson *et al*, in press).

C. BIORHYTHMS IN URINARY EXCRETION OF HORMONES, METABOLITES AND ELECTROLYTES AND THE SLEEP-WAKE CYCLE IN THE UNRESTRAINED CHIMPANZEE

This study was designed to determine the relationship of the sleep/wake cycle and the rhythmicity in micturition and urinary excretion patterns in chimpanzees under normal home cage environment conditions. For each run the urines were collected for seven successive days and nights by means of a special fraction collector (which collected each urination separately while noting the time). Electrophysiological measurements of the sleep/wake cycle (EEG, EOG, and EMG) were recorded with the use of a 7-channel biotelemetry system. Three animals were used in the study with a repeat on one animal (thus four runs altogether).

All urine samples were analyzed for volume, pH and osmolarity. A minimum of three full days was analyzed for the four runs for all other parameters mentioned in Section A above. Sodium and potassium measurements remain to be done.

One can say, in general, that the frequency of urinations is greater during the light hours than in the night. Urinations at night appear to be preceded by an awake period. The highest urine volume is voided in the morning upon awakening and the total urine excretion is decreased during the night. Urine pH decreases at night and increases during the day, especially after meals showing the "alkaline tide" which is well known for man. The osmolarity shows some trends in that it appears to peak in the afternoon and shows a decrease during the night period. The excretory data, especially of the steroids, creatinine and phosphorus appear to show rhythmic trends; these remain to be statistically analyzed.

The CNS data of the sleep/wake cycle complement the results of the previous sleep study and have contributed to the following manuscripts: "Sleep of unrestrained chimpanzee: differences between first and last REM period" (Freemon et al, 1969); Sleep of unrestrained chimpanzee: cortical and subcortical recordings" (Freemon et al, 1970); "The chimpanzee sleep cycle" (Freemon et al, in press). Data from the earlier sleep study also contributed to the former two papers. The manuscripts on the endocrine system and that relating the endocrine system and CNS biorhythms have not yet been prepared.

D. 30-DAY ISOLATION STRESS AND ITS EFFECTS ON CENTRAL NERVOUS AND METABOLIC VALUES AS WELL AS BIORHYTHMS IN THE UNRESTRAINED CHIMPANZEE

This study was concerned with prolonged stress and followed a protocol similar to that suggested for a future orbital flight and was to study the activity, sleep/wake and excretory rhythms in an isolated chimpanzee during various light/dark cycles.

The study was divided into the following periods: a) two-week period of initial adaptation to cage and routine (12L/12D: 0700: 1900L); b) 30 days of complete isolation: (12L/12D: 1430:0230L)--the photo-period was "locked-in" on animal's free running rhythm; c) period of five days after isolation with the animal back on the original L/D cycle (0700:1900L); d) period of 10 days with the animal in his home cage environment under the same conditions of diet and sample collection. The results obtained here were used as control data.

The food and liquid intakes were closely monitored as were the activity periods and EEG. Hourly urine samples were collected by means of our specially adapted fraction collector. Throughout the study, urines were continuously monitored for pH, specific gravity, glucose, ketone bodies, blood content and total protein in order to observe the animal's state of health. The urine samples were then stored at -15°C and later analyzed for volume, osmolarity, creatinine, creatine, urea-N, 17-OH corticosteroids, VMA, Ca and P. Only the Na and K determinations remain to be completed.

Fecal samples were collected daily and were analyzed for weight, percentage of water, total Ca, phosphorus and nitrogen.

Table 1, Part A shows a 5-day means of liquid and solid intakes for the actual 30 days of isolation. Urine and fecal excretion values (5-day averages of 24-hour excretion) are also presented. One can note a decrease in urine output during the periods of continuous light (days 16-20) and "locked-in" period (days 26-30) without a decrease in liquid intake.

TABLE IA

Part A General Information

Days	K Cal	Solids	Liquid	Urine	Urine as % Intake	Fecal Wt.
	$\bar{x}$ KCal	$\bar{x}$ g Pkts	$\bar{x}$ ml	$\bar{x}$ ml	x	g
1-5	1063.4	291.6	699.0	379.1	54.0	42.5
6-10	1031.8	280.0	643.4	346.6	53.9	52.5
11-15	998.4	276.8	625.6	370.2	59.2	75.7
16-20	998.6	270.0	638.0	234.9	36.8	54.6
21-25	1084.0	300.0	602.0	311.3	51.7	67.5
26-30	1156.6	324.0	680.0	238.2	35.0	76.5

The above mentioned micturition study indicated that the chimpanzee has his largest urine output upon awakening. Examination of the urination patterns throughout the 30-day study showed the maximum urination to be highly correlated with awakening (or start of MSSD). See Fig. 1. For the maximum micturition volume during the 30 days of isolation, the following rhythms were observed: days 1-10 about 24 hours; days 11-20, about 24.75 hours; days 21-30, about 24 hours again. An increase in rhythm period has been observed for man under constant illumination conditions.

An abstract on above has been submitted to the Aerospace Medical Association for presentation at the Annual Scientific Meeting in Houston (April, 1971). It's title is "Effect of 30 days of isolation on the periodic micturition patterns of an unrestrained chimpanzee".

The 24-hour urine excretion values from the 30-day isolation study were compared to the control data (period d) 10-day micturition). See Fig. 2. Examining the excretion of some of our stress indicators, one can note that the highest steriod and VMA values occur during the pre-test or adaptation days and appears to indicate that the animal was most stressed when he was isolated from the colony. As the study progresses, one sees a lowering in steroid values (days 1-10 of isolation) which points to adaptation. The VMA values, however, do not start decreasing for another 10 days (i.e., days 11-20).

Calcium and phosphorus excretion were two other important stress indicators which were found in the food deprivation study and were of interest here because of possible effects of the chimpanzee's confinement in the isolation chamber for a period of 48 days. This isolation and confinement to cage producing a certain amount of inactivity (lack of

Fig. 1

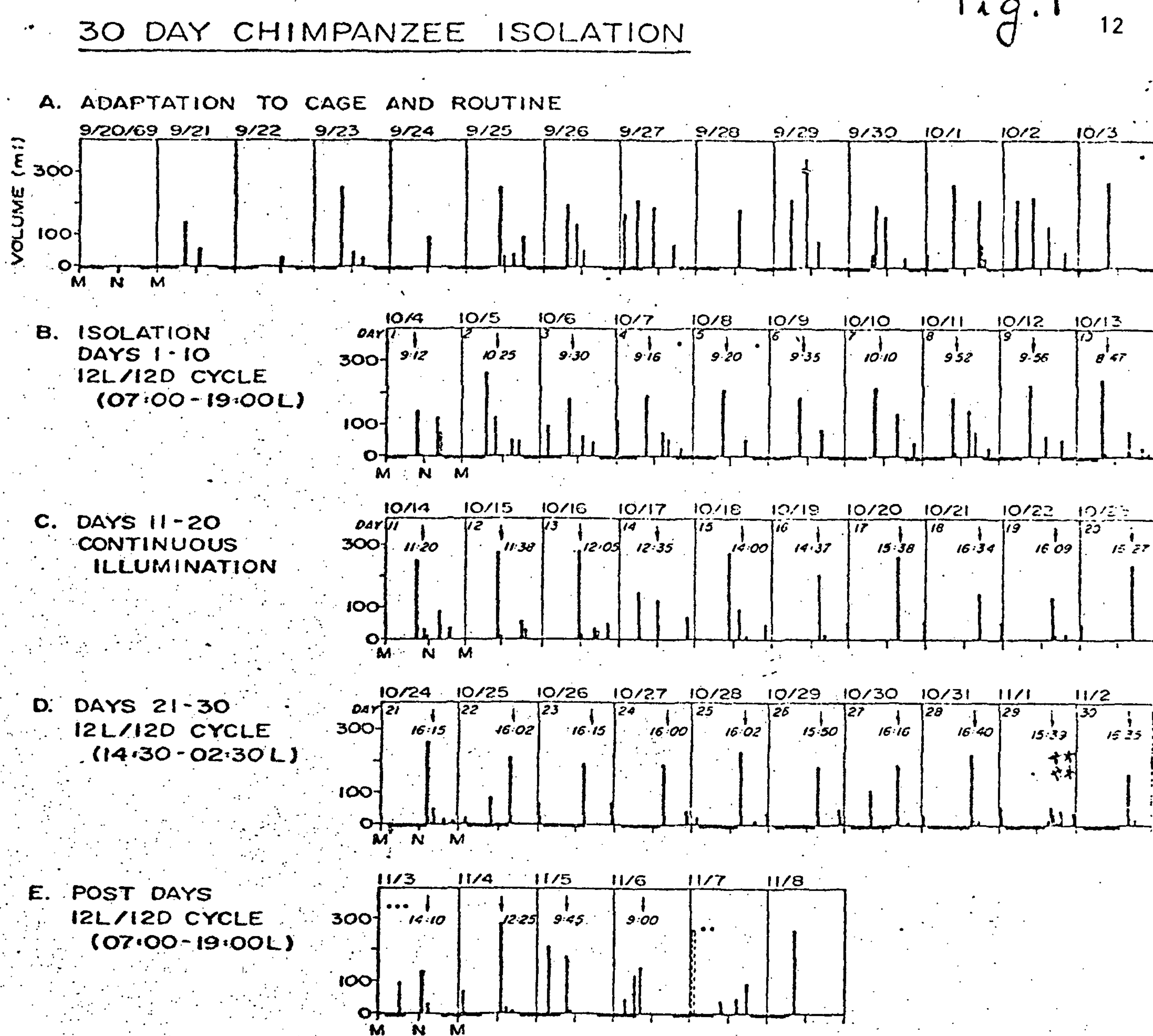


Fig. 1: Micturition in 30 Day Chimpanzee Isolation.

Urine volume are plotted versus time for the periods of adaptation to cage and routine, the 30 Days of Isolation and, for the post-isolation Days.

↓ MSS Start time (30 min. post awakening)

* Some disturbance by personnel in p.m. (i.e.: not complete isolation)

** Fraction collector stuck on bottle from 19:00 - 08:00

*** Animal awakened at noon for 29 min., was awakened from outside for MSS. activity. -- Isolation was broken in the afternoon, loss of urine and feces occurred (on floor) due to excitement.

**** Kink in the collection tube (15:00 thru 18:00) muscle and bone utilization) could affect bone and muscle metabolism. Increases in Ca and P excretion have been reported for humans subjected to bed rest and inactivity.

Examination of Ca and P excretion values in Fig. 2 shows a decrease from control values for Ca in pre-adaptation days, followed by an increase lasting about 15 days and a lower, relatively stabilized excretion for the rest of the study period. Phosphorus values, on the other hand, show a marked initial increase in the first days of separation from the colony, followed by a decrease, then gradual increase during the isolation period with the highest excretion occurring during the continuous light days (days 11-15). The values decrease considerably in the post-days of the study, not quite to normal or control values. The results are probably due to the breaking of isolation and the animal's being put back on the original 12L/12D cycle.

Mean 24-hour electrolyte values for 5-day intervals were determined for total intake and urine and fecal output in order to check out the metabolic balance and possible effect of diet on both Ca and P excretion. Total intake and combined urine and fecal outputs are presented in Table 1B.

Although there is some variation between the mean Ca and P intake, the Ca/P ratio appears to be almost constant throughout the 30-day experiment. The total Ca/P excretion ratio (urine and feces) on the other hand, is the same as the intake ratio during the initial 5-day period (2.42:1) but decreases gradually to 0.4:1 in the final 5-day period. The results seem to indicate that the change is not due to dietary influences.

Our current hypothesis is: skeletal or bone homeostasis is favored by physical activity whereas inactivity (especially immobilization) promotes

Fig. 2

URINARY EXCRETION VALUES

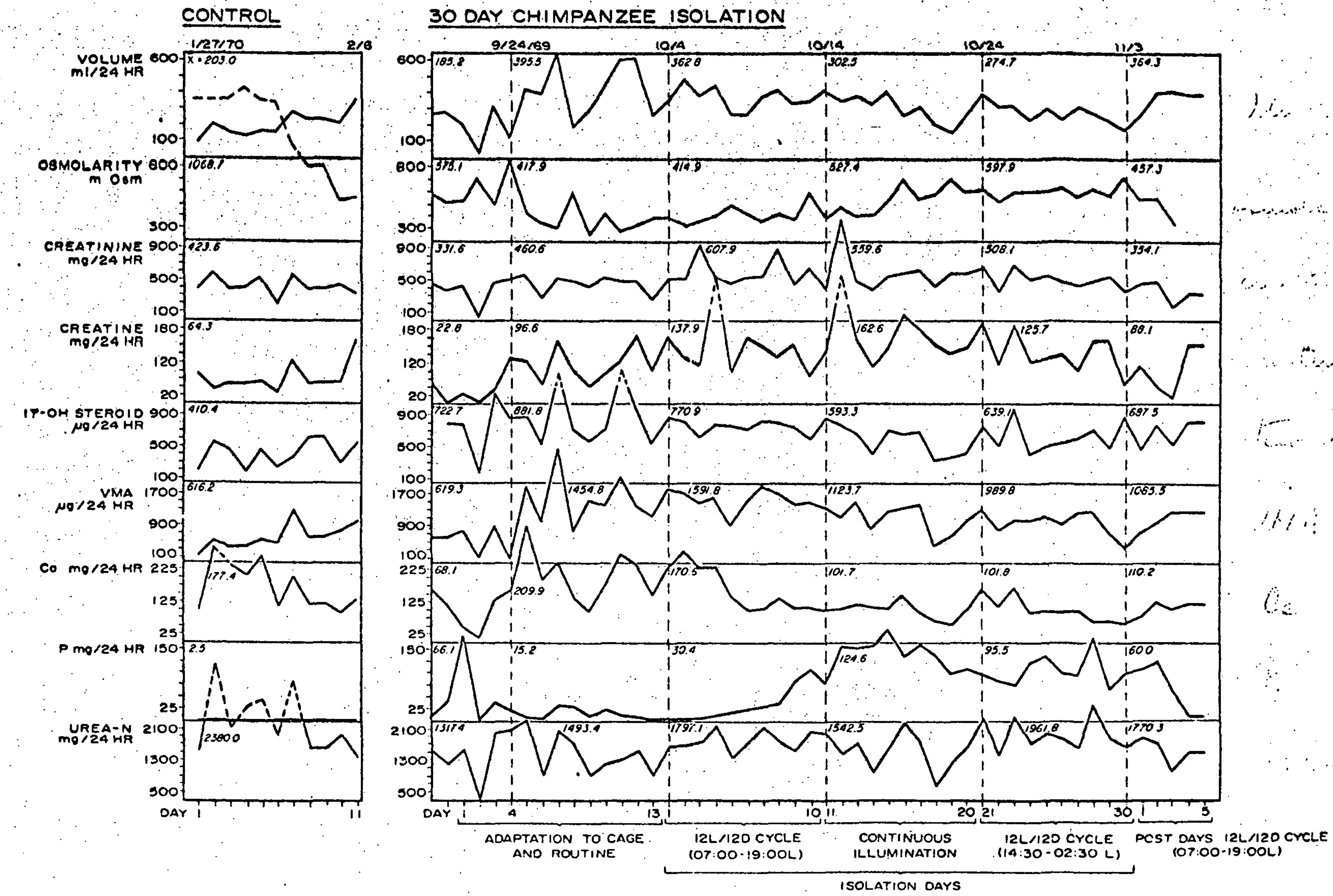


Fig. 2

TABLE 1B

Part B Electrolyte Balance

Days	Calcium: Intake $\bar{x}$ mg	Calcium Excretion: Urine $\bar{x}$ mg	Fecal $\bar{x}$ mg	Total $\bar{x}$ mg	% Intake	Phosphorous: Intake $\bar{x}$ mg	Phosphorous Excretion: Urine $\bar{x}$ mg	Fecal $\bar{x}$ mg	Total $\bar{x}$ mg	% Intake
1-5	1118.8	227.1	306.7	533.8	47.0	478.9	8.17	212.1	220.3	45.0
6-10	1074.0	114.3	308.9	423.2	39.0	459.7	52.7	269.7	322.4	70.0
11-15	1061.6	108.95	296.0	404.9	38.0	446.1	133.2	712.4	845.7	189.0
16-20	1035.8	94.6	187.1	281.7	27.0	435.3	115.9	457.3	573.2	131.0
21-25	1149.7	127.1	331.2	458.3	39.0	483.1	93.5	911.8	1005.3	208.0
26-30	1242.1	76.6	425.0	501.6	40.0	521.9	99.1	1186.3	1285.4	246.2

Calcium/Phosphorus Ratios (ca/P)

Days	Intake	Excretion
1-5	2.34	2.42
6-10	2.34	1.31
11-15	2.38	0.48
16-20	2.38	0.49
21-25	2.38	0.46
26-30	2.38	0.39

bone resorption and loss of bone mass. The parathyroids regulate bone resorption and the secretion of parathyroid acts to maintain the proper calcium and phosphate content of the internal environment (mainly plasma levels). The complex homeostatic mechanism which maintains plasma Ca levels within narrow limits involve parathyroid hormone (PTH), bone, kidney, small intestine, thyroi-calcitonin and vitamin D.

Following a depression of Ca plasma levels (hypocalcemia), PTH is secreted. Its principle target organs are: bone, kidney and intestinal mucosa. There is an increased mobilization of Ca and phosphate from non-exchangeable bone; the kidney responds by increased renal tubular reabsorption of Ca (i.e., decrease in urine Ca) and block the tubular reabsorption of phosphate (i.e., causing an increase in urine phosphate) without alteration in the glomerular filtration rate (GFR). The intestinal cells respond to PTH by an increased absorption of dietary calcium and phosphate. The renal regulator responds rapidly to small concentration of PTH, but the capacity is limited; the gastrointestinal regulator is slower to respond and also has a limited capacity. On the other hand, the bone regulator is relatively insensitive to Ca concentrations in plasma, and is slow to respond, but its capacity is unlimited. The increased phosphate absorption it produces is offset by an increase in urine phosphate excretion. Our phosphorus excretion results favor a slowly responding mechanism.

PTH apparently also affects the kidney by enhancing excretion of NA, K, Cl and bicarbonate. We shall have to examine this fact when analyses on Na and K are completed.

It would have been helpful (to support our hypothesis) if analysis on plasma calcium levels could have been obtained during isolation, but this was not feasible without breaking isolation.

Data from Gemini VII flight showed decreases in bone density. We believe if another long term flight experiment is planned, this type of information should be obtained and checked.

An abstract was submitted to the Aerospace Medical Association and accepted for presentation at the annual Scientific Meeting in Houston (April, 1971). Its title is "Calcium and phosphorus excretion during short term stress and prolonged stresses in the unrestrained chimpanzee".

Preliminary analysis of the animal's biorhythm patterns of EEG activity during the 30 days of isolation has been completed. Under the light/dark entraining conditions of the first and last 10 days, the chimpanzee's sleep/wake cycle was 24 hours. During the continuous light period of isolation, the mean duration of the circadian sleep/wake rhythm was 24.75 hours. A longer Sleep phase was evidenced in this extended circadian rhythm. Duration of the Sleep phase (onset of nocturnal sleep to morning wakening) during the 12D:12L periods of the study averaged a little more than 14 hours whereas the duration of the Sleep phase during the continuous light period approximated 15 hours. The increase was due to more time spent in the nocturnal Awake and the REM stages. The amount of time spent in nonREM sleep remained about the same in all three 10-day periods.

The Wake phase of the circadian cycle during continuous light was similar in duration (between 9.5 and 10 hours) to the Wake phase of the 12D:12L periods. With the light/dark conditions the animal averaged about 1 hour, 10 min of sleep midway through the Wake phase. These naps averaged only about 50 min during the continuous light period.

For the total 30-day isolation period the chimpanzee averaged approximately 43% of his circadian rhythm in the Awake stage, 47% in non-REM sleep, and 10% in REM sleep.

An abstract on the above was submitted to the Aerospace Medical Association for presentation at the Scientific Meeting in Houston (April, 1971). Its title is "Effect of continuous light on the sleep/wake cycle of an unrestrained isolated chimpanzee."

E. THE SLEEP/WAKE CYCLE AND THE BIOCHEMICAL INVESTIGATION OF URINARY EXCRETION PATTERNS IN THE COUCH RESTRAINED CATHETERIZED CHIMPANZEE

Couch restrained, catheterized chimpanzees were run on a 12L:12D schedule for 10 successive days. Urine fractions were collected every 12 minutes (by means of a fraction collector) for the duration of each experiment (120 samples per day and 1200 samples for the 10-day experiment). Electrophysiological measures of the sleep/wake cycle were recorded.

Three animals were used in the study: (A) Victor, (B) Kathy, and (C) Kelly. Two catheterization studies were successful for the 10-day duration (animals A and C). The third animal (B) was studied 2 times for a period of 7 and 5 days respectively, but the collection had to be discontinued due to the clogging of the catheter and the collection tube. Urine fractions were to be analyzed for volume, pH, osmolarity, creatinine, 17-hydroxy-corticosteroids, VMA, calcium and phosphorus. When instrumentation was available, sodium and potassium were to be analyzed also. To date, all samples (for animals A, B, and C) have been analyzed for volume, pH and osmolarity.

In general, animals A and C (Victor and Kelly) showed increased volumes in the morning with minor peaks occurring sometime between 21:00

and 05:00 during the dark period (especially from days 5 through 10). Animal B manifested little fluctuation--her average 12 minute excretion volumes stayed between 5 and 10 ml and rarely ranged to 15 ml and above.

One also notes the decrease in pH during the night and increase during the day and following meals (alkaline tide) in animals A and C. Animal B again showed little variation and her values were on the high alkaline side. These findings in animal B led to the decision that further collection studies performed in the laboratory used cranberry juice as part of the liquid intake. This juice has been used in patients with renal calculi of the calcium phosphate matrix. Its intake lowers the pH of the urine to between 6 and 7 at which pH, calcium phosphate is relatively soluble and this can be passed through the urinary system without clogging. Animal C (Kelly) was put on this juice and the catheterization study was probably successful for the 10-day period because of this added factor.

Animals A and C show definite inverse relationships in urine volume and osmolarity, while animal B again does not show this (in both "runs") pointing to possible impairment in kidney function.

Urine fractions have also been analyzed for days 8, 9, and 10 on the first chimpanzee for all parameters, except the electrolytes (Ca, P, Na and K). One sees a 17-hydroxy-corticosteroid rhythm--an early morning rise followed by a fall for the rest of the day and with the lowest values at night. Also noted was a post-REM increase in steroids and volume output as has been reported earlier for man. To check this out further, more samples must be analyzed and more EEG records read.

To check out excretion patterns throughout the 10 days of catheterization and restraint, urine fractions were analyzed at 4 hour intervals

(6 samples per day) for the first animal (A). All parameters except Na and K were examined (Fig. 3). One can see a rhythmicity in all, except VMA (most 12 minute samples were too low in volume to allow analysis). The steroid peaks do not vary greatly in value, even for the first two days where one would have expected increases due to surgical trauma; the animal appeared to have adapted itself quite well to the situation. The calcium and phosphorus levels on day 1 show similar trends as those of day 2 food deprivation (a decrease in calcium and increase in phosphorus) thus probably indicating stress.

We hope to complete the following analyses in the next 6 to 9 months:

Animal A (Victor):
1. Hourly creatinine and creatine, 17-hydroxy-corticosteroids
2. 24 minute samples of electrolytes: Na, K, Ca, P

Animal B (Kathy):
1. Hourly electrolytes: Na, K, Ca, P

Animal C (Kelly):
1. 12 minute samples of creatinine, creatine, and steroids (if possible)
2. 12 minute samples on electrolytes: Na, K, Ca, P

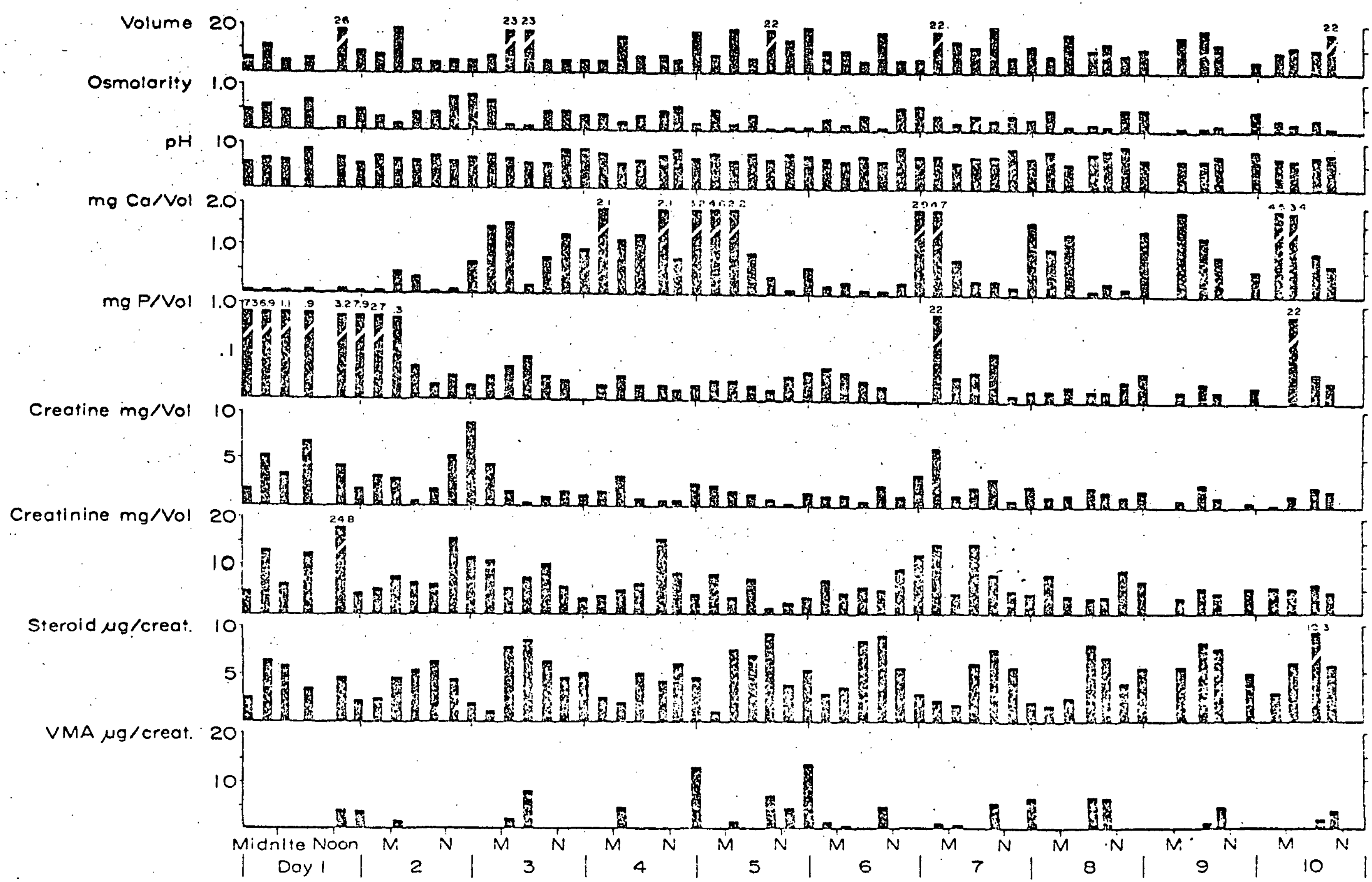
In all of the above we shall look for rhythmicity in parameters, correlation with sleep/wake cycle and for effects of prolonged restraint.

F. VESTIBULAR FUNCTION

Modification of three of the four channels of the telemetry pack for ENG (electronystagmagraphic) recordings has been accomplished. A simple monkey restraining couch and head restraint device have been constructed. One implanted monkey has been surgically prepared for head restraint in a variety of positions around three axes. Preliminary caloric, torsion swing and rotational tests have been performed on this monkey.

With the aid of Dr. A. Eviater, nystagmus was to be monitored using

EFFECT OF CATHETERIZATION - RESTRAINT STRESS ON URINARY PARAMETERS IN DEVELOPING CHIMPANZEE



a multiple channel electrode configuration which employs horizontal, vertical and two additional diagonal pairs of electrodes. Paper recordings will be taken on a polygraph using a modified four channel biotelemetry pack, excepting where standard recording techniques are feasible. Following the initial pilot studies, the data were to be recorded on magnetic tape for a vectorial analysis.

This vectorial electronystagmagraphic method of vestibular analysis allowed the differential analysis of the dual system of the peripheral vestibular complex, the otolith system and the semicircular canal system. Information regarding the shape of the nystagmic pattern, the result of the summation of the vertical and diagonal impulses elicited from the otolith system and the horizontal impulses elicited from the semicircular canal system, would be easily obtainable. Labyrinthine preponderance and directional preponderance were to be calculated by the average number of beats per sec, their duration and amplitude in each vector channel.

In addition to these nystagmic variables, measurement of the slow component, latency of response and the period of culmination (time of greatest amplitude of nystagmic responses) were to be accomplished. However, Dr. A. Eviater accepted a position at another university and the above vestibular research program was postponed until a replacement could be found.

Part Two

ENGINEERING

I. TELEMETRY

A. MISSION REQUIREMENTS

A totally implantable telemetry system to continuously condition and transmit the physiological data requirements of Table 2 throughout the mission was the objective of our design considerations. The telemetry system is envisioned to be divided into two independent units; one to transmit data from the central and peripheral nervous system, mounted on the bones of the calvarium and the other to transmit data from the cardiovascular system implanted in the abdominal or pleural cavity (See Fig 4).

The neurological data acquisition unit will transmit data obtained from surface and deep brain electrodes in accordance with stereotaxic techniques established in this laboratory. Typical electrode placements are shown in Fig 5. From a physiological standpoint, the unit must weigh no more than 350 g and occupy a volume of less than 150 cm^3. The cardiovascular telemetry unit, if implanted in the pleural cavity must weigh no more than 100 g, occupy a volume of no greater than 100 cm^3, and be of specific gravity 1.0 to 1.1, and be shaped as shown in Fig 6. This area of implantation was selected primarily for its low rejection characteristics, ease of surgical implantation, and dynamic damping characteristics.

B. TELEMETRY SYSTEM ACHIEVEMENTS

A large segment of the total program effort was devoted to telemetry system advancement, resulting in the total development of two distinct data processing concepts; the former utilizing frequency multiplexing techniques and the more recent utilizing time division methods. Early

Table 2

PHYSIOLOGICAL DATA REQUIREMENTS
TRANSMITTED BY DIGITAL TELEMETRY SYSTEM

PRIMATE IMPLANTS

Description	No. Of Channels	(Hz) Freq. Range	(μv) Physiological Input Range	Resolution Bits Min/Max	(Sec^{-1}) Sampling Rate Min/Max	(Bits/Sec) Data Rate Per Channel Min/Max	(Bits/Sec) Data Rate Per Parameter Min/Max
1. EEG	16	0.5-100	2-500	6/8	250/512	1500/4096	24,000/65,538
2. EOG	2	0.5-20	100-5000	6/8	100/140	600/1120	1,200/2,240
3. EMG	2	10-50	100-5000	6/8	250/350	1500/2800	3,000/5,600
4. EKG	1	0.5-100	100/5000	6/8	250/512	1500/4096	1,500/4,096
5. Blood Flow	2	0-50	N/A	6/8	250/350	1500/2800	3,000/5,600
6. Blood Pressure	2	0-50	N/A	6/8	250/350	1500/2800	3,000/5,600
7. Galvanic Skin Response	1	0-10	N/A	6/8	50/70	300/560	300/560
8. Brain Temperature	1	0-1	N/A	8/10	5/7	40/70	40/70
9. Core Temperature	1	0-1	N/A	8/10	5/7	40/70	40/70
10. Brain Impedance	1	0-1	N/A	8/10	5/7	40/70	40/70
11. Intercranial Pressure	1	0-1	N/A	6/8	5/7	30/56	30/56
Total	30	---	---	---	---	---	36,270/89,724

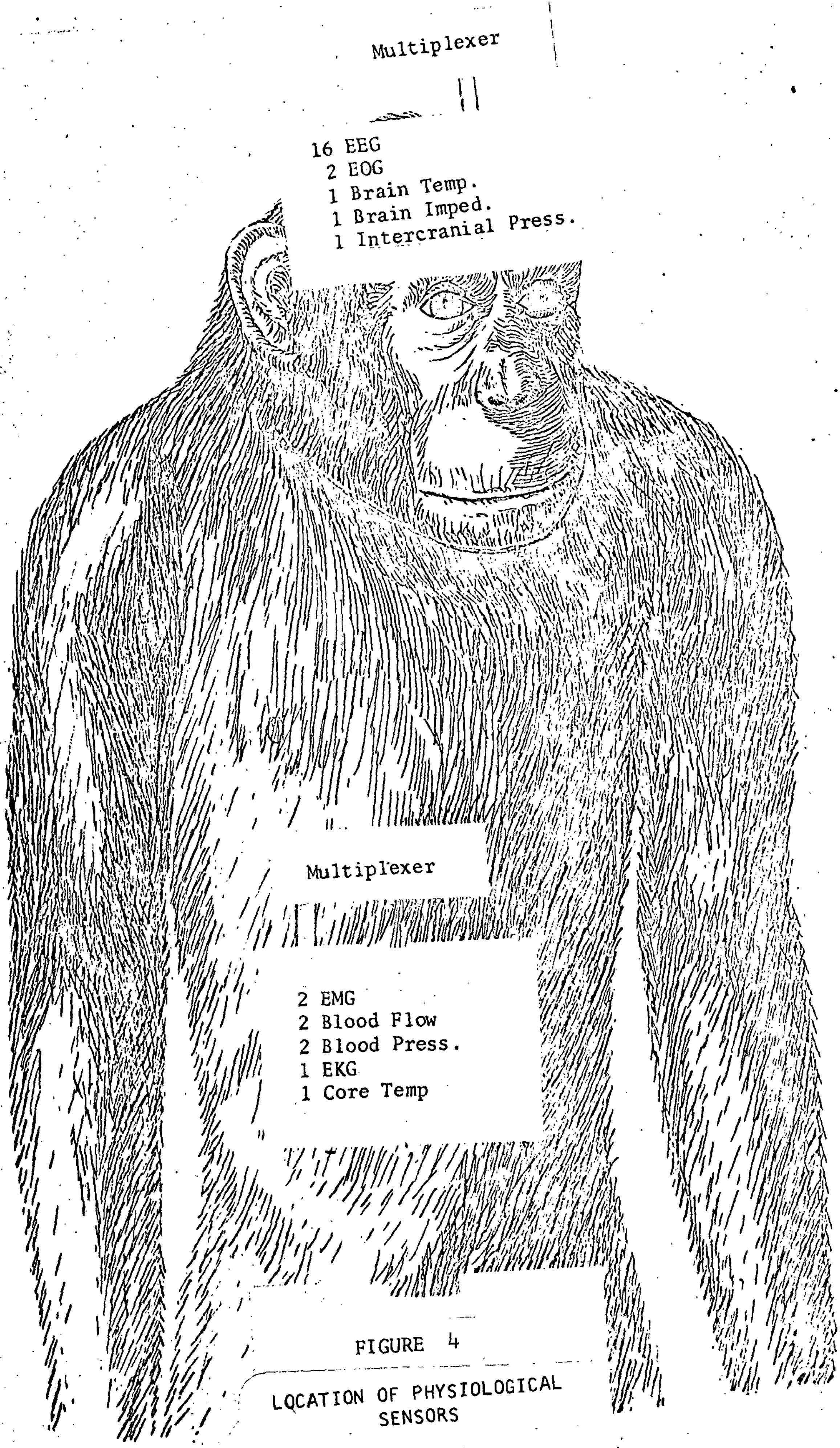


FIGURE 4

LOCATION OF PHYSIOLOGICAL SENSORS

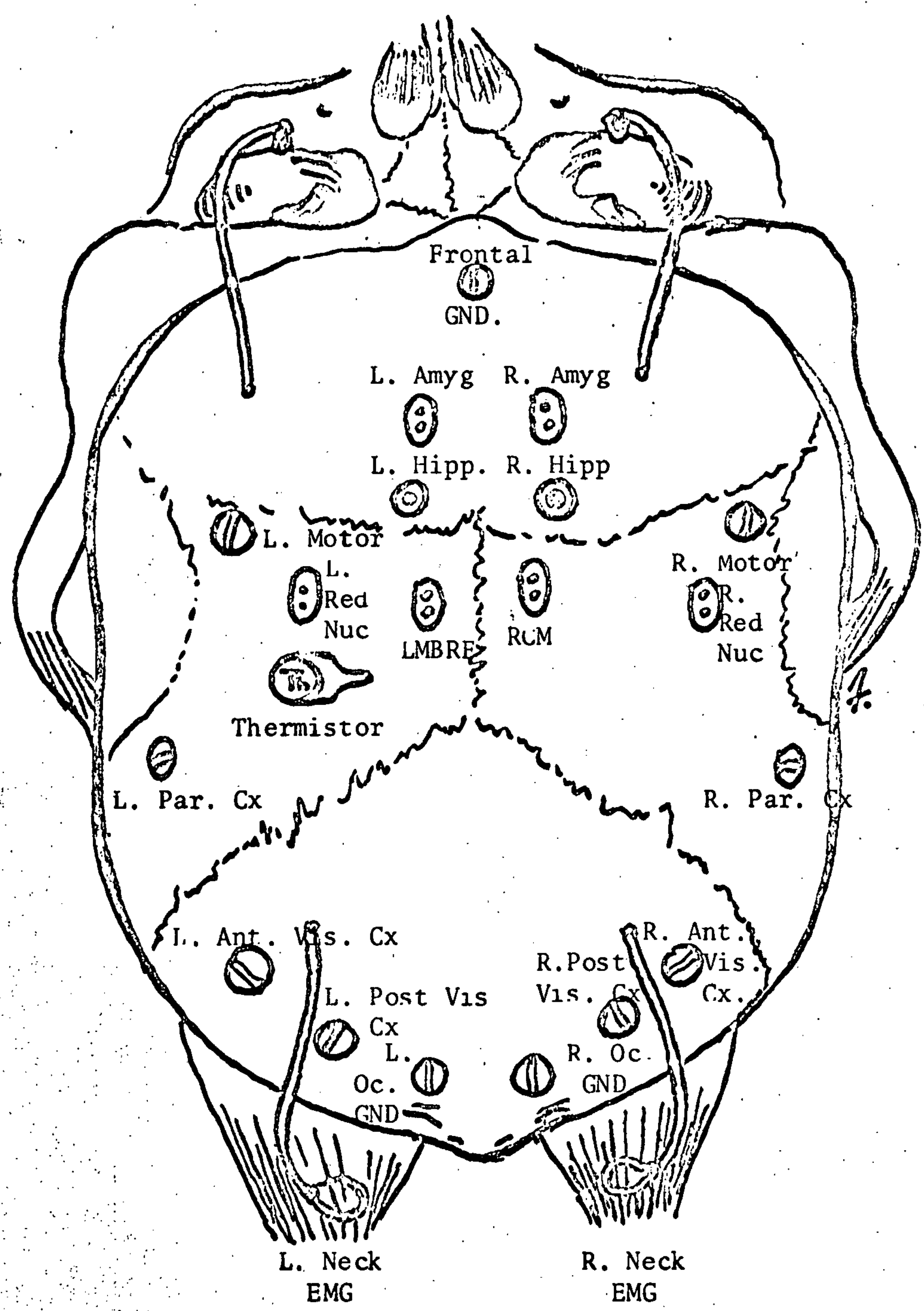


FIGURE 5

TYPICAL ELECTRODE LOCATIONS

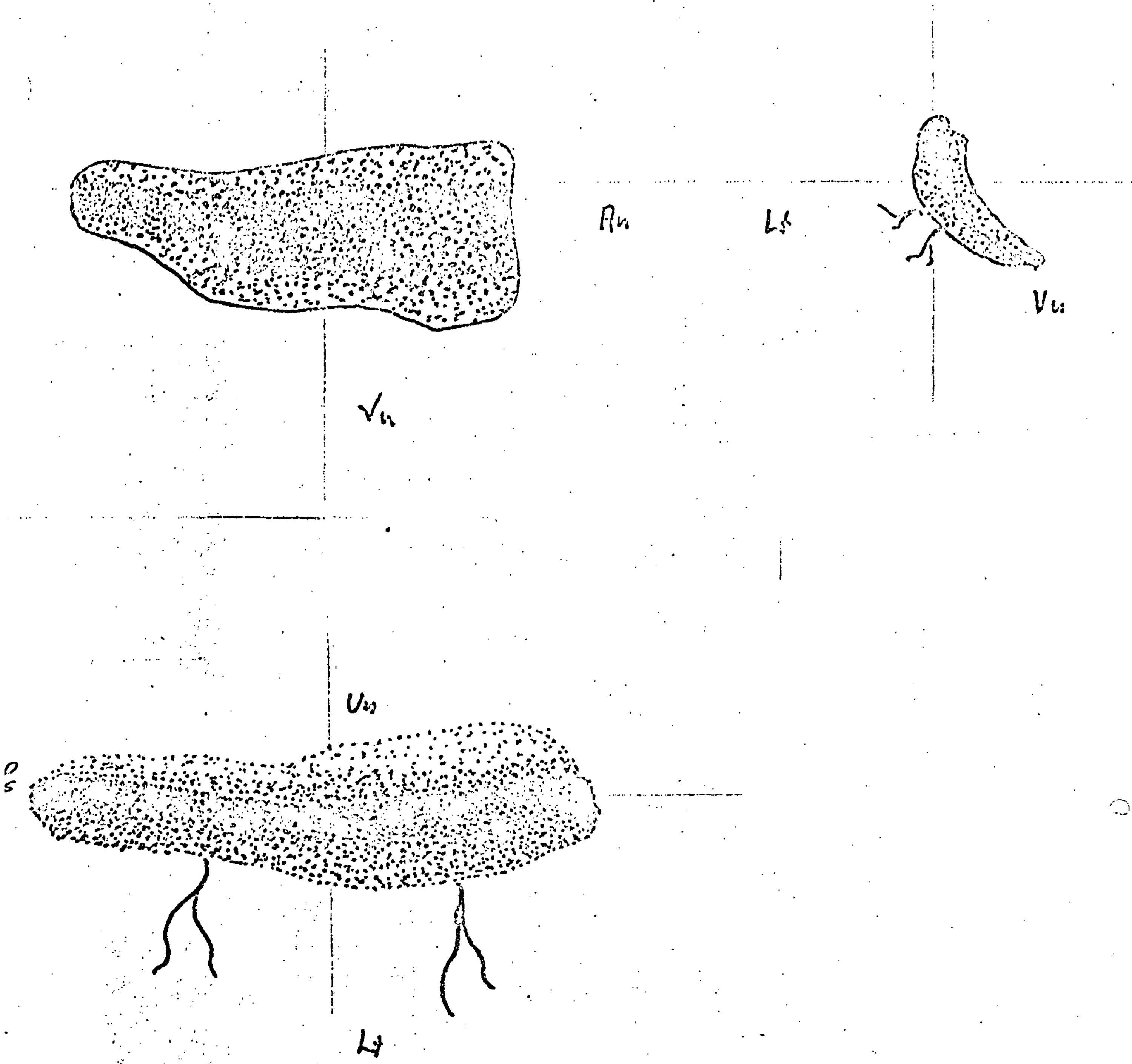


FIGURE 6

PLUERAL CAVITY TELEMETRY UNIT

in the program, a seven channel FM/AM telemetry system was completed and has been used extensively with outstanding results for data acquisition during behavioral training, primate inserted system tests, and in the daily recording periods. More recently, a PAM/FM system has been developed that features considerably lower power consumption and is more efficiently packaged to meet mission objectives.

B.1 PAM/FM SYSTEM

Time-division multiplexing was selected in preference to frequency-division multiplexing after analysis of the size and power requirements of each. The advantages of the former have increased greatly with the recent development and commercial availability of Complementary Symmetry Metal Oxide Semiconductor (CMOS) integrated circuits. Moreover, often considering the trade-off between signal-to-noise ratio and circuit complexity, PAM was chosen over PCM and other time-division methods.

a. PAM/FM SYSTEM DESCRIPTION

Design, development, fabrication, and test of an eight channel PAM/FM telemetry system was accomplished. To the best of our knowledge, the system represents a major breakthrough in the area of remote sensing and transmission of physiological data and is indeed state of the art. Furthermore, the design concept when extended to a twenty-one channel system is capable of satisfying the mission requirements as set forth above.

A multichannel biotelemeter consists of signal conditioners, multiplexer, and transmitter. A description of each is offered below:

1. AMPLIFIERS

Each differential amplifier is comprised of three Fairchild μA 735 integrated circuit operational amplifiers per data channel, two of which are connected as direct input voltage follower stages (unit gain). The output of each pair of amplifiers represents the differential physiological signal and is capacitively coupled to the third integrated circuit which is configured as a differential gain stage. The AC coupling between stages sets the lower 3 dB cutoff frequency to 0.5 Hz and is required to block the often large DC offset potential on the monitoring electrodes and to minimize the 1/f noise contribution between DC and 0.5 Hz. This design provides three important performance characteristics. First, the voltage follower stage has extremely high input impedance (>50 MΩ). Second, the low, reasonably matched source impedances of the voltage follower results in increased rejection of signals common to both inputs. Third, through the use of integrated circuits, the number of components is minimized, and optimal efficiency may be realized utilizing hybrid packaging techniques. The amplifier circuit design is shown in Fig 7.

2. MULTIPLEXER

Time-division multiplexing was selected in preference to frequency-division multiplexing after analysis of the size and power requirements of each. Moreover, after

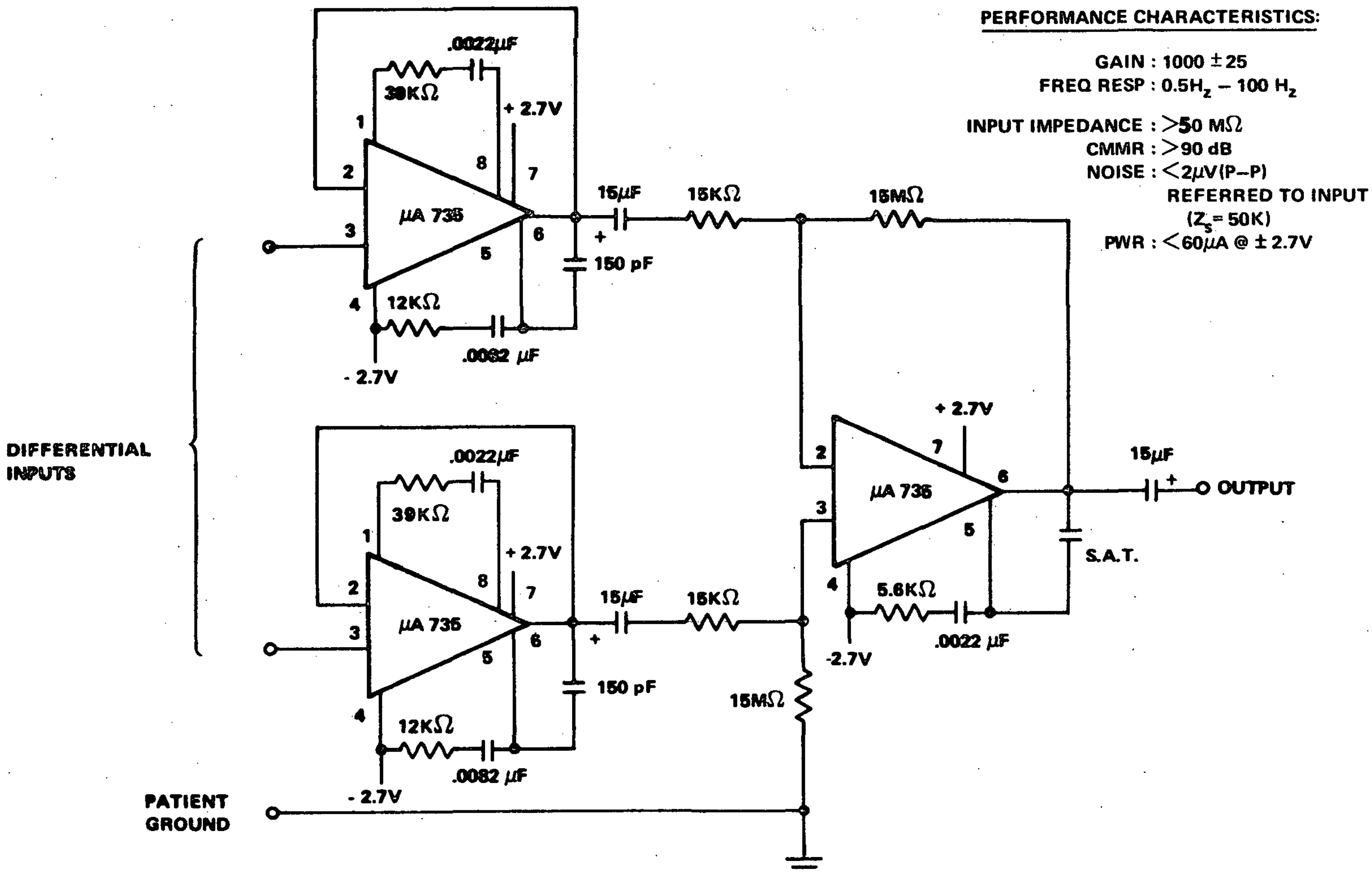


Figure 7. EEG Amplifier

considering the trade-off between signal-to-noise ratio and circuit complexity, PAM was selected over PCM and other time-division methods. The resultant multiplexer design, shown in Fig 8 for an eight channel system is noteworthy for its simplicity and for its extremely low power consumption (<7 μA @ ± 2.7 VDC). The eight channel multiplexer is comprised of two RCA CD4016 four channel analog switch integrated circuits, one RCA CD4001D, an integrated circuit device containing four dual input digital gates, two of which are interconnected as a free running multivibrator to provide the timing signal, and one RCA CD4017 decade counter integrated circuit. The multivibrator timing is set to provide a 2.56 kHz square wave to the decade counter which in response generates an output level sequentially from each of the ten gates. Two of the decade counter outputs are connected to resistive voltage dividers which generate appropriate voltage levels to form two synchronization pulses. The remaining decade counter outputs are used to control the eight analog gates. The sync pulses and sampled analog levels are connected in common (summed) to form a single PAM pulse train. Each gate is sampled 256 times per sec. The voltage divider networks at the input of the analog switches are designed to deliberately offset the amplifier output signals so that they always remain positive. This is done to avoid the dead zone characteristics of the bipolar analog switches.

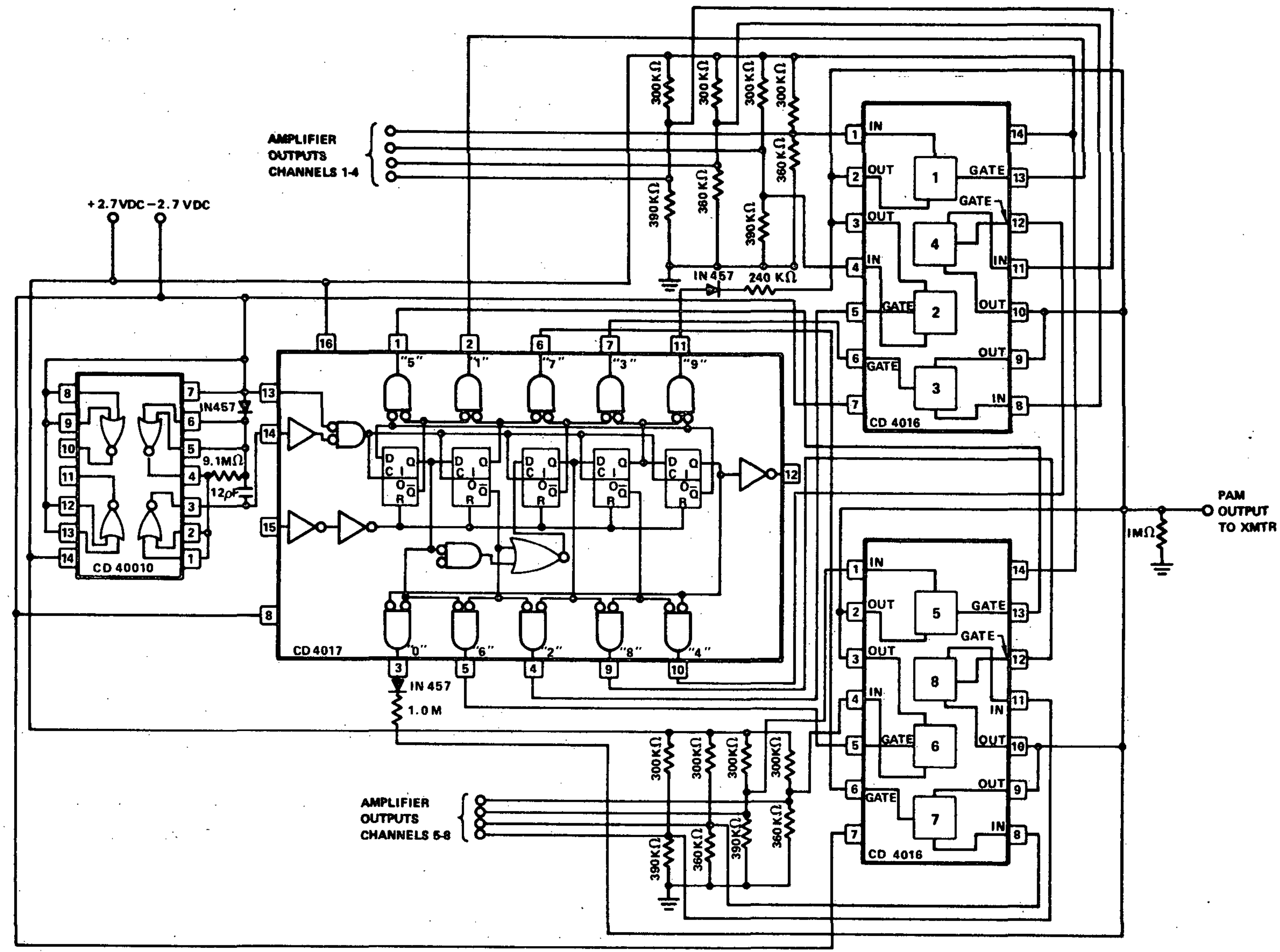


Figure 8. PAM Multiplexer Schematic

In addition, the DC offset between adjacent channels are deliberately set to differ by 50 mV to reduce the possibility of losing channel synchronization.

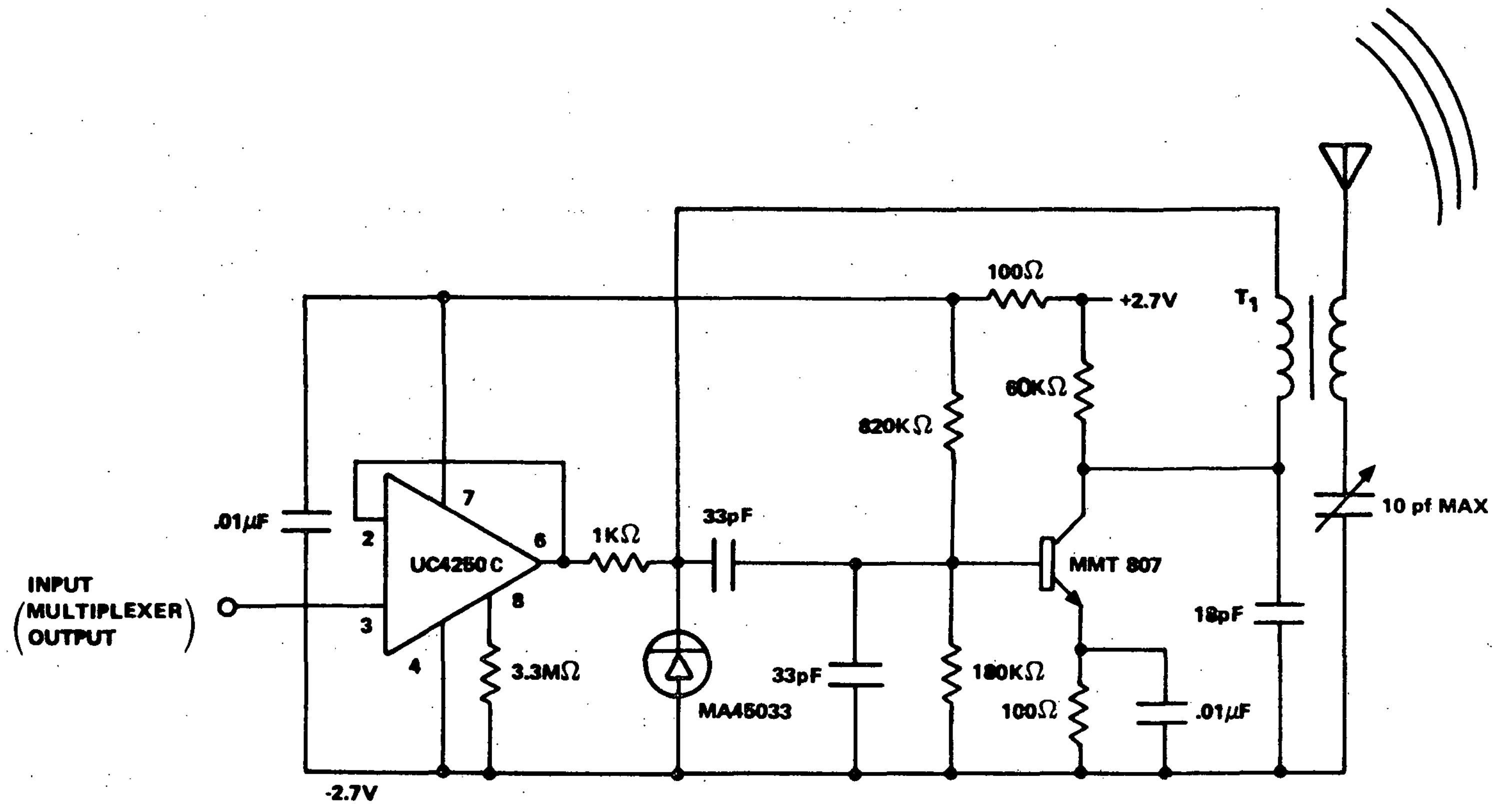
3. TRANSMITTER

A 90 MHz variation of the Vackar oscillator is shown in Fig 9. The resultant design has excellent stability for a single transistor oscillator over a wide range of both temperature and supply voltage. The oscillator frequency is modulated by replacing one of the oscillator's tank circuit capacitors with a varactor diode fed by a voltage follower integrated circuit amplifier. The transmitter is operated at 330 μA @ ± 2.7 VDC and, for the near field application, generates adequate RF power.

4. PACKAGING DESIGN

An eight channel prototype unit was constructed using standard printed circuit board techniques in an 8.573 cm x 8.573 cm x 3.175 cm package (See Fig 10). This unit was subjected to extensive functional and environmental testing. Successful test results provided the go-ahead for fabrication of an eight channel implantable telemetry system using thick film hybrid packaging techniques.

The assembly consists of eight hybrid thick film amplifiers fabricated on individual ceramic substrates. The substrate is processed using various conductive and resistive inks to form a passive network of resistors and conductors to which active devices are attached with conductor epoxy.



NOTE: T_1 = 7 TURNS PRIMARY, 3 TURNS SECONDARY WOUND ON AMIDON T 30-12 CORE

Figure 9. Transmitter Schematic

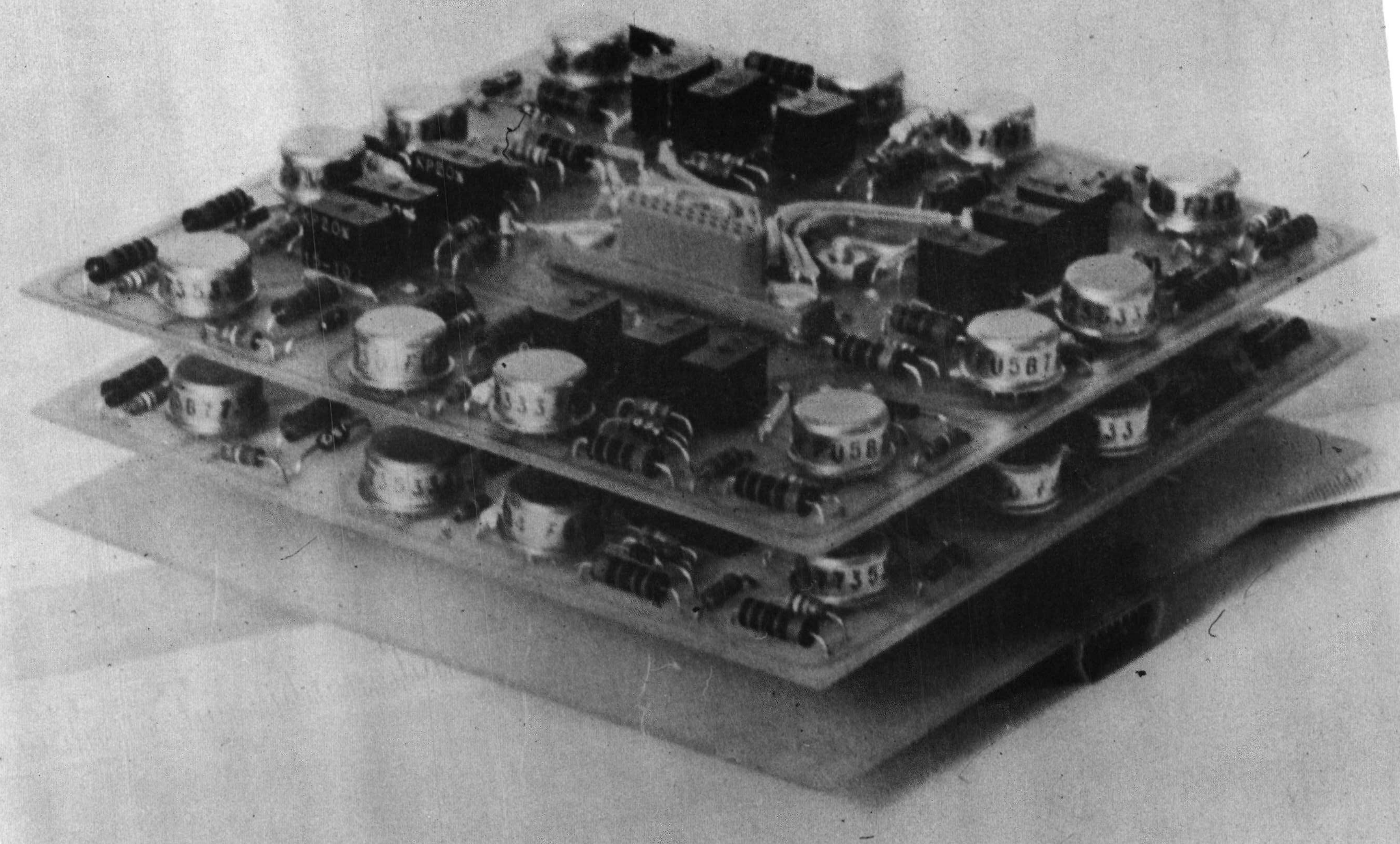


Fig. 10
PAM System Prototype

The units are mounted on a circular ceramic mother board containing the multiplexer circuitry. Internal interconnections are made using conventional fired thick film conductor patterns and thermocompression wirebonding techniques. Future assemblies will use beam lead techniques to maximize yield and minimize cost. After functional testing, the units will be sealed with glass. The amplifiers and multiplexer were combined on a circular alumina substrate, 7.35 cm in diameter by 0.97 cm thick (See Fig 11).

b. SPECIFICATIONS

The subsystem specifications as measured from the prototype unit are shown below:

BIOTELEMETRY AMPLIFER

1.	Gain:	1000 ± 25 (Selectable)
2.	Frequency Response:	0.5 Hz to 100 Hz (3 dB pt.)
3.	Noise:	<2 μV P-P referred to input (Z_S = 50 K)
4.	Common Mode Rejection Ratio	>90 dB
5.	Input Impedance:	>50 MΩ
6.	Power Consumption:	<60 μAC ± 2.7 VDC
7.	Maximum Voltage Swing:	±2.5 VDC
8.	Supply Voltage:	±2.7 VDC

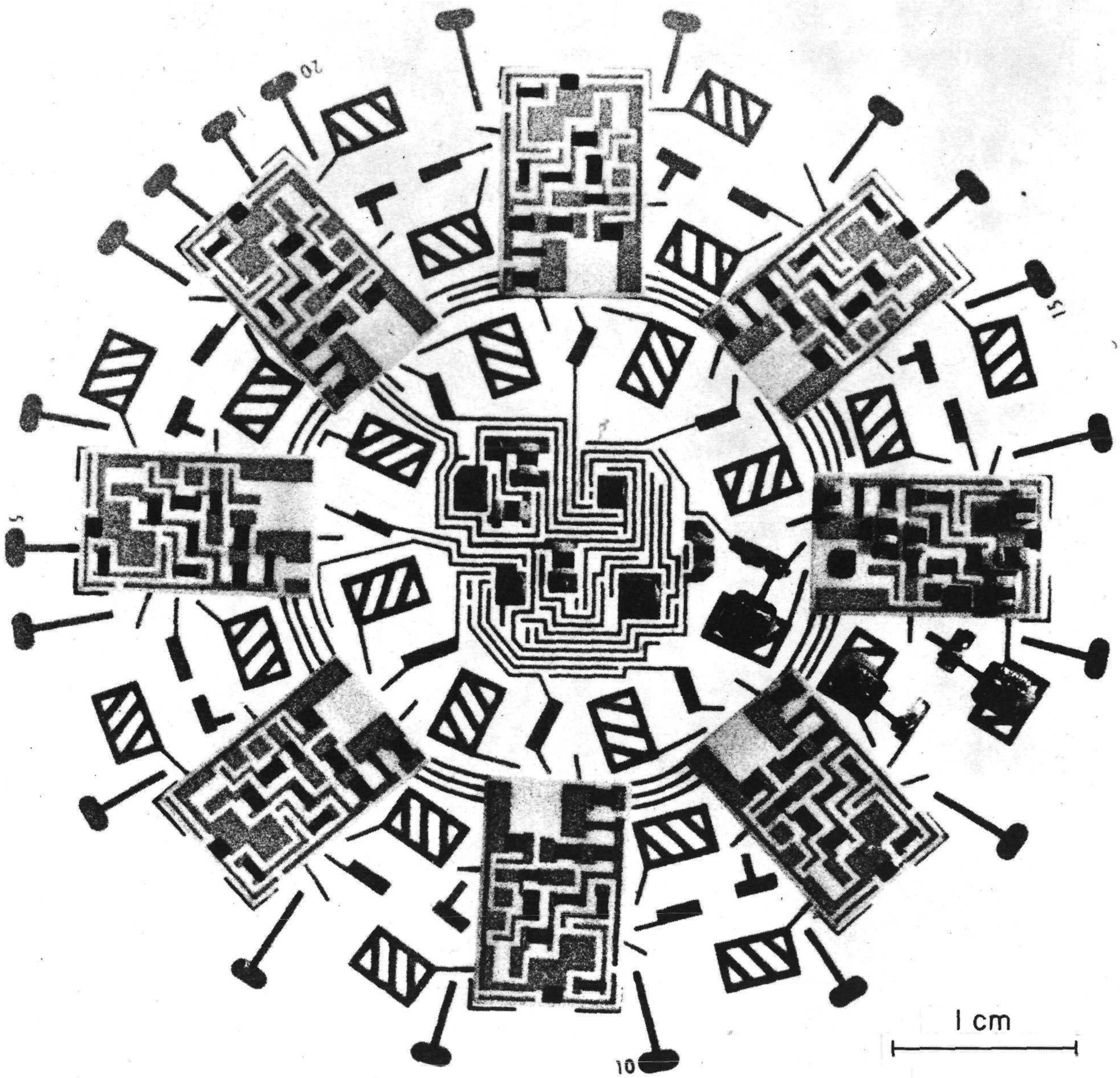


Figure 11. THICK FILM HYBRID PACKAGE

EIGHT AMPLIFIERS PLUS MULTIPLEXER

FM TRANSMITTER

1.	Frequency of Oscillation	90 MHz
2.	Power Consumption:	330 μAC @ ± 2.7 VDC
3.	Noise:	<1 μV rms (Z_s = 100 K)
4.	Size (printed circuit board):	5.08 cm x 2.16 cm x .635 cm
5.	Weight:	5 grams
6.	Deviation Sensitivity:	1 kHz/mV P-P
7.	Frequency Response:	DC to 10 kHz

c. POWER CONSIDERATIONS

The power budget of an eight channel system for near field applications is shown in Table 3.

TABLE 3

8 CHANNEL SYSTEM POWER BUDGET

	VDC Voltage	μamps Current	μwatts Power
Amplifer	±2.7	54	292
Multiplexer	±2.7	7	38
Transmitter	±2.7	330	1782

The current drain of an eight channel system would be

$8(I_{amp}) + I_{mult} + I_{xmtr} = 8(54) + 7 + 330 = 769$ μA.

The 180 day mission therefore requires a power source delivery of 3.32 amp hr.

Extension to a larger number of channels merely requires the addition of supplementary analog switches and an extension of the sequential digital output from ten to the required number of channels. The clocking rate would necessarily be increased in order to maintain an equivalent bandwidth response. Higher sampling rates require additional power consumption by CMOS elements. A power budget is shown in Table 3 for a twenty-one channel system.

TABLE 4

21 CHANNEL SYSTEM POWER BUDGET

	VDC Voltage	µamps Current	µwatts Power
Amplifer	±2.7	54	292
Multiplexer	±2.7	26*	140
Transmitter	±2.7	330	1782

Possible power sources, including nuclear sources, biological fuel cells, and piezoelectric devices have been reviewed and were found not compatible with the voltage requirement of our system. To date, we have used commercially available mercury cells exclusively. Approximately 80% of the rated capacity of certified cells can be expected. The specifications of one such cell, the Mallory RM1CC is presented below:

Maximum suggested current drain	20 mA
Service Capacity	1000 mAh
Service Rated at	5 mA
Diameter	1.59 cm
Length	1.65 cm
Weight	12.2 g
Volume	3.28 cm^3

*Estimated

d. DATA ACQUISITION

The transmitted signal may be detected by any high quality receiver that has been modified by removing the AFC network. The removal of AC coupling within the receiver eliminates cross talk between adjacent channels. In our receiving station the wavetrain is then routed to an EMR model 515 PAM Synchronizer which is used to decode frame and channel sync timing pulses, and to recalibrate the signal level as a function of the maximum to minimum sync pulse voltage difference. The synchronizer also reformats the amplitude variant PAM signal into a binary ten bit parallel output which, along with the frame and channel sync pulses, is routed to an EMR 516 Demultiplexer where it is reconverted into the eight analog channel outputs. The digital output from the PAM is also connected to a PDP-81 computer that formats the digitized data for recording on digital magnetic tape. The eight analog outputs from the demultiplexer are routed in parallel to a Beckman type R oscillograph and a Sanborn model 769 eight channel high persistance oscilloscope for display. The total system block diagram is shown in Fig 12. We are presently evaluating several receiving antenna systems in an attempt to obtain omnidirectional reception with minimum physical size. A modification of the three orthogonal antenna system reported by Mackay appears to be the best system for minimizing dropouts resulting fron nonalignment of transmitter and receiving antenna.

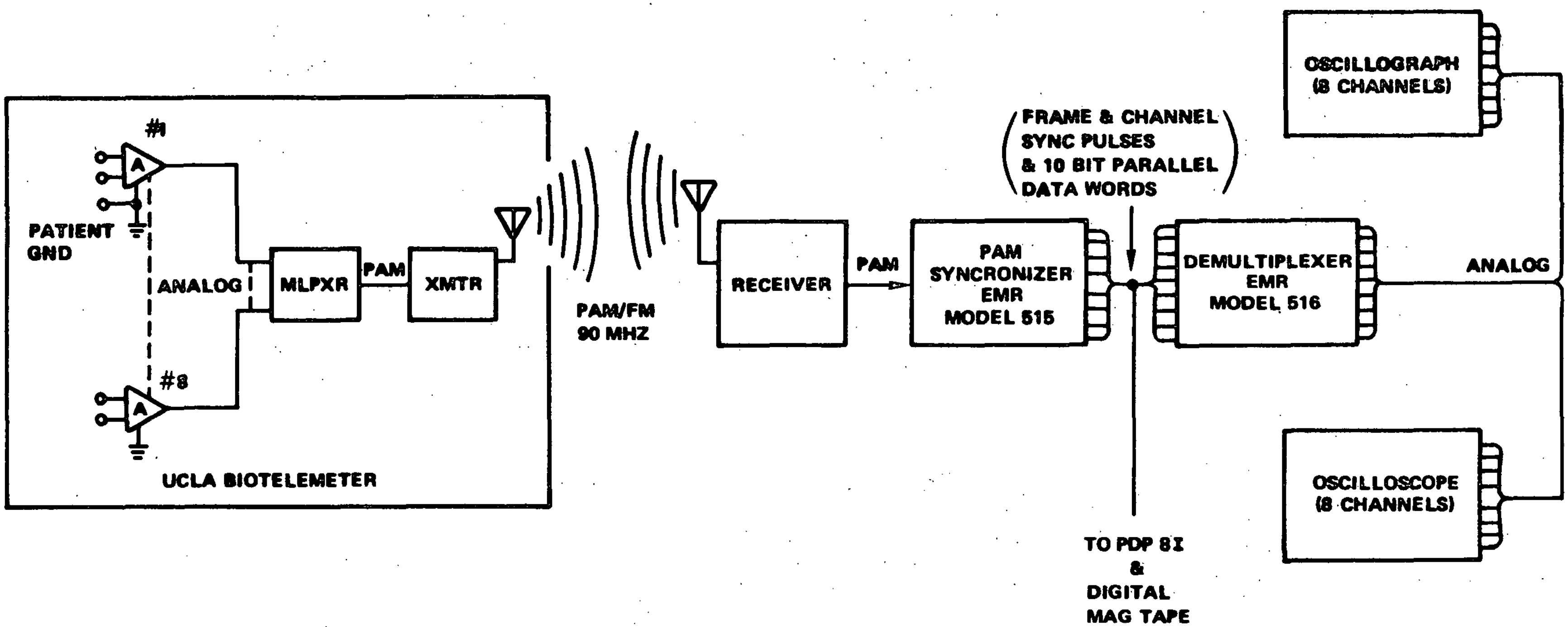


Figure 12. System Block Diagram

The data acquisition and processing equipment described above were combined with associated test apparatus as shown in block diagram form in Fig 13, to form a test console containing all the equipment necessary for complete functional testing of PAM/FM telemetry systems. A photograph of the console is shown in Fig 14.

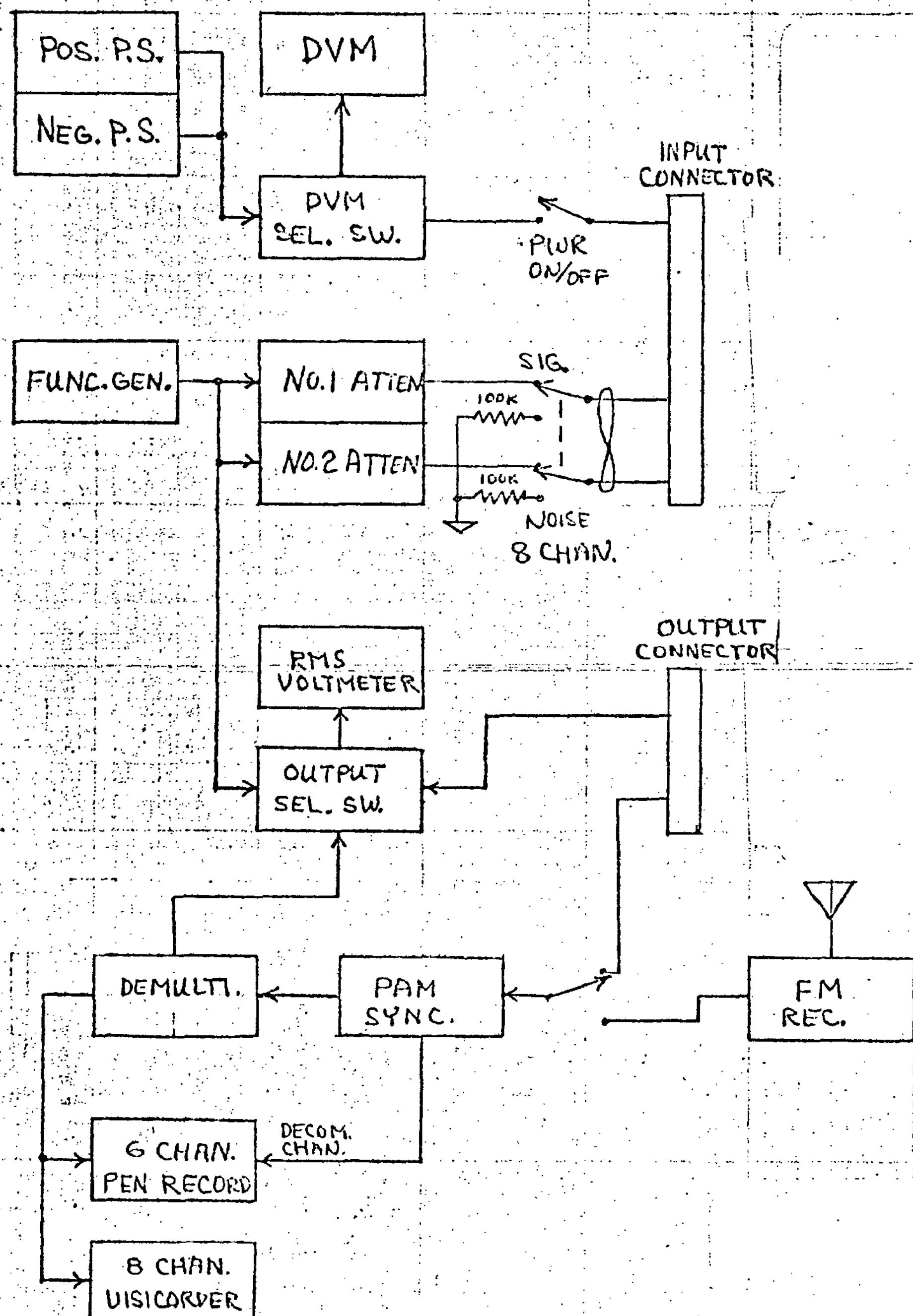


FIGURE 13
TELEMETRY SYSTEM
TEST CONSOLE

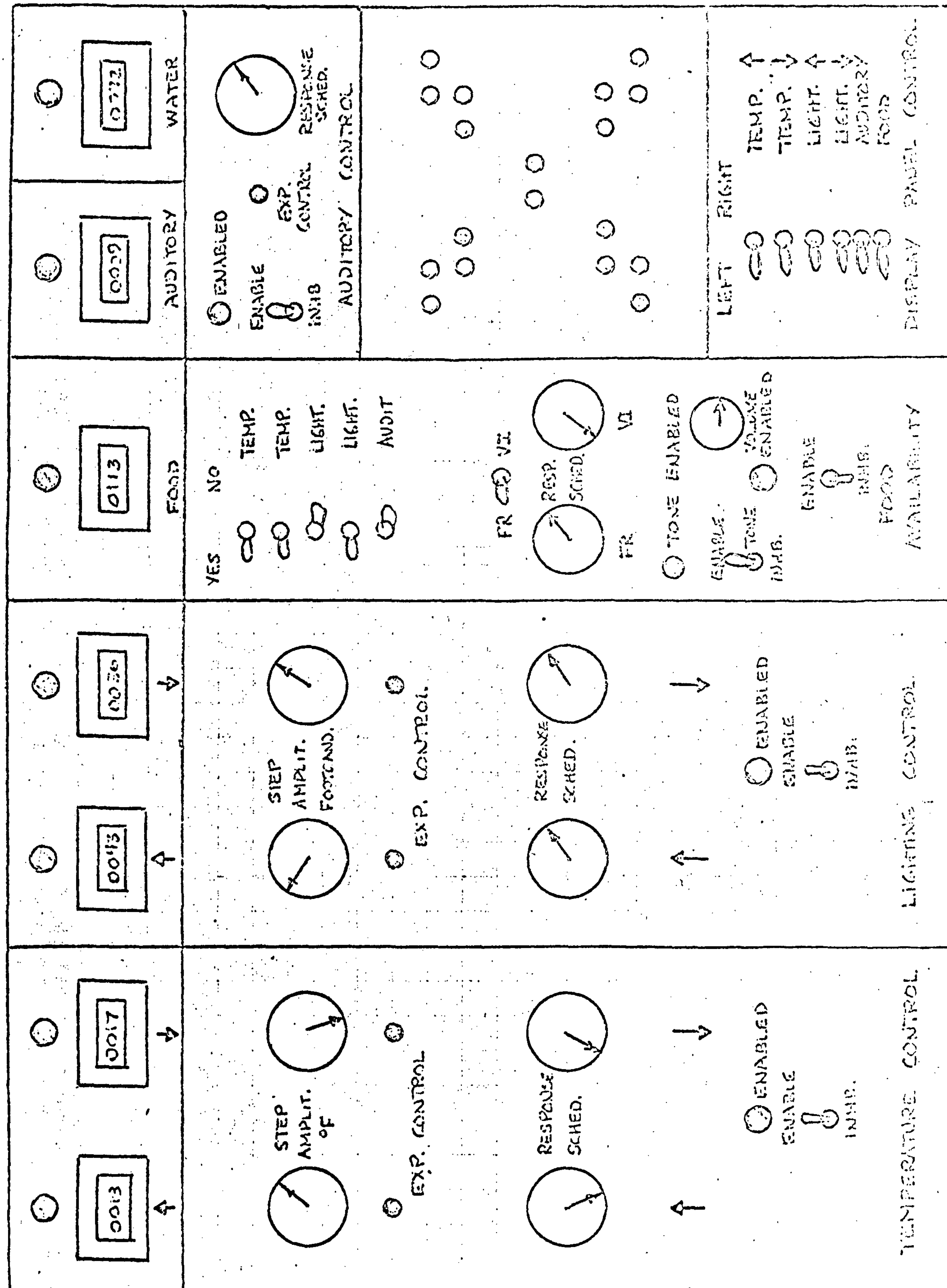


FIGURE 14
TEST CONSOLE

B.2 FM/AM SYSTEM

a. DESCRIPTION

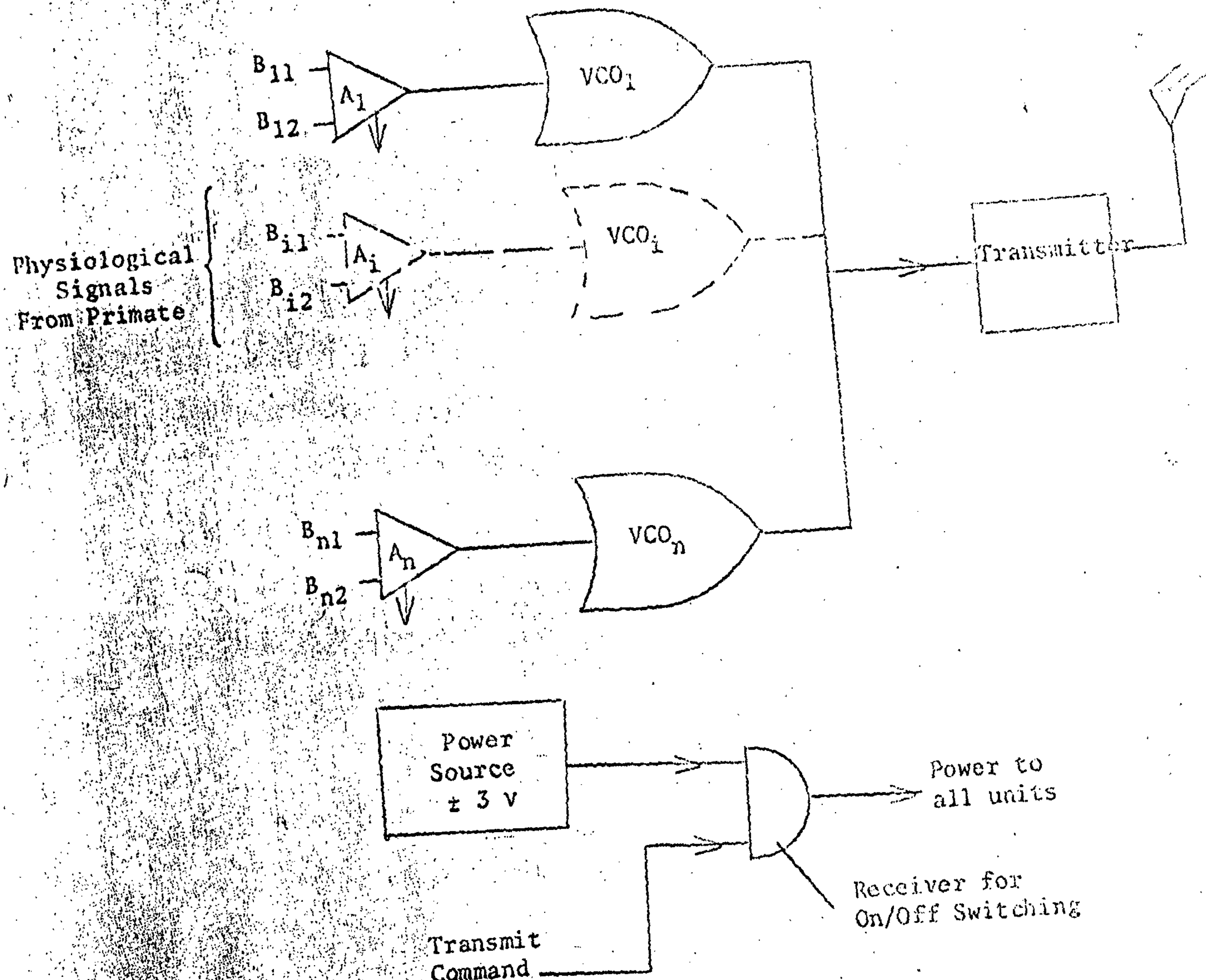
Design, development, fabrication, and test of a seven channel FM/AM telemetry system was accomplished. The system employs seven voltage controlled oscillators to generate IRIG standard frequency modulated subcarriers which are linearly summed and used to amplitude modulate a crystal controlled transmitter. The subcarriers carry the physiological data signals and thus, the calibration of the data channel is independent of signal strength. The system is shown in block diagram form in Figure 15. The system has been well documented[1] therefore, the circuits operation will not be discussed. The schematic of the amplifier, voltage controlled oscillator and AM crystal controlled transmitter are shown in Figures 16, 17, and 18 respectively.

b. SPECIFICATIONS

The specifications of the individual components are set forth below:

AMPLIFIER

1. Frequency response: 0.5 to 50 K Hz (bandwidth may be restricted to 100 Hz by utilizing 220 pf capacitors across feedback resistors.
2. Supply voltage: ± 3 volts D.C. nominal: Circuit operates from ± 2.8 to ± 4.2 volts.
3. Gain: 1500 nominal (may be increased to 10,000): From 1200 to 3000 over supply voltage range.
4. Input impedance: 500 K to 250 K (differential) over supply voltage range; 260 K at ± 3 volts supply.



CONCEPT 1

FIGURE 15
IMPLANTABLE TELEMETRY SUBSYSTEM

5. Common mode input impedance: 500 K

6. Dimensions: Height: 1.5 cm
   Depth: 1.5 cm
   Length: 1.2 cm

7. Weight: 7 gms

8. Power dissipation: 300 μ watts (50 μ amp at $\pm$ 3 VDC.)

9. DC offset: 250 mv

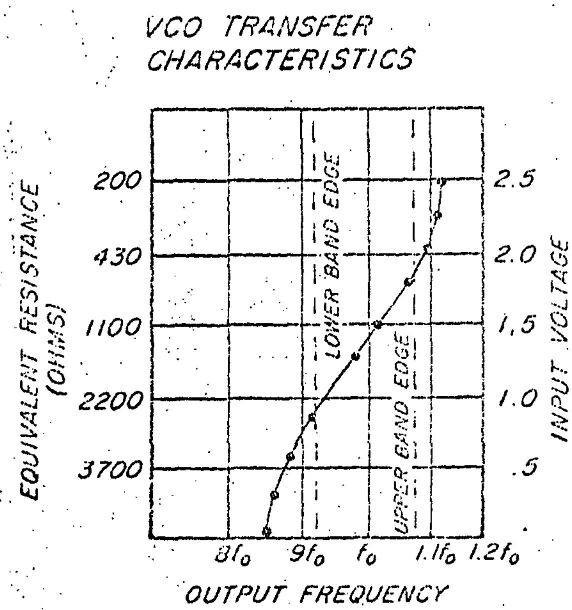
10. CMMR: 80 db

11. Output impedance: < 300 Ω

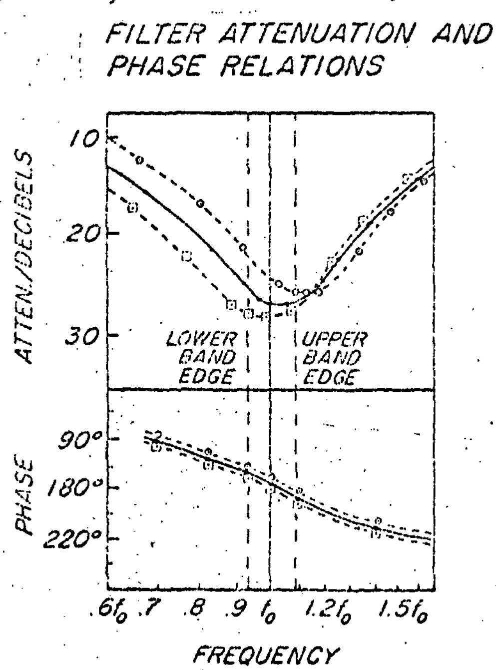
12. Noise: 1μv rms, 10 K ohm source impedance
    20μv rms, 250 K ohm source impedance

VOLTAGE CONTROLLED OSCILLATOR

1. Voltage-Frequency Characteristics



2. Phase Shift, Attenuation-Frequency Characteristics



3. Dimensions: Height: 1.5 cm
   Depth: 1.5 cm
   Length: 1.2 cm

4. Weight: 7 gms

5. Power dissipation: 640 μwatts (107 μamp at ± 3 VDC)

AM CRYSTAL CONTROLLED TRANSMITTER

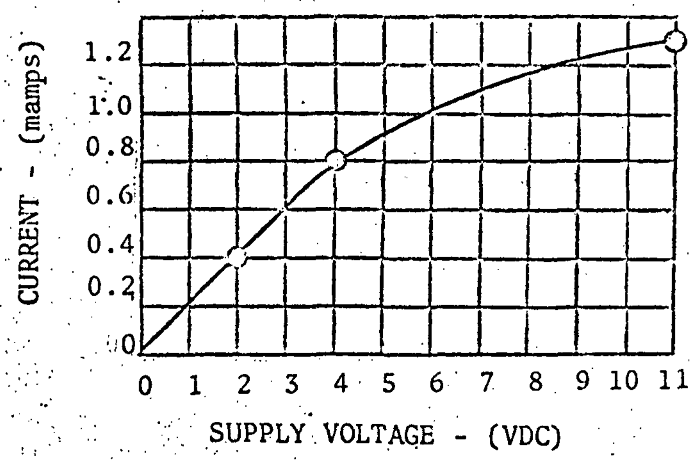
1. Frequency of oscillation: 89.2 MHz ± 0.01%

2. Frequency vs. Voltage Sensitivity: less than 40 Hz per volt

3. Modulation frequency response: 10 Hz to 50 KHz within 3 db at B+ = ± 5.5 volts; 20 Hz to 35 K Hz within 3 db at B+ = ± 3 VDC.

4. Supply voltage operating range: ± 2 volts to ± 7.5 volts

5. Power dissipation -



6. Modulation characteristics (at ± 5.5 volts)

   Input impedance > 1 megohm
   Voltage for 100% modulation: 3 v.pp.
   Distortion at 80% modulation:
      Less than 0.25% 2nd harmonic
      Less than 0.5% 3rd harmonic

7. Signal strength at 100 feet (quarter wave omnidirectional antenna): > 30 μ volts at ± 5.5 volts; approximate 40 db at 12 feet and ± 3 volts.

8. Noise (shorted input) < 10 μv rms

9. Dimensions: Height: 1.9cm
   Depth: 1.3 cm
   Length: 2.9 cm

10. Weight: 11 gms

11. Power Dissipation: 6 mwatts (1 ma at ± 3 VDC)

c. POWER CONSIDERATIONS

The power budget for the FM/AM telemetry system for near field applications is shown in Table 5.

TABLE 5

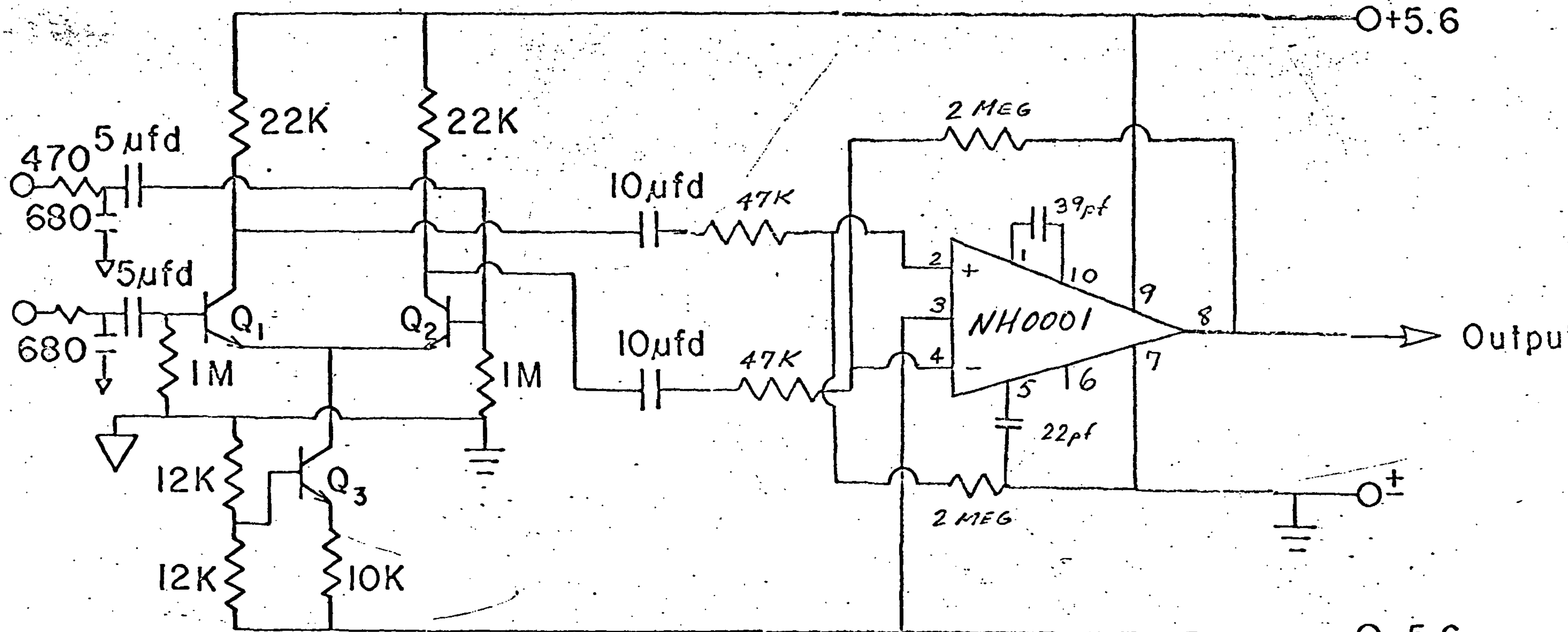
FM/AM Power Budget

	VDC VOLTAGE	(µ amps) CURRENT	(µ watts) POWER
Amplifier (each)	± 3	50	300
VCO (each)	± 3	107	640
Transmitter	± 3	1000	6000

d. DATA ACQUISITIONS

In our laboratory, the transmitted signal was received by a Defense Electronics Inc., model TMR-5A receiver with a model TMH-B5 tuning unit. The receiver provides a demodulated output which is connected parallel to Electro-Mechanical Research Inc. model 189 standard IRIG discriminators. The subcarrier discriminator outputs reformat the signal to analog and are routed in parallel for recording.

BIOTELEMETRY PREAMPLIFIER



Q_1, Q_2, Q_3 Texas Instrument TIS-24

CONCEPT 1
FIGURE 16

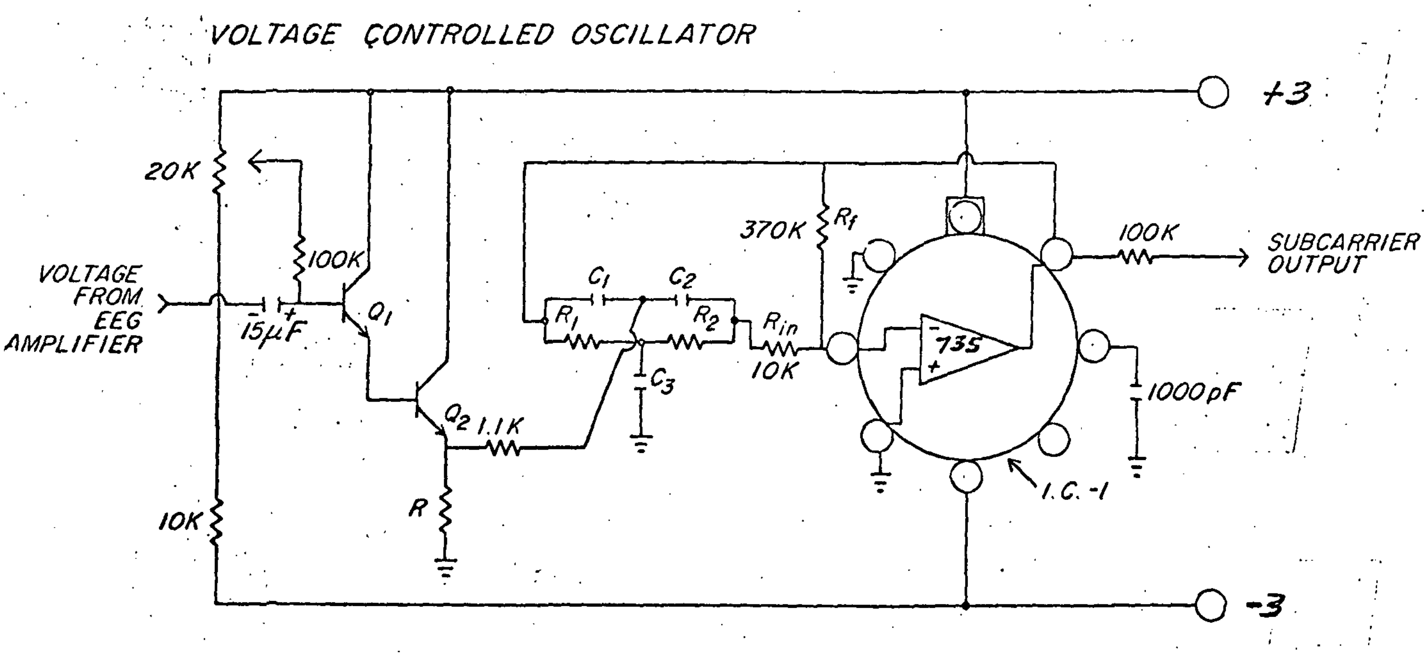
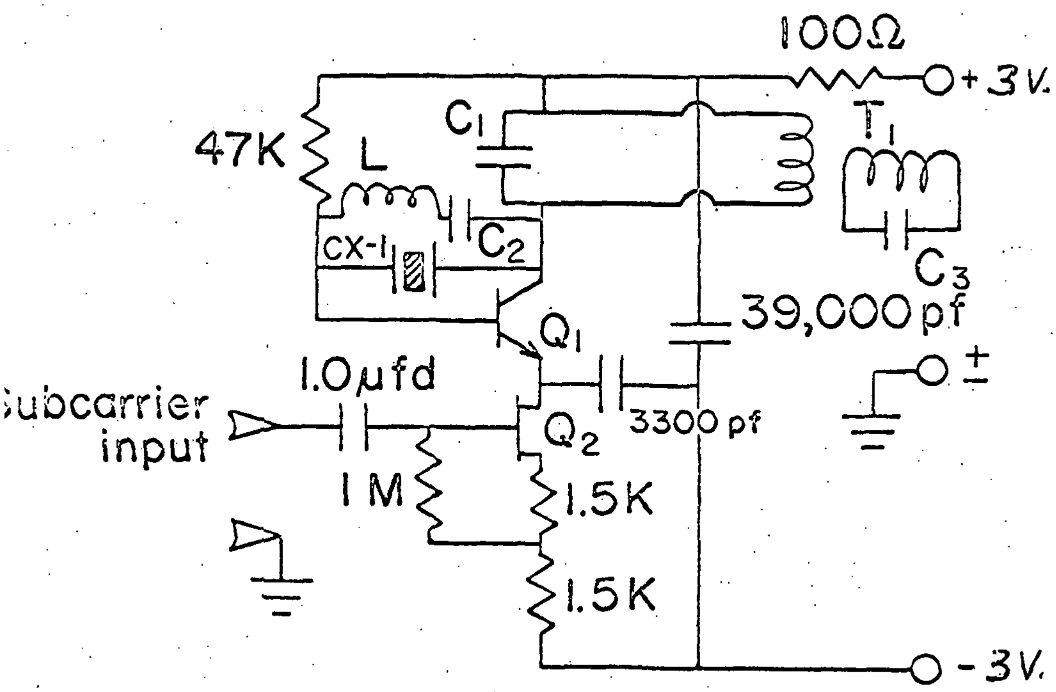

VOLTAGE CONTROLLED OSCILLATOR
+3
20K
370K
R_f
100K
SUBCARRIER OUTPUT
VOLTAGE FROM EEG AMPLIFIER
100K
Q_1
15μF
C_1
C_2
R_1
R_2
R_{in}
10K
735
1000pF
C_3
Q_2
1.1K
R
10K
I.C.-1
-3

FIGURE 17

:RYSTAL CONTROLLED AM TRANSMITTER



Q_1 2N3570 Texas Instrument

Q_2 RCA 40461

T_1 5½ turns on ¼" form 20 wire (1.2 μh), 5½ turns //28 at 90°

L .57 μh - ferrite core (adjust to crystal capacitance)

C_1 27 pf JFD Uniceram UY01

C_2 680 pf U.S. Capacitor C11A 681K

CX_1 Monitor Products MC-18 89.2 MHz

C_3 27pf JFD Uniceram with JFD MT209 in parallel

FIGURE 18

II. BEHAVIORAL TRAINING

The behavioral training program is divided into four distinct, interrelated phases to optimally advance the primates from simple domestication procedures through the most difficult matching to successive sample behavioral tasks. The engineering accomplishments in support of the behavioral training program are described below.

A. PRIMARY TRAINING

A.1 PURPOSE

Primary training places the subject's food and water intake contingent upon button press responses. It is used to (1) build strong button press habits highly resistant to extinction and interference from extraneous events, (2) acquaint the animal with the response schedule requirements of the environmental control tasks, (3) manipulate the rate of button press response in order to maximize the probability of observing response necessary for learning the matching to successive sample task, (4) allow early evaluation of collective and idiosyncratic motivational performance characteristics of each subject, (5) investigate behavioral and drug-induced stresses, (6) test efficacy of training techniques, and (7) adapt to isolation early in the animal's laboratory life.

A.2 BEHAVIORAL PANEL

The primary behavioral panel (Fig 19)is fabricated of black lucite and may be readily mounted on one wall of the subject's home cage. Smoothly integrated into the surface of the panel and visible to the subject are two proximity switches, speaker holes and a pellet

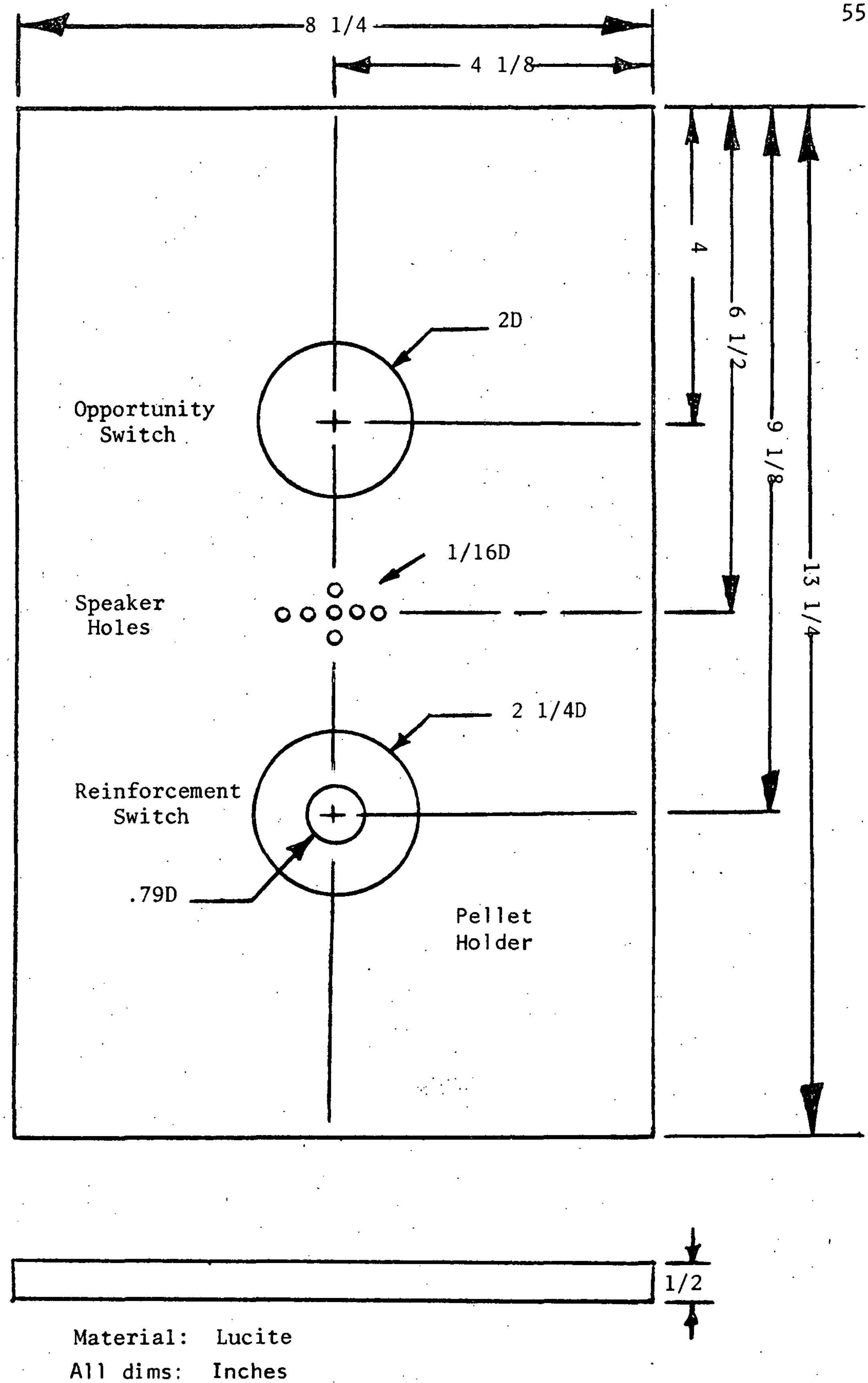


Figure 19

PRIMARY BEHAVIORAL PANEL

holder. The interior of the panel (Fig 20)consists of light bulbs positioned directly behind each proximity switch's diffusion surface and associated driver circuits, a speaker mounted directly behind the speaker holes and a pellet storage container and dispensing unit. A description of the switches is tabulated below:

Switch Designation	Color	Diameter (inch)	Shinkolite A Color Number
Opportunity	White	2.00	432
Reinforcement	Red	2.25 O.D. 0.75 I.D.	136

A.3 BEHAVIORAL ELECTRONICS

An elementary computer with patch board input language known as the "logic rack", Fig 21, was developed specifically for primary and secondary behavioral training operations. It is comprised of pure logical elements (flip-flops, nand gates, etc.) as well as modular digital and analog circuits (counters, tone generators, attenuating networks, etc.). A brief description of the logic rack is offered here. For a more detailed presentation, see the "Logic Rack Instruction Manual", POCO-05-70-003.

A.3.1 LOGIC RACK DESCRIPTION

The input language of the logic rack is comprised of two 440 pin patch boards. Designation of pins to provide access to the elements within the logic rack is shown in Fig 22 and 23. The contents of the unit are shown in tabular form below:

TABLE 6

LOGIC RACK CONTENTS

QUANTITY	DESCRIPTION
28	universal J-K flip flops
50	two input nand gates
5	two input power nand gates
30	three input nand gates
9	four input expandable nand gates
2	power inverters
16	isolation diodes
6	dual output oneshots
2	attenuation networks
4	multivibrators
4	unijunction clocks
3	variable amplitude, variable frequency tone generators
1	variable amplitude, 2000 Hz sine wave tone generators
2	six bit digital counters
1	nine bit digital counter
1	event summer
4	six position switches
10	mechanical counters
1	thumb select countdown counter
1	zero to five volt DC voltmeter
1	zero to three amp ammeter
51	lamps for digital counter status, flip flop status, +5 VDC, and +24 VDC status
1	power on/off toggle switch
1	power preset switch
1	lamp check switch
6	oneshot trigger switches
3	digital counter increment switches
3	digital counter reset switches
2	attenuator network control panels
1	thirty-seven pin output connector
1	BNC coaxial connector
1	three pin power connector

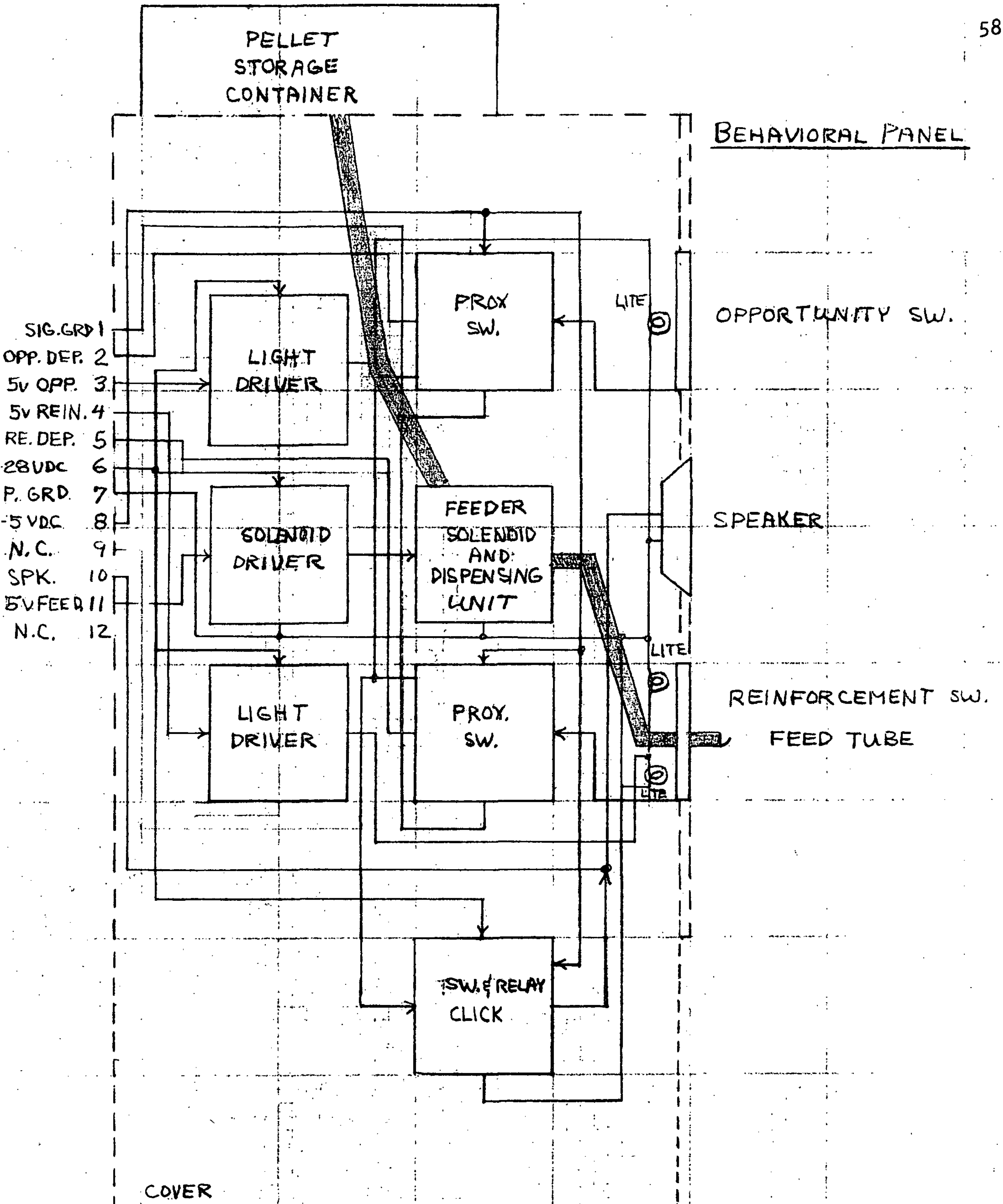

PELLET STORAGE CONTAINER
BEHAVIORAL PANEL
SIG.GRD 1
OPP. DEP. 2
5v OPP. 3
5v REIN. 4
RE. DEP. 5
28VDC 6
P. GRD. 7
-5 VDC 8
N.C. 9
SPK. 10
5v FEED 11
N.C. 12
LIGHT DRIVER
PROX SW.
LITE
OPPORTUNITY SW.
SOLENOID DRIVER
FEEDER SOLENOID AND DISPENSING UNIT
SPEAKER
LITE
LIGHT DRIVER
PROX. SW.
REINFORCEMENT SW.
FEED TUBE
LITE
SW. & RELAY CLICK
COVER

FIGURE 20

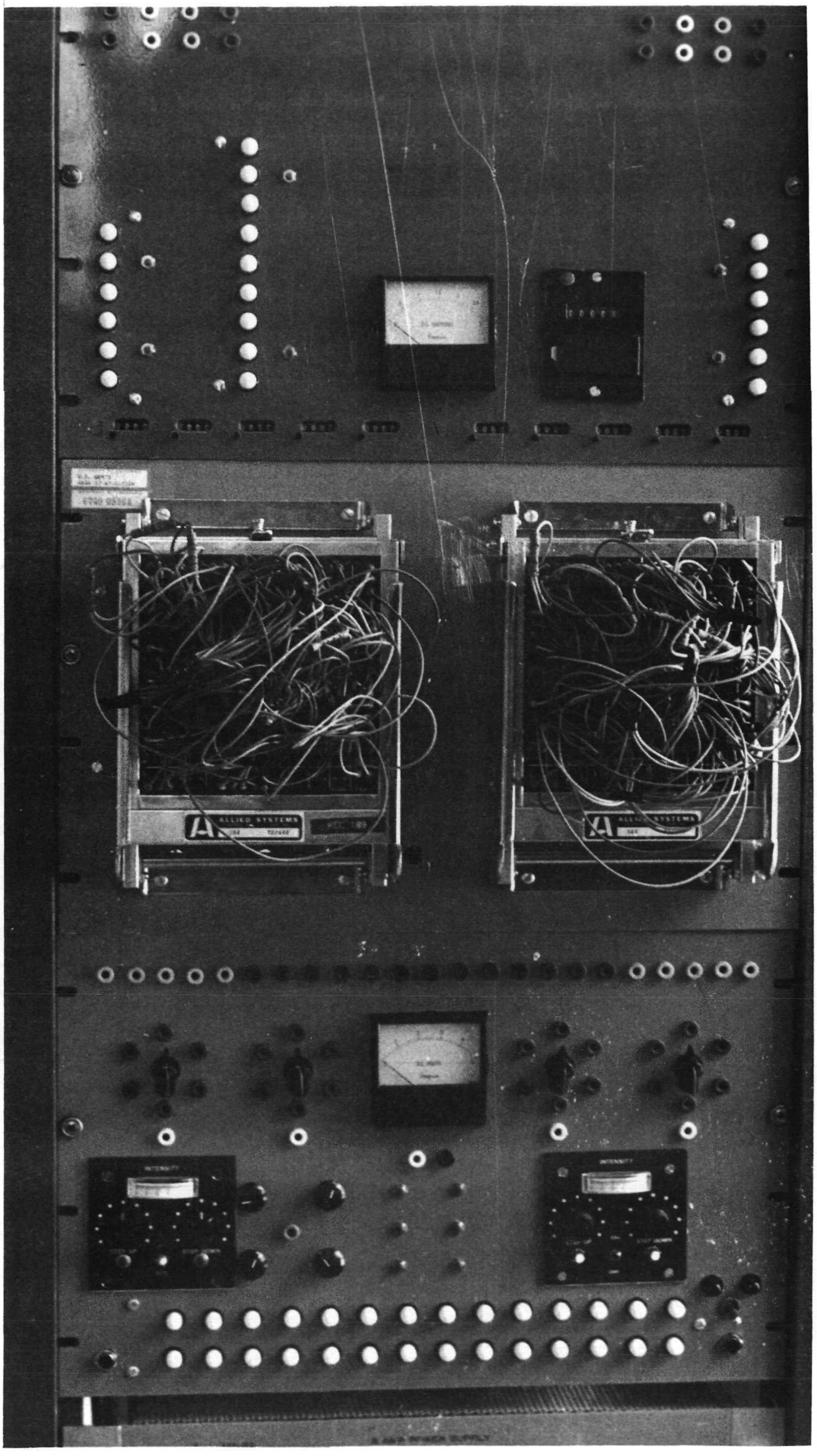


Fig. 21
Logic Rack

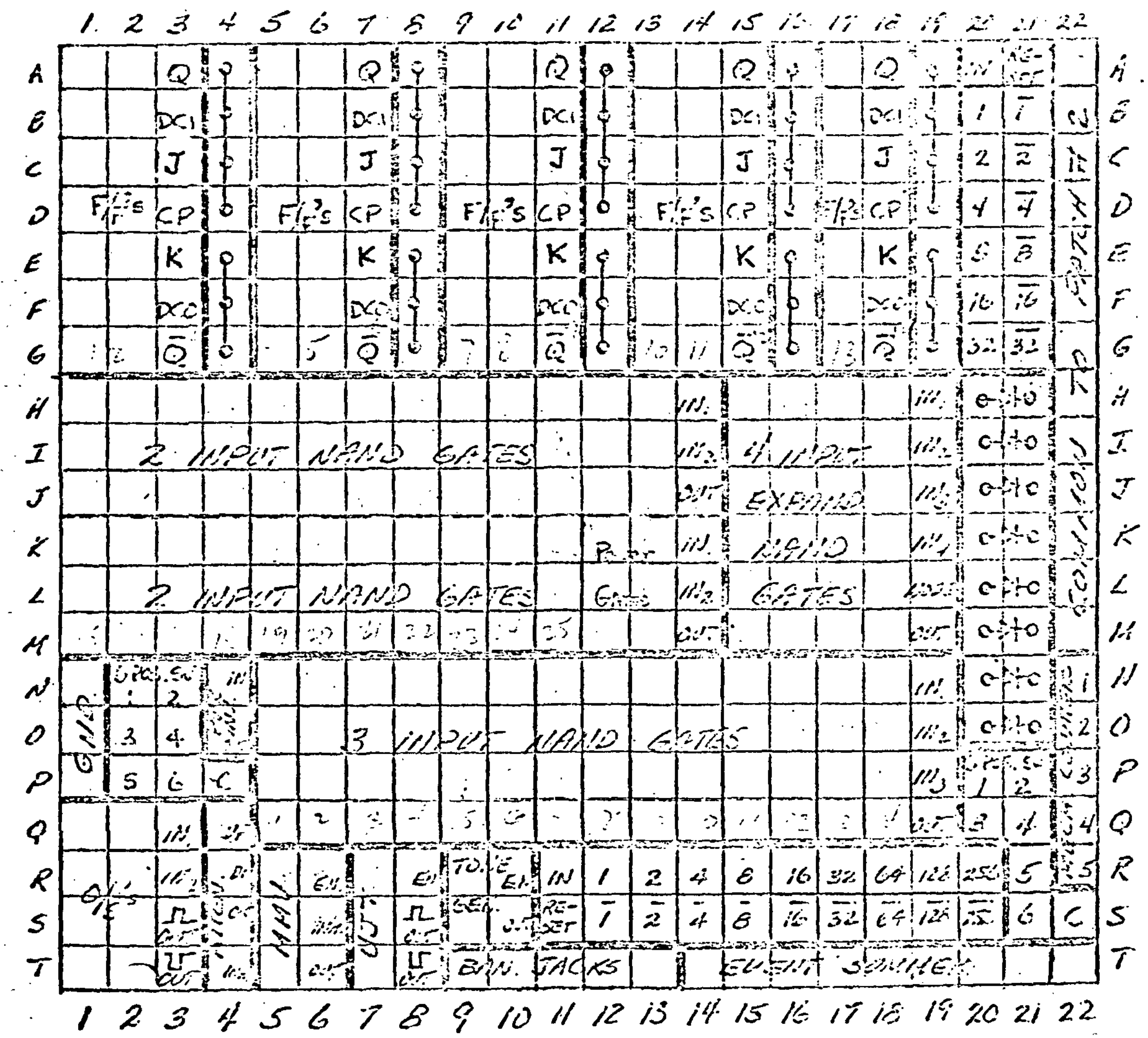


FIGURE 22

PATCH BOARD #1
PIN DESIGNATIONS

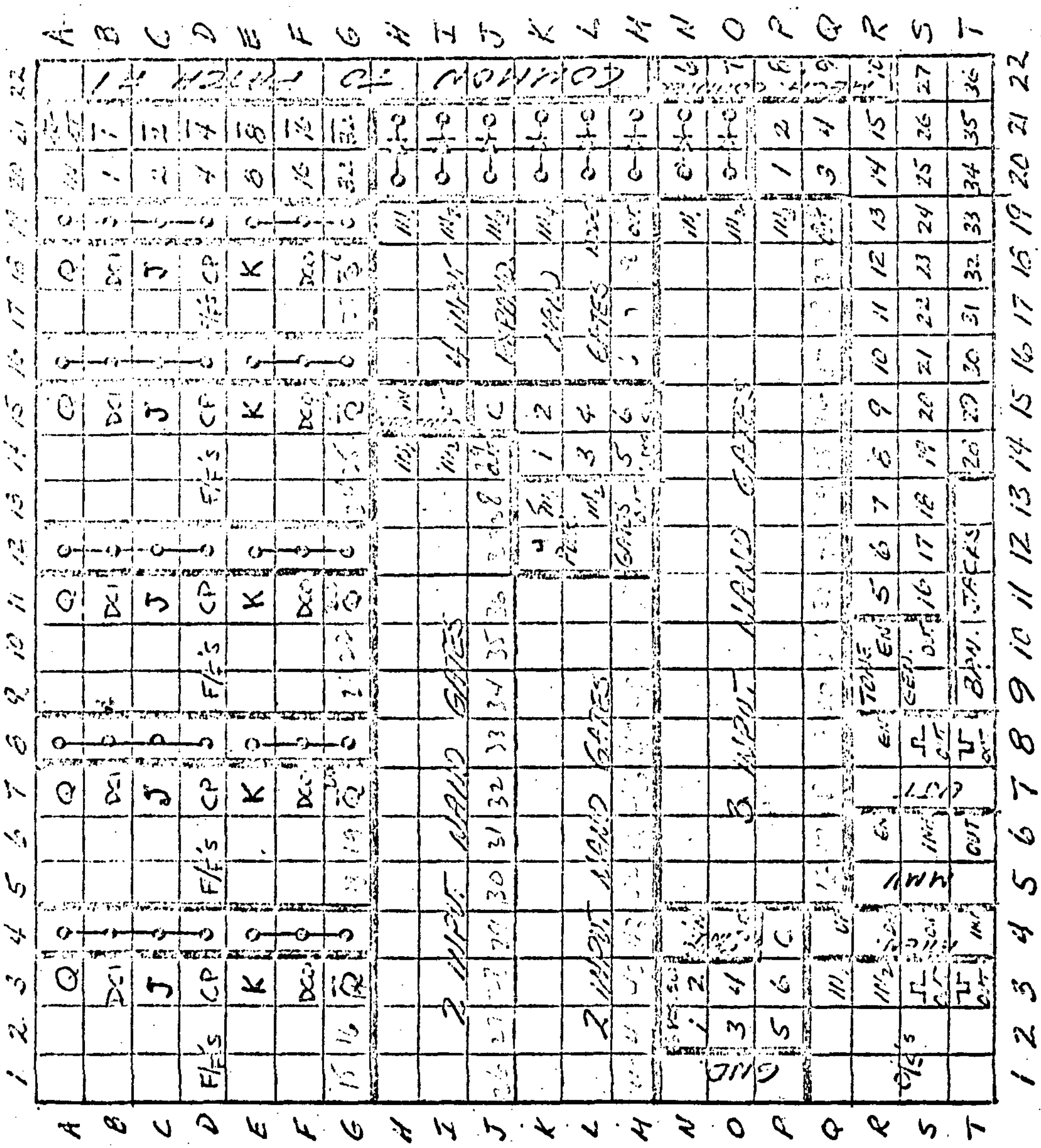


FIGURE 23

PATCH BOARD #2
PIN DESIGNATIONS

There are two "status/control" panels in the logic rack, the contents of which are shown in Fig 24 and 25. Behavioral panel control is accomplished via a 37 pin connector located on the back of the lock rack.

A.4 PRIMARY TRAINING PROGRAMS

The major training techniques utilized during primary training are described below:

A.4.1 REINFORCEMENT BUTTON TASK

At the initiation of the reinforcement button task, the reinforcement switch is illuminated simultaneously with the presentation of a 2000 Hz (sine wave) tone. The primate is given a fixed duration, selectable by the experimenter, of 1 to 60 sec in which to respond.

The response required of the primate is "N" reinforcement switch depressions within the time allotted. "N" is selectable by the experimenter to the particular values of 1,2,4,10,20, or 50. "N" switch depressions within the allotted time extinguishes the tone and light, arms the pellet feeder, and initiates the inter-trial interval. If "N" switch depressions are not performed within the specified duration, the tone and light are extinguished, and the inter-trial interval is initiated. In this case, no food reward is offered. The inter-trial interval is defined as the duration from reinforcement light off to the initiation of the subsequent trial and is selectable by the experimenter within the range of 0 to 60 sec.

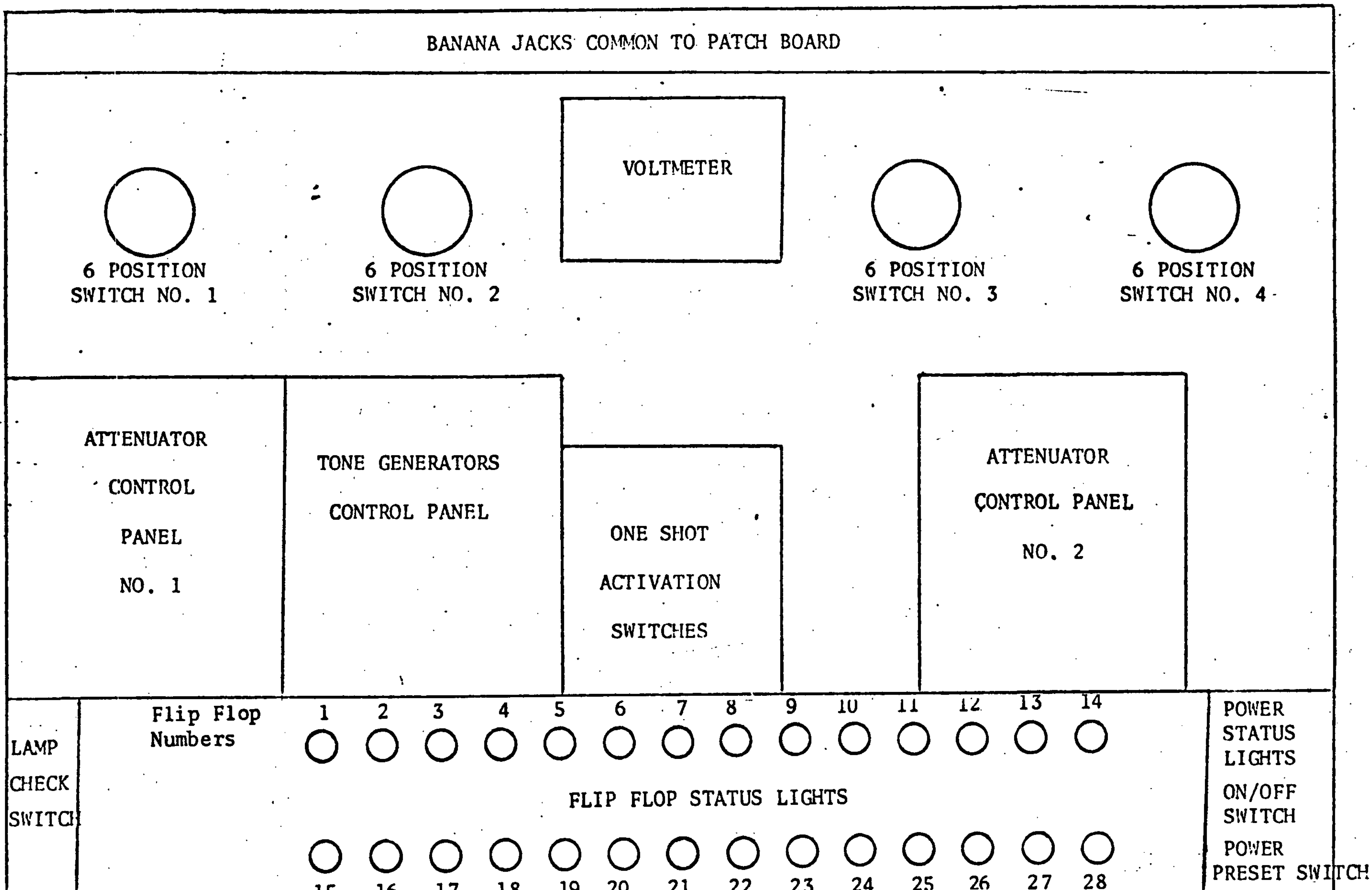


FIGURE 24

LOWER PANEL SUMMARY

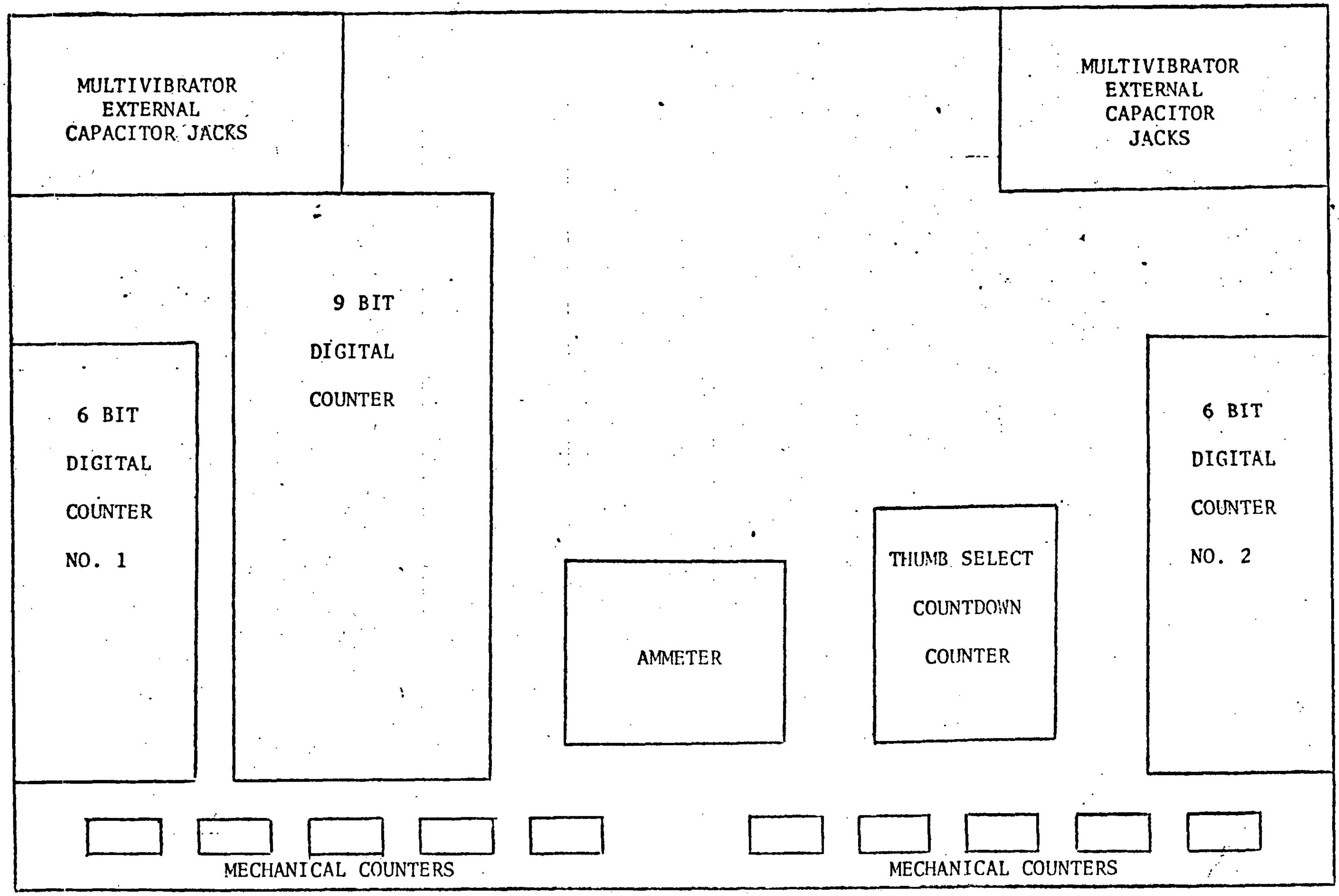


FIGURE 25
UPPER PANEL SUMMARY

Feeder malfunction may be simulated by inhibiting feeder armings requiring "X" successful trials prior to pellet delivery. "X" is defined by a variable ratio schedule with experimenter selectable means of 2,3, or 5. The selection of a particular mean defines certain discrete possible numerical values of "X" each having the same probability of occurrence. The numerical distribution, establishing "X", is presented in Table 7.

TABLE 7

Selected Mean	Possible Values of "X"
2	1, 2, 3
3	1, 2, 3, 4, 5
5	2, 3, 4, 5, 7, 9

The values that can be assigned to "X" for a particular mean have equal probability of occurrence except that they are mutually exclusive. That is, when one of the possible values of "X" is selected, it cannot be again selected until all of the remaining possible values have been selected. The associated behavioral task flow chart is shown in Fig 26.

A.4.2 OPPORTUNITY BUTTON TASK

The onset of the opportunity button task is characterized by the presentation of a 1000 Hz tone for a duration chosen by the experimenter of 1 to 60 sec. Simultaneously with tone termination, the opportunity switch is illuminated. The primate is given a fixed duration, selectable by the experimenter, of 1 to 60 min in which to

REINFORCEMENT BUTTON TASK

PRIMARY TRAINER

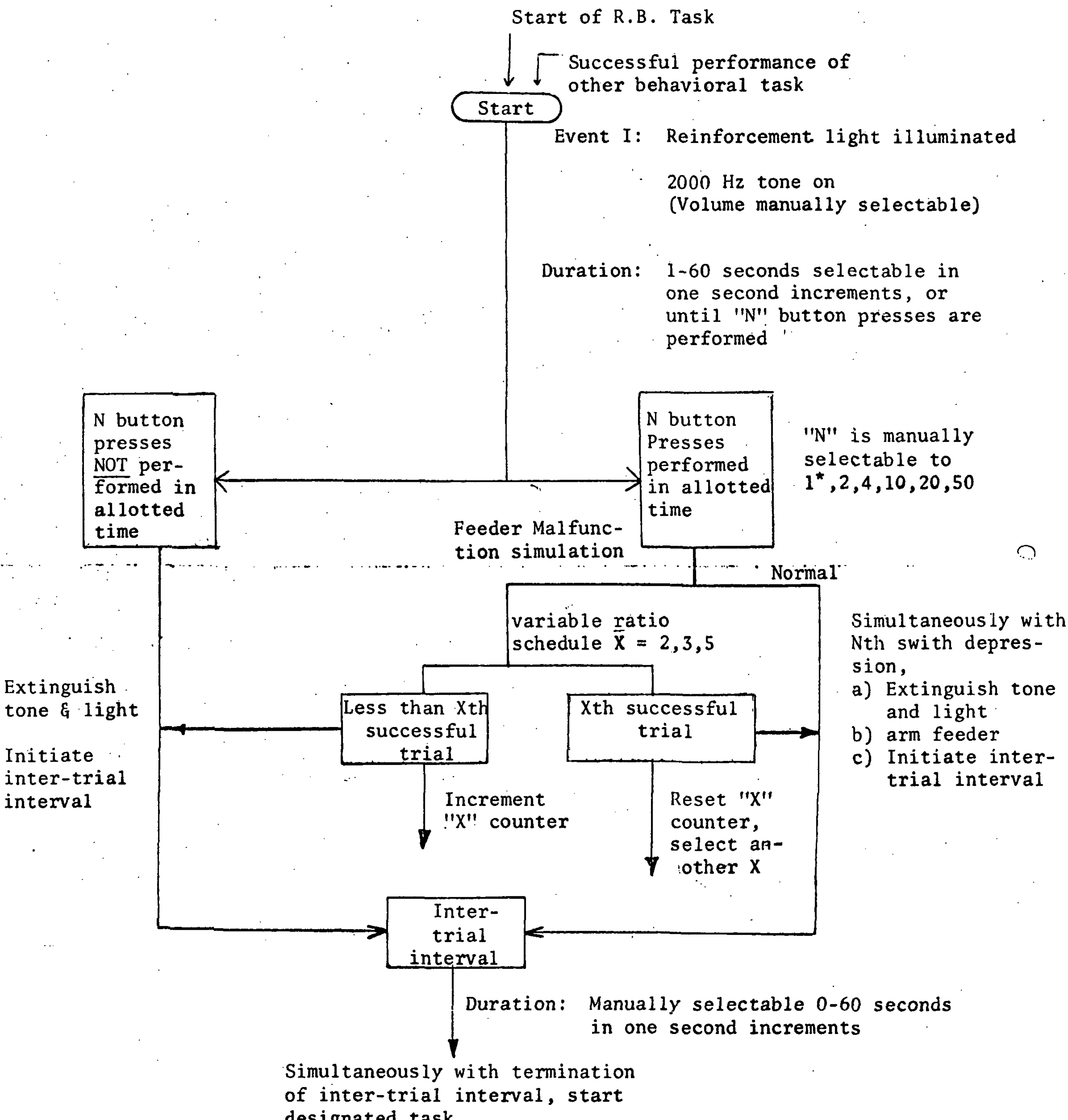


FIGURE 26

*N=1 represents continuous reinforcement

OPPORTUNITY BUTTON TASK

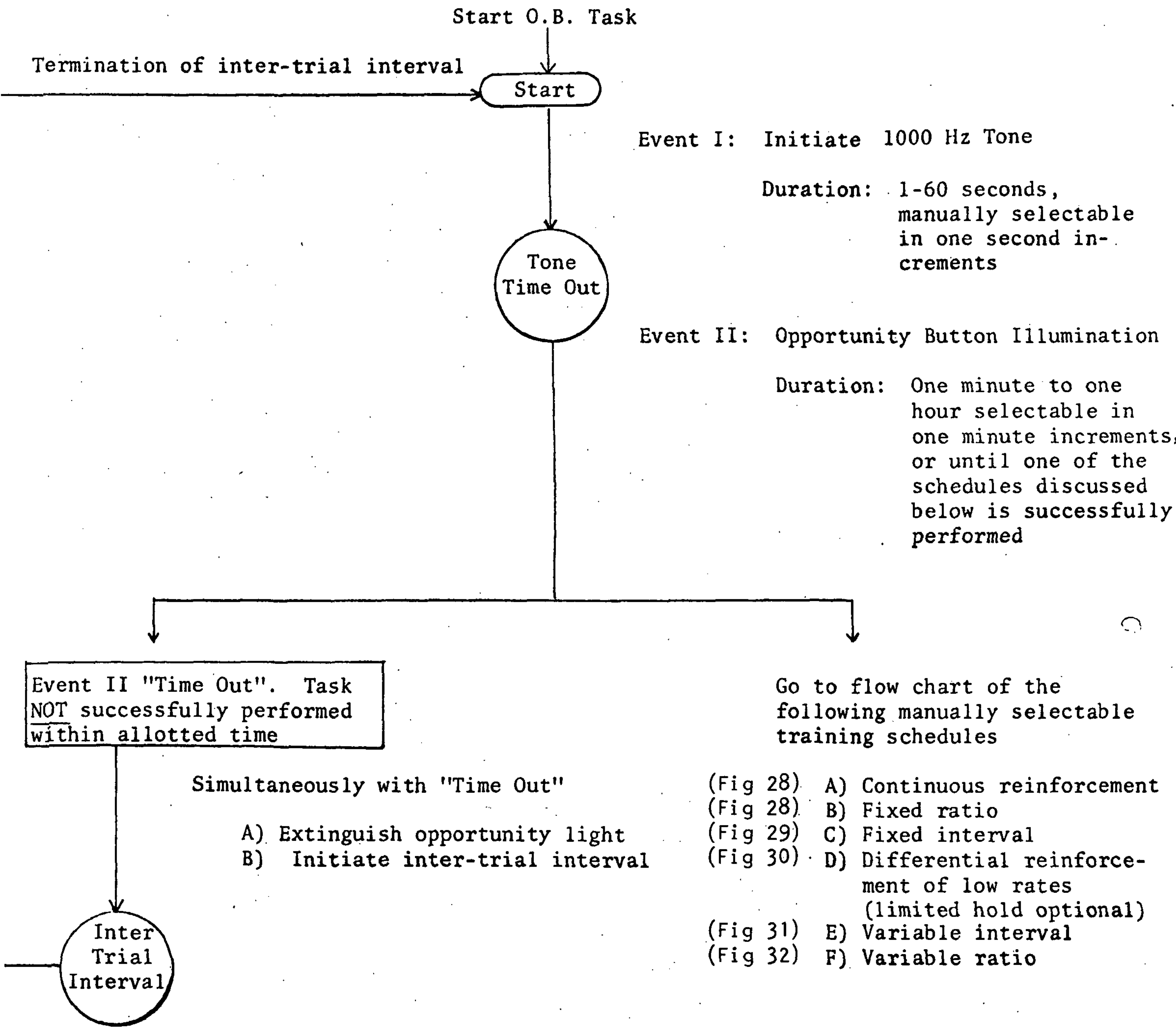


FIGURE 27

OPPORTUNITY BUTTON TASK

(CRF AND FR) CONTINUOUS REINFORCEMENT

AND FIXED RATIO SCHEDULES

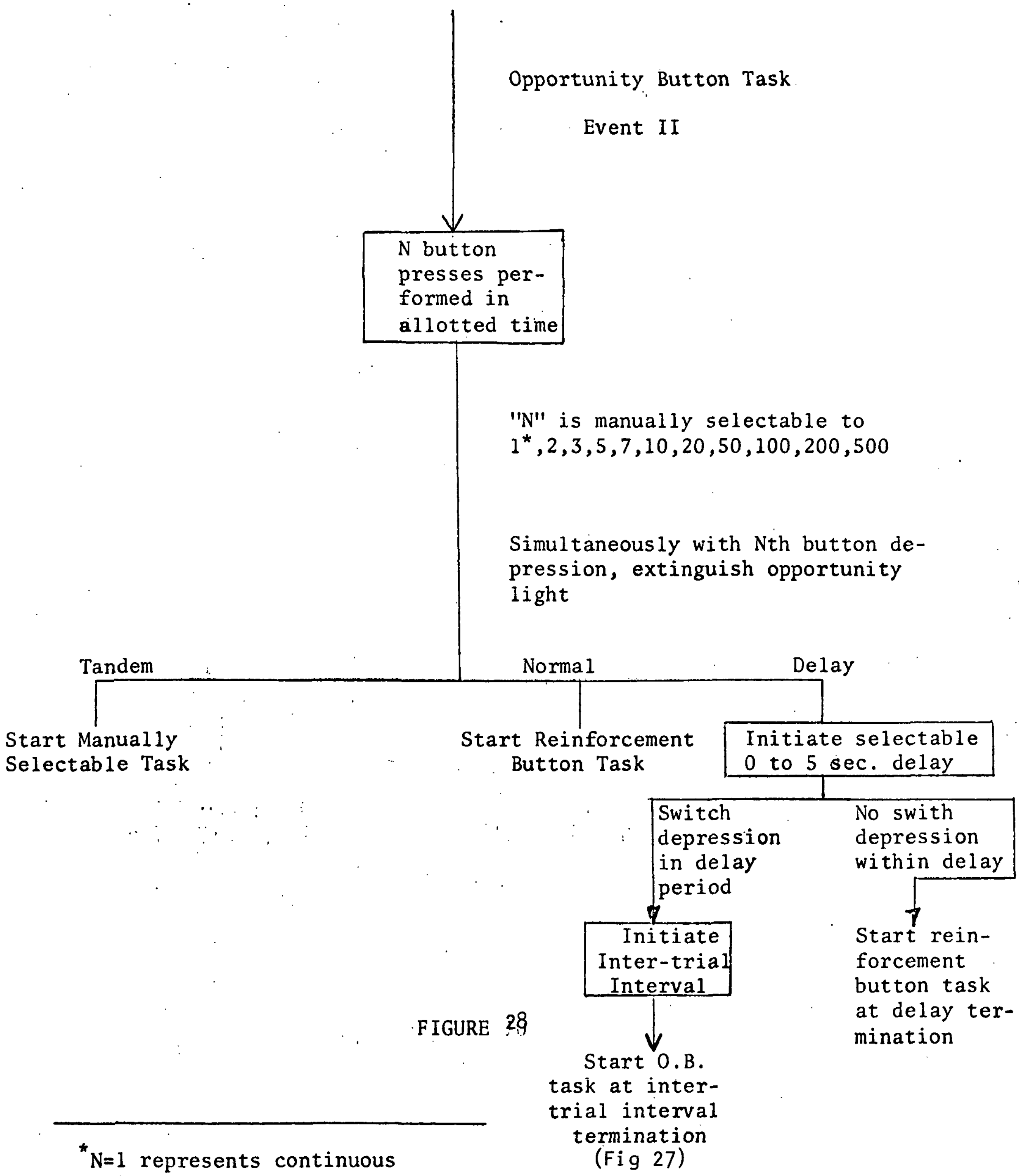


FIGURE 28

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*N=1 represents continuous reinforcement schedule respond. If a "successful" response is not performed within the allotted time, the opportunity light is extinguished and the inter-trial interval is initiated. The inter-trial interval is selectable by the experimenter within the range of 0 to 60 sec. At its completion, the task is again presented.

A variety of operant training schedules are utilized. That is, the experimenter may select the particular response to the opportunity switch required of the primate, (see Fig 27). The task definition of these operant training schedules is offered below:

A.4.2.1 CONTINUOUS REINFORCEMENT AND FIXED RATIO (CRF AND FR)

The response required of the primate is "N" opportunity switch depressions within the time allotted. "N" is selectable by the experimenter to 1*, 2, 3, 5, 7, 10, 20, 50, 100, 200, or 500. "N" switch depressions within the allotted time extinguishes the opportunity light at the "Nth" depression and initiates the reinforcement button task. The experimenter has the option of delaying the initiation of the reinforcement button task from 0 to 5 sec after the Nth switch depression has been performed where any additional opportunity switch depressions in this delay period would terminate the trial and cancel the reinforcement button task initiation. The associated behavioral task flow chart is shown in Fig 28.

A.4.2.2 FIXED INTERVAL (FI)

Simultaneously with the illumination of the opportunity switch, a fixed interval is initiated. The interval duration is selectable by the experimenter to 10, 20, 30, 60, 120, or 180 sec. The first

*N=1 represents the continuous reinforcement schedule.

opportunity switch depression after the fixed interval has elapsed extinguishes the opportunity light and initiates the reinforcement button task. The associated behavioral task flow chart is shown in Fig 29.

A.4.2.3 DIFFERENTIAL REINFORCEMENT OF LOW RATES (DRL)

Simultaneously with the illumination of the opportunity switch, an interval selectable by the experimenter at 1, 3, 5, 10, or 20 sec, is initiated. An opportunity switch depression prior to the completion of this interval causes the interval to reset and start again. The first opportunity switch depression after the interval has elapsed (with no switch depressions during the interval) causes the opportunity light to extinguish and initiates the reinforcement task.

A.4.2.4 DRL LIMITED HOLD

In the DRL task described above, the subject must wait a specified duration prior to switch depression for "successful" task completion. The experimenter has the option to impose a limited hold duration of 0 to 5 sec, giving the primate only that duration after the termination of the DRL interval to respond to the opportunity switch. If the limited hold duration expires prior to switch depression, the opportunity light extinguishes and the inter-trial interval is initiated. At the termination of the inter-trial interval, the task is again presented. Switch depression within the limited hold duration extinguishes the opportunity light and initiates the reinforcement button task. The associated behavioral task flow chart is shown in Fig 30.

OPPORTUNITY BUTTON TASK

(FI) FIXED INTERVAL SCHEDULE

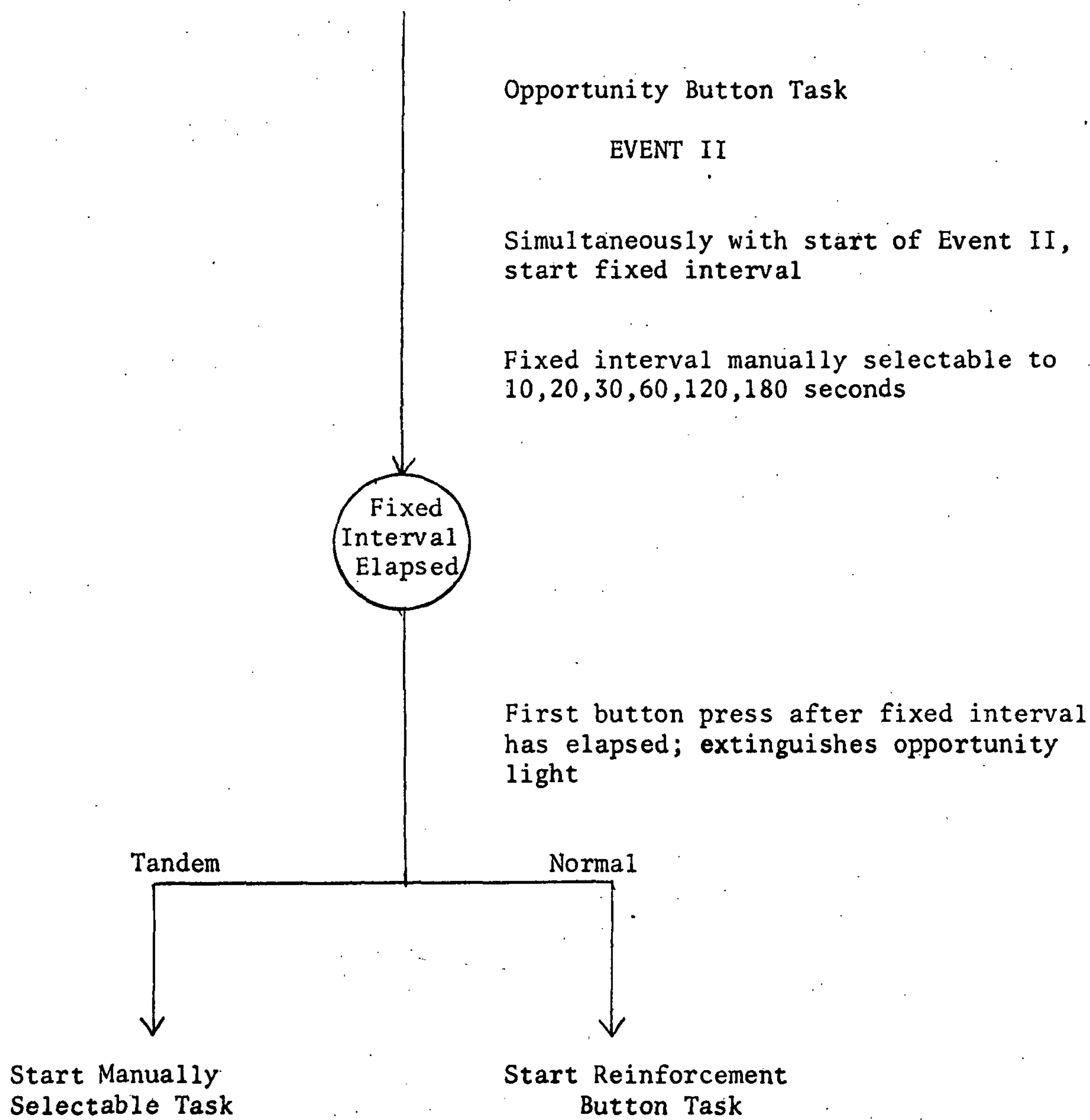


FIGURE 29

OPPORTUNITY BUTTON TASK

(DRL) DIFFERENTIAL REINFORCEMENT OF LOW RATES SCHEDULE

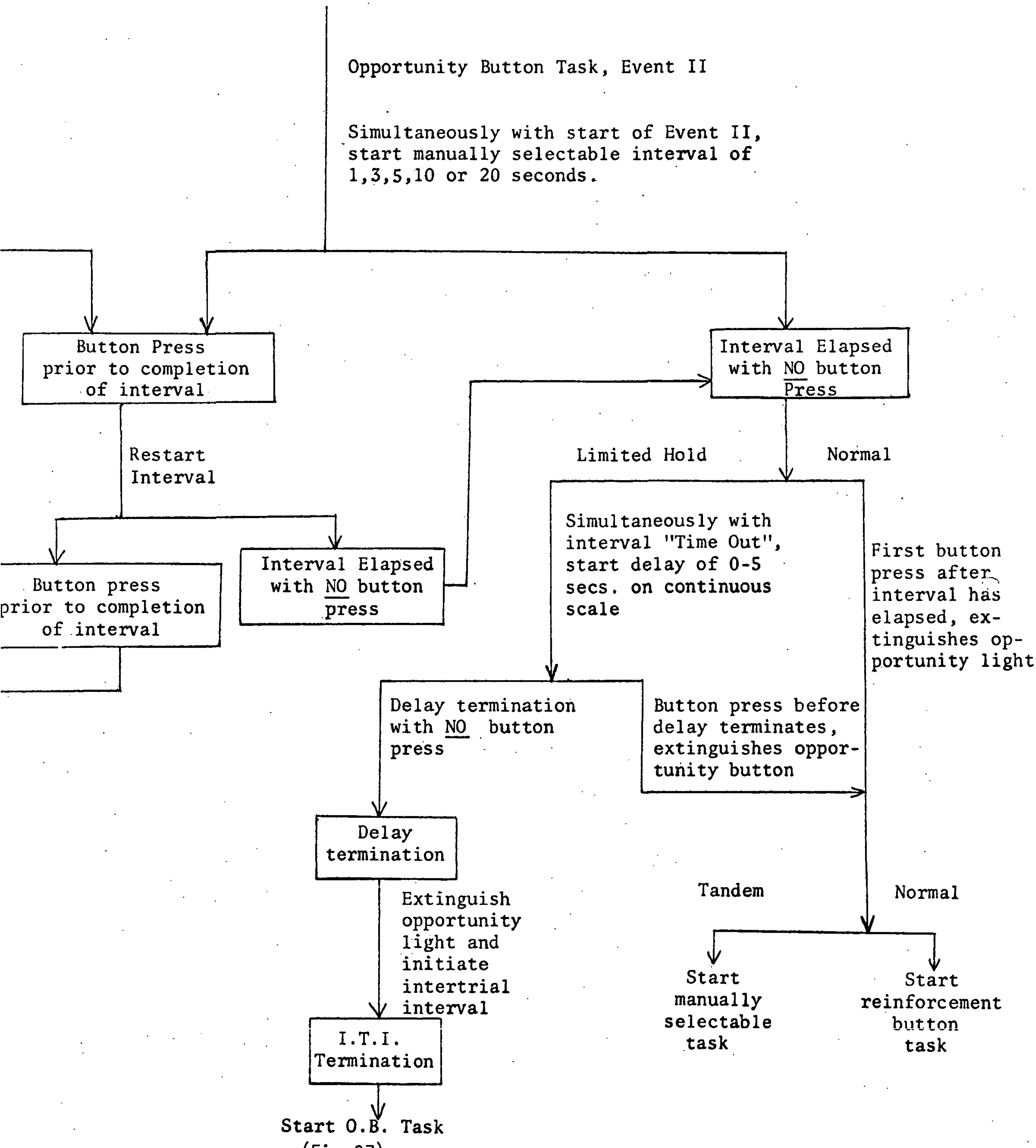


FIGURE 30

A.4.2.5 VARIABLE INTERVAL (VI)

Simultaneously with the illumination of the opportunity switch, a variable interval is initiated. The variable interval is defined by a uniform probability distribution with minimum and maximum limits being 0.4 times the mean and 1.6 times the mean. The mean of the uniform distribution is selectable by the experimenter to 10, 20, 30, 40, 50, 60, 120, or 180 sec. The first opportunity switch depression after the variable interval has elapsed extinguishes the opportunity light and initiates the reinforcement button task. The associated behavioral task flow chart is shown in Fig 31.

A.4.2.6 VARIABLE RATIO (VR)

The response required of the primate is "X" opportunity switch depressions within the time allotted. "X" is defined by a variable ratio schedule with experimenter selectable means of 3, 5, 7, 10, 20, 50, 100, or 200. The selection of a particular mean defines certain discrete possible numerical values of "X", each having the same probability of occurrence. The numerical distribution establishing "X" is presented in Table 8.

VARIABLE

TABLE 8

Selected Mean	Possible Values of "X"
3	1,2,3,4,5
5	2,3,4,5,7,9
7	2,3,6,7,10,14
10	4,7,9,10,14,16
20	5,10,15,20,30,40

OPPORTUNITY BUTTON TASK

(VI) VARIABLE INTERVAL SCHEDULE

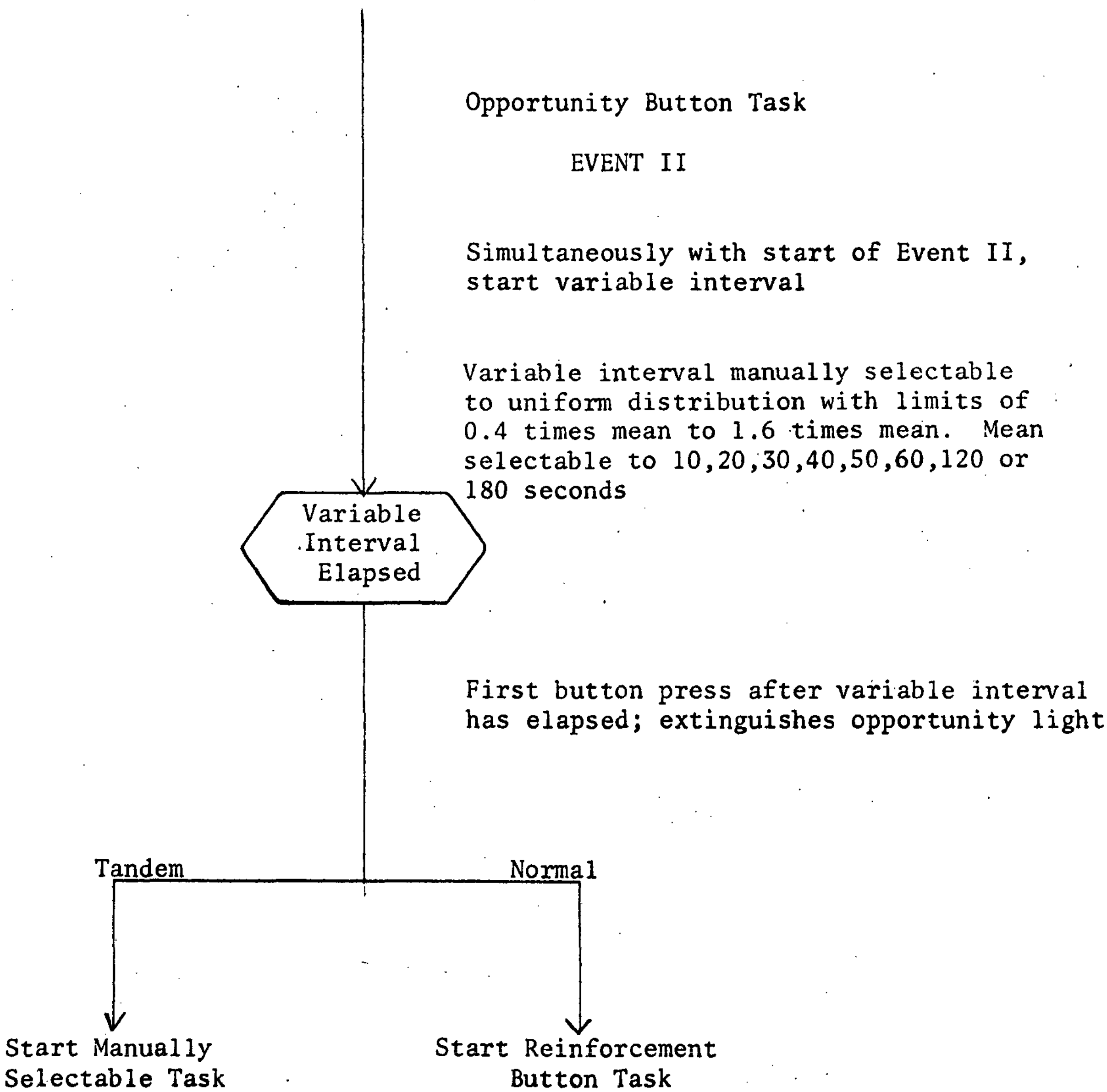


FIGURE 31

TABLE 8 (continued)

Selected Mean	Possible Values of "X"
50	20,30,40,50,70,90
100	40,70,90,100,140,160
200	50,100,150,200,300,400

The values that can be assigned to "X" for a particular mean have equal probability of occurrence except that they are mutually exclusive. That is, when one of the possible values of "X" is selected, it cannot be again selected until all of the remaining possible values have been selected. "X" switch depressions within the allotted time extinguishes the opportunity light and initiates the reinforcement button task. The associated behavioral task flow chart is shown in Fig 32.

A.4.2.7 TANDEM TASKS, AUTOMATIC TASK PROGRESSION

In each of the operant training schedules described above, successful task completion initiated the reinforcement button task. In some instances, a serialization of these tasks is desired; that is, the successful completion of one schedule will initiate any other schedule. Additionally, programs have been utilized such that the task presented to the subject automatically progressed to a different one after completion of a specified number of trials or attainment of a specified number of trial successes.

OPPORTUNITY BUTTON TASK

(VR) VARIABLE RATIO SCHEDULE

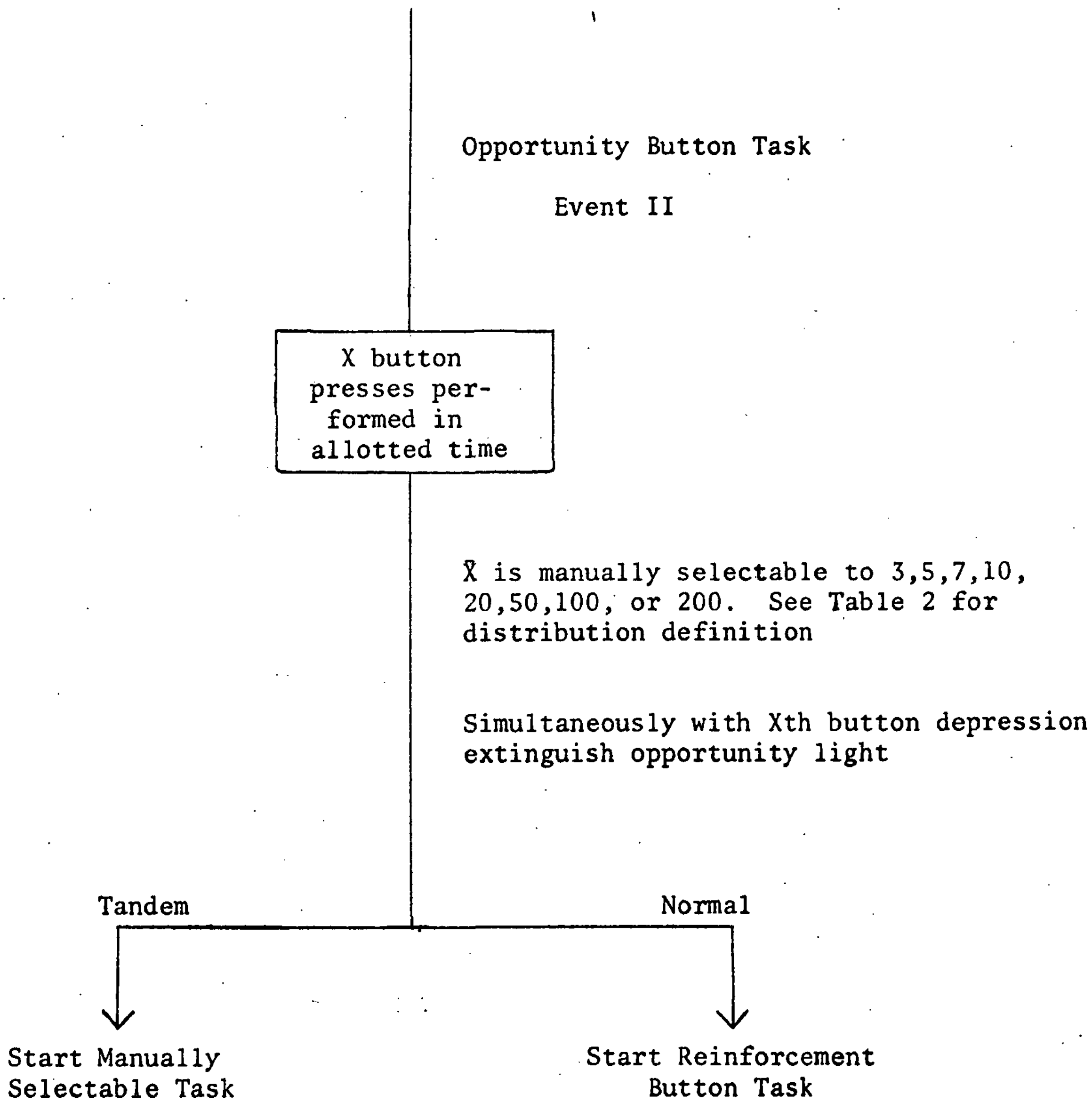


FIGURE 32

A.5 PRIMARY TRAINING PROTOCOL

1.0 GROSS OBSERVATION

1.1 All candidates should be observed daily by animal trainers and all gross behavioral characteristics should be noted and logged. Of special interest here is each candidate's native resourcefulness, curiosity, dominance and dexterity.

1.2 All these notes and records should be continuously updated as the colony grows and the candidates age.

2.0 DEPRIVATION

2.1 Twenty-four hours prior to commencement of button press training each candidate shall be totally deprived.

2.2 From this beginning phase as close to 100% as possible of the candidate's daily k/cal requirement should be earned by operant performance.

2.3 During non-training or terminal phases of training, the diet may be supplemented, if necessary, by a regime dictated by the project veterinarian.

3.0 REINFORCEMENT BUTTON PRESS TRAINING

3.1 Upon presentation of the primary trainer display panel in the home cage, the reinforcement button is lighted and armed, and a 2000 Hz tone is emitted. A button press (BP) to the reinforcement button emits a BP click and activates the feeder, delivering one 150 to 180 mg food pellet.

3.2 Following 1000 reinforcements, reinforcement button press training is terminated. Opportunity button press schedules will commence on the following day.

4.0 OPPORTUNITY BUTTON PRESS SCHEDULES

4.1 CRF/CRF (opportunity button schedule/reinforcement button schedule) to satiation (7 days).

4.2 The opportunity button is armed (lighted). A response to the lighted button will extinguish the light and arm and light the reinforcement button. A response to the reinforcement button will dispense two 150-180 mg reward pellets, extinguish the reinforcement button, and arm the opportunity button.

4.3 CRF/CRF for daily food requirement (5 days).

4.4 DRL-10 sec/CRF: Standard method (10 days or until stable performance). (Group One)

4.4.1 400 reinforcements/day. Terminate daily sessions with CRF/CRF for daily food requirement. Onset of this CRF/CRF schedule will be cued by S^D Tone.

4.5 DRL-10 sec/CRF: Errorless method (10 days or until stable performance). (Group Two)

4.5.1 400 reinforcements/day. Terminate daily sessions with CRF/CRF to daily food requirement.

4.6 FR4/CRF 20 reinforcement; advance to 4.6.1

4.6.1 FR7/CRF 20 reinforcements; advance to 4.6.2

4.6.2 FR10/CRF 10 reinforcements; advance to 4.6.3

4.6.3 FR20/CRF 10 reinforcements; advance to 4.6.4

4.6.4 FR50/CRF 10 reinforcements; advance to 4.6.5

4.6.5 FR100/CRF 100 reinforcements; terminate session with CRF/CRF to daily food requirement.

4.7 If characteristic pauses and ratio end effect occur at FR100/CRF, then begin session with FR100/CRF for 5 reinforcements; advance to FR100/CRF for 100 reinforcements. Terminate session with CRF/CRF for daily food requirement.

4.7.1 If no pause or ratio end effect occur at FR100/CRF, then begin session with FR100/CRF for 5 reinforcement; then advance to FR200/CRF for 50 reinforcements. Terminate session with CRF/CRF for daily food requirement.

4.8 If 4.7, then begin session with VR100/CRF for 5 reinforcement; then advance to VI 3 min/CRF for 40 reinforcements. Terminate session with CRF/CRF for daily food requirement.

4.8.1 If 4.7.1 and pauses on ratio end effect occur at FR200, then procede to FR200 for 50 reinforcements. Terminate session with CRF/CRF for daily food requirement.

4.8.2 If 4.7.1 and no pauses or ratio end effect occur, then begin session with FR200/CRF for 5 reinforcement; then advance to FR500/CRF for 20 reinforcements. Terminate session with CRF/CRF for daily food requirement.

4.8.3 (Option) If pauses and ratio end effect do not occur on the 5 reinforcements at that FR/CRF that began a session, when they did occur on the previous session, then advance to the next FR schedule for specified reinforcement.

4.9 If 4.8, then begin session with VI 3 min/CRF for 5 reinforcement; then advance to FI 3 min/CRF for 40 reinforcements. Terminate session with CRF/CRF for daily food requirement.

4.9.1 If 4.8.1, begin session with VR200/CRF for 5 reinforcement; then advance to VI 3 min/CRF for 40 reinforcements. Terminate session with CRF/CRF for daily food requirement.

4.9.2 If 4.8.2, begin session with FR500/CRF for 5 reinforcements; then advance to VR500/CRF for 20 reinforcements. Terminate session with CRF/CRF for daily food requirement.

4.10 If 4.9, begin session with FI 3 min/CRF for 50 reinforcements; terminate session with CRF/CRF for daily food requirement.

4.10.1 If 4.9.1, begin session with VI 3 min/CRF for 5 reinforcements; then advance to FI 3 min/CRF for 40 reinforcements. Terminate session with CRF/CRF for daily food requirement.

4.10.2 If 4.9.2, begin session with VR500/CRF for 5 reinforcements; then advance to VI 3 min/CRF for 40 reinforcements.

4.11 If 4.10, then repeat 4.10.

4.11.1 If 4.10.1, then begin session with FI 3 min/CRF for 50 reinforcements. Terminate session with CRF/CRF for daily food requirement.

4.11.2 If 4.10.2, then begin session with VI 3 min/CRF for 5 reinforcements; then advance to FI 3 min for 40 reinforcements.

4.12 Begin session with FI 3 min/CRF for 50 reinforcements. Terminate session with CRF/CRF for daily food requirement.

4.12.1 After 4 daily sessions of FI 3 min/CRF, if definite scalloping not present, then advance to FI 4 min/CRF.

If still characteristic scallops are not present after 2 sessions of FI 4 min/CRF, advance to FI 5 min/CRF for 2 sessions. Advance to longer FI, if necessary, to produce stable scallops.

4.12.2 Tandem Schedules: Begin session with DRL-10 sec/FR10/CRF for 400 reinforcements. Terminate session with CRF/CRF for daily food requirement.

4.12.3 The 4.12.2 schedule will prevail until the DRL histograms and the FR rates are stable.

4.13 Begin session with DRL 10 sec-Limited Hold 2 sec for 400 reinforcements. Terminate session with CRF/CRF for daily food requirement.

4.13.1 With stable histograms from this schedule, change LH contingency to 1 sec.

4.13.2 Additional tandem or mixed schedule combinations may be added to protocol to provide further tests of performance capabilities and to prepare S's for schedule requirements of MSS task (e.g., DRL 3 sec-FR4, and PEC task; DRH schedules).

5.0 DATA OUTPUT AND RECORDING

5.1 All button press responses will be accumulated in raw form on accumulative recorders, session by session. These shall be identified, dated, and stored in permanent training files.

5.2 All responses from all schedules performed will be counted on appropriate counters and logged to their respective schedule component in the individual training files.

5.3 Inter-response time (IRT) histograms will be drawn up and maintained for each session involving DRL performances.

5.4 All reinforcements will be recorded on a daily session-by-session basis and will be logged in the training charts and converted to k/cal and entered in the colony feeding charts. All k/cal supplements will also be entered in the training and feeding records.

5.5 Response rates and schedule efficiency charts will continually be updated for each subject and maintained in individual training records.

5.6 As criteria for candidate selection become more refined, quantitative proficiency graphs relative to these criteria will be maintained for progress evaluation and selection. Further detailed instructions may be added periodically to this protocol as candidate proficiency requirements become more stringent.

B.5 SECONDARY TRAINING PROTOCOL

1.0 SEQUENTIAL BUTTON PRESS AND MSS PROTOCOL

A. OSIC - ONE SAMPLE-ONE CHOICE TASK

1. The logic of this and every other display will be tested before presenting task to the S. A trial orientation tone (TOT) (1000 Hz) of 1 sec duration will cue the subject to the onset of a trial. The TOT will be followed by a variable interval (1/4 to 2 sec). A button press (BP) to the sample switch by the S during this interval will initiate the inter-trial interval (ITI) of 0 to 60 sec, tentatively 4 sec.

If no BP occurs, the interval will be followed by the appearance of a randomly selected symbol Δ,+,□, O, or Z on the sample switch. Completion of the tandem response schedule (initially DRL 4 sec: FR3 in LH of 5 sec) will extinguish the sample and initiate the delay period (1/4 sec). Unsuccessful completion of the tandem response schedule initiates ITI. A choice orientation tone (COT) of 1/4 sec will occur simultaneously with the delay period. *Following the delay period the sample symbol will reappear* on the sample switch and on one of the two choice switches selected randomly. BP's to the sample switch has no consequence while a BP to the unlighted switch will lead to a time out period and the concomitant sounding of a buzzer (TO) of 0 to 20 sec (tentatively 10 sec). The TO will be followed by ITI. A BP to the lighted choice switch will extinguish the symbols and initiate the reinforcement cues (S^{rs}), lighting of the red reinforcement button and onset of the reinforcement tone (2000 Hz), which signals the availability of reinforcement (S^{R}). A BP to the reinforcement button will terminate the S^{rs} and deliver the primary S^{R} and initiate the ITI.

2. This task will remain in effect until the S displays a criterion performance of 90% correct on two successive sessions of 100 trials.

B. OS2C (+,0) MATCHING TO ONE SAMPLE-TWO CHOICE TASK

1. Sample phase of trial (from onset of TOT to onset of COT) is same as in OSIC task, except that the sample symbol on

each trial will be selected randomly from two preselected symbols, in this case from + and 0.

2. At the termination of the delay period and COT, the symbol which appeared as sample will reappear on the sample switch as a "redisplay symbol." A BP to the redisplay symbol switch has no consequence. Concomitant to the onset of the redisplay symbol is the appearance of both preselected symbols as choice symbols, randomly positioned from trial to trial on the choice switches. The correct choice symbol (the symbol that appeared as the sample symbol) will appear at maximum brightness. The incorrect choice symbol will appear on the other choice switch attenuated in brightness near or below visual threshold. The incorrect choice symbol attenuator will initially be set such that the correct and incorrect choices will increment and decrement, respectively, the brightness of the incorrect choice symbol on the subsequent trial by a step of approximately 1/60 of the brightness scale, 0 to maximum. This step setting will be reset below the just noticeable difference (JND) threshold level once the brightness of the incorrect symbol reaches midpoint of the brightness continuum. A BP to the incorrect choice symbol extinguishes all symbols, terminates the trial, and initiates a TO. The TO is followed by ITI. A BP to the correct choice symbol extinguishes all symbols and initiates the reinforcement phase of trial followed by ITI. A trial repeat option will be included in order to break position habits of S if necessary.

3. Scores will be recorded in banks of 25 trials. Correct and incorrect counters are to be reset after each session. Attenuation level of the incorrect symbol is to be noted.
4. When the S first attains a score of 20 correct choices/25 trials after the incorrect choice symbol intensity has reached maximum, the attenuator will be inhibited, counters reset and scores will be recorded in banks of 25 trials. The S will be allowed to perform without choice attenuation unless the score for any bank falls below 18 correct/25 trials.
5. After eight consecutive banks of 25 trials where choice attenuation has been inhibited, session length will be increased to 100 trials/session without the choice attenuation parameter. With 90% correct performance on 2 consecutive sessions of 100 trials, then the S will be advanced to task OS2C with redisplay dimming.

C. OS2C (+,0) WITH REDISPLAY DIMMING

1. This task is identical to OS2C (+,0) task with the exceptions that there is (1) no attenuation of the incorrect choice symbol and (2) there is trial attenuation of the sample redisplay symbol. Each session will be composed of 100 trials. Every correct trial in this phase will be followed by an intensity reduction of the sample redisplay for the subsequent trial by a step setting less than 1/2 JND threshold. Each incorrect trial will be followed by an intensity increment of the sample redisplay by a step setting less than 1/2 JND threshold intensity level.

2. Following two successive sessions of 90% correct performance, the task will be advanced to OS2C (+,Δ) 1/4 sec delay.
3. OS2C (+,Δ) 1/4 sec delay is identical to previous task; however, there is no redisplay symbol appearance and the symbol 0 has been replaced by the symbol Δ. Following criterion performance of 90% correct/100 trial session, the task will be advanced to OS2C (Z,Δ) 1/4 sec delay.
   NOTE: On all phases of matching to successive sample training E will have the option of using the sample redisplay parameter.
4. OS2C (Z,Δ) 1/4 sec delay. Same as previous task except + symbol replaced by Z symbol. After criterion performance, task will be advanced to OS2C (□,Δ) 1/4 sec delay.
5. OS2C (□,Δ) 1/4 sec delay; same as preceding task excepting replacement of the Z symbol with the □ symbol. With criterion performance the task will be advanced to OS2C (+,0,Δ,Z,□).
6. OS2C (+,0,Δ,Z,□). This task is similar to the above tasks with the exception that the sample and the choice confusion symbol will be selected randomly from trial to trial from the symbols +,0,Δ,Z,□. If any particular symbol combimation is found to repeatedly contribute to errors on this task, the animal will be given a "review" session using that combination in task C6.
7. With criterion performance the task progression will be repeated beginning with OS2C (+,0) 1/4 sec delay thru OS2C (+,0,Δ,Z,□) on the flight configured panel. The sample and

choice symbols will be positioned randomly on the display switches. With 90% correct one session, the task will be advanced to OS3C 1/4 sec delay.

D. OS3C (+, 0,Δ,Z,□) 1/4 sec delay: Delayed matching to single sample with three choice symbols. This task is like the previous task. One of 5 symbols will appear randomly from trial to trial as the sample. The sample symbol and 2 additional confusion symbols, selected randomly from the remaining 4 symbols, will appear as choice symbols: 22 correct trials in block of 25 will advance the task to OS4C 1/r sec delay.

E. OS4C (+,0,Δ,Z,□) 1/4 sec delay. Matching to single sample with 4 choice symbols. This task is similar to the previous task except during the choice phase of the trial the symbol that appeared as the sample will reappear along with 3 additional symbols: 22 correct out of a block of 25 trials will advance the task to OS5C (+,0,Δ,Z,□) 1/4 sec delay.

F. OS5C (+,0,Δ,Z,□) 1/4 sec delay. 90% for 100 trials to OS5C (+,0,Δ,Z,□) with delay progression.

G. OS5C (+,0,Δ,Z,□) delayed matching progression. This task is similar to the preceeding task; however, the COT will occur following the delay and before the onset of the choice symbols. There will be an option to increase the duration of the COT to 1 sec. A performance of 22 correct during a block of 25 trials will advance the delay between the sample phase and choice phase of the trial through the following time increment progression 0, 1/4, 1/2, 3/4, 1.0, 1.5, 2.0, 3.0, 5.0, 7.0, 10.0 sec. With an 80% correct performance during a 100 trial session with a 5 sec delay, the progression will be repeated with the response schedule requirement on the sample changed to CRF. With criterion performance at a 5 to 10 sec delay, the S will advance to the next task.

H. TWS2C (+,0) with white light as "interference" sample: two symbol matching task with white light as an interference sample. This task is similar to the OS2C (+,0) 1/4 sec delayed matching task but with an added "retroactive" interference sample in the sample phase. One quarter sec after the response schedule (tandem DRL 4"/FR3 in LH 5 sec) to the first sample symbol is completed, a white light sample appears on the sample key. A single press to this interference sample extinguishes the light and produces the 1/4 sec COT followed by the onset of choice symbols +,0, randomly positioned on the 5 choice switches. No white light appears in choice phase of trial. 22 correct trials/ 25 trial block will advance S to TWS2 (+,0) 1/4 sec delay. NOTE: The white light interference variable will be replaced by sample focus attenuation variable when available.

I. TWS2C (+,0) 1/4 sec delay

1. The white light interference sample is replaced in this task by the second or alternate symbol so that both symbols (+,0) are presented randomly in sequence during the sample phase. All other events are as in the above task. A 90% performance during a 100 trial session will advance the S to the next task.

2. Reinforcement following the second correct choice. The sample phase of the task is like the TWS2C task above; however, during the choice phase of the paradigm, the

correct BP to the choice symbol which appeared previously as the first sample symbol of the sequence extinguishes only that symbol. The second choice symbol remains lighted. A BP to this symbol extinguishes it and initiates the reinforcement phase of the trial. Following 3 sessions of 100 trials/session with 90% correct performance, the S will be advanced to TWS2C (Δ,0), (Δ,Z), (□,0).

3. TWS2C (Δ,0), (ΔZ), (□,0). A 90% correct performance level for 100 trial sessions on each of these symbol configurations will advance the S to the TWS2C (+,0,Δ,Z,0) task.

4. TWS2C (+,0,Δ,Z,□). This task is identical to the above tasks except that the symbol configurations used on each trial will be selected randomly from the five symbols +,0, Δ,Z,□. 90% correct performance on 2 successive sessions of 100 trials each will advance the subject to the TWS3C task.

J. TWS3C (+,0,Δ,Z,□) 1/4 sec delay. This task (delayed matching to two symbols with 3 choice symbols) is identical to the above task except that a third symbol (a confusion symbol) now appears in the choice phase though it has had no mate in the sample phase. A FR response schedule may be an added requirement to extinguish the second sample and the choice brightness attenuation procedures may be used for the confusion choice symbol. Reinforcement contingencies still occur at the BP emitted correctly to the second choice symbol and the confusion choice symbol extinguishes simultaneously. 90% correct performance on 2 successive sessions of 100 trials where no attenuation is used will advance the S to TWS4C task.

K. TWS4C (+,0,Δ,Z,□) 1/4 sec delay. This task (delayed matching to two sample with 4 choice symbol) is as the above task except 2 confusion choice symbols are present in the choice phase of the trial. No attenuation procedures are used: 90% correct performance on 1 session of 100 trials will advance the S to TWS5C.

L. TWS5C (+,0,Δ,Z,□) 1/4 sec delay. This matching to two sample with 5 choice symbols task is as the above task except 3 confusion symbols are used in the choice phase: 90% correct performance on a session of 100 trials to TWS5C with a delay progression.

M. TWS5C delayed matching progression. This task is similar to the preceeding task; however, the COT will occur following the delay and before the onset of the choice symbols. There will be an option to increase the duration of the COT to 1 sec. A performance of 22 correct during a block of 25 trials will advance the delay between the sample phase and the choice phase of the trial through the following time increment progression: 0, 1/4, 1/2, 3/4, 1.0, 1.5, 2.0, 3.0, 5.0, 7.0, 10.0 sec. With 80% correct performance during a 100 trial session with a 5 sec to 10 sec delay, the task delay progression will be repeated with the response schedule requirements changed to CRF and the 1/4 sec ISI increased to 1/2 sec of 1 sec. Criterion performance with the longer delays will advance S to the next task.

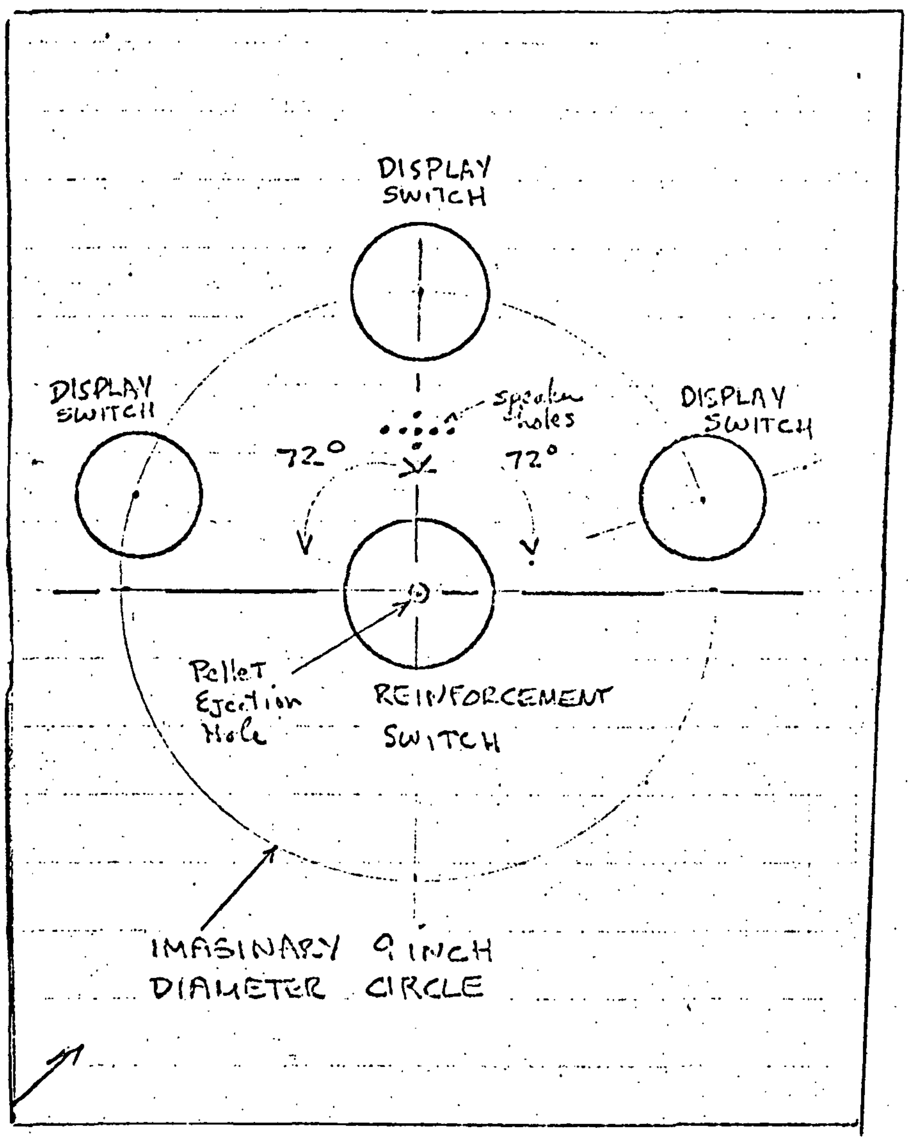


FIGURE 33

MSS TRAINING BEHAVIORAL PANEL

B. SECONDARY TRAINING

B.1 PURPOSE

The secondary training phase is a transition between primary training and flight training. It consists of symbol recognition, delayed matching, and introduces the basic timing and operation of the matching to successive sample (MSS) tasks (one and two symbol only) to the primate.

B.2 BEHAVIORAL PANEL

The secondary behavioral panel (Figure 33) is fabricated of black lucite and is easily mounted on one wall of the subject's home cage. Smoothly integrated into the surface of the panel and visible to the subject are four proximity switches, speaker holes, and a pellet holder. The interior of the panel consists of IEEE symbol display projectors positioned directly behind each proximity switch's transparent surface and associated drivers. Each display is capable of illuminating the following five 1-inch symbols:

SQUARE	□
CIRCLE	○
SLASH	/
CROSS	X

The panel also contains an 8 OHM speaker mounted directly behind the speaker holes and a pellet storage container and dispensing unit. A description of the switches is tabulated below:

SWITCH DESIGNATION	DIAMETER (INCHES)	COLOR
Display Switch A	2.00	Clear
Display Switch B	2.00	Clear
Display Switch C	2.00	Clear
Reinforcement Switch	2.25 O.D. 0.75 I.D.	Red, Shinkolite Color No. 136

B.3 BEHAVIORAL ELECTRONICS

The secondary panel is controlled by the logic rack, as described in sections A.3 and A.3.1.

B.4 SECONDARY TRAINING PROGRAMS

The major training techniques utilized during secondary training are described below.

B.4.1. ONE SAMPLE, ONE CHOICE RANDOM TASK

The one sample, one choice random task requires a response to a single sample, and a subsequent response to its matching choice symbol appearing on the sample behavioral display switch.

This task tests the critical integrity of vestibular function to mediate multiple press responses over a sustained trial duration.

The one sample random behavioral task requires three successive button presses for successful completion of the task. A trial is initiated by a one sec duration audio and visual orientation cue. At the completion of the orientation cue, one of five symbols is selected randomly and presented on a randomly selected behavioral display switch. The primate has a specified time to depress the switch located directly in front of the excited symbol. Failure of the primate to depress the switch within the allotted time constitutes a failure whereby the symbol is extinguished and the inter-trial interval begins.

Primate button depression within the allotted time extinguishes the symbol and initiates a delay period initially set between 0 and 1 sec. Following the delay period, a one sec orientation tone is presented to cue the onset of the choice phase of the trial. At the completion of the orientation cue, the same symbol reappears in a randomly selected window of the behavioral display panel. The primate must respond within the allotted response time by button depression. Failure to do so initiates the inter-trial interval. Successful button depression results in a simultaneous third orientation cue whereby the reinforcement switch lights up simultaneously with a tone. The remainder of the task is identical to the reinforcement button task. A flow diagram and time charts are shown in Figures 34 through 35d.

The one sample, two choice task, through the one sample, five choice task are identical to the task just described with the exception that multiple symbols will appear randomly on the switches of the behavioral panel during the choice time of the trial. Reinforcement contingencies are dependent upon the subject selecting the switch on which is displayed the sample symbol whereas a response to any other illuminated symbol constitutes a failure, terminating the trial with a one sec duration buzzer sound.

B.4.2 TWO SAMPLE, TWO CHOICE RANDOM TASK

The delayed matching to successive sample (MSS) tasks

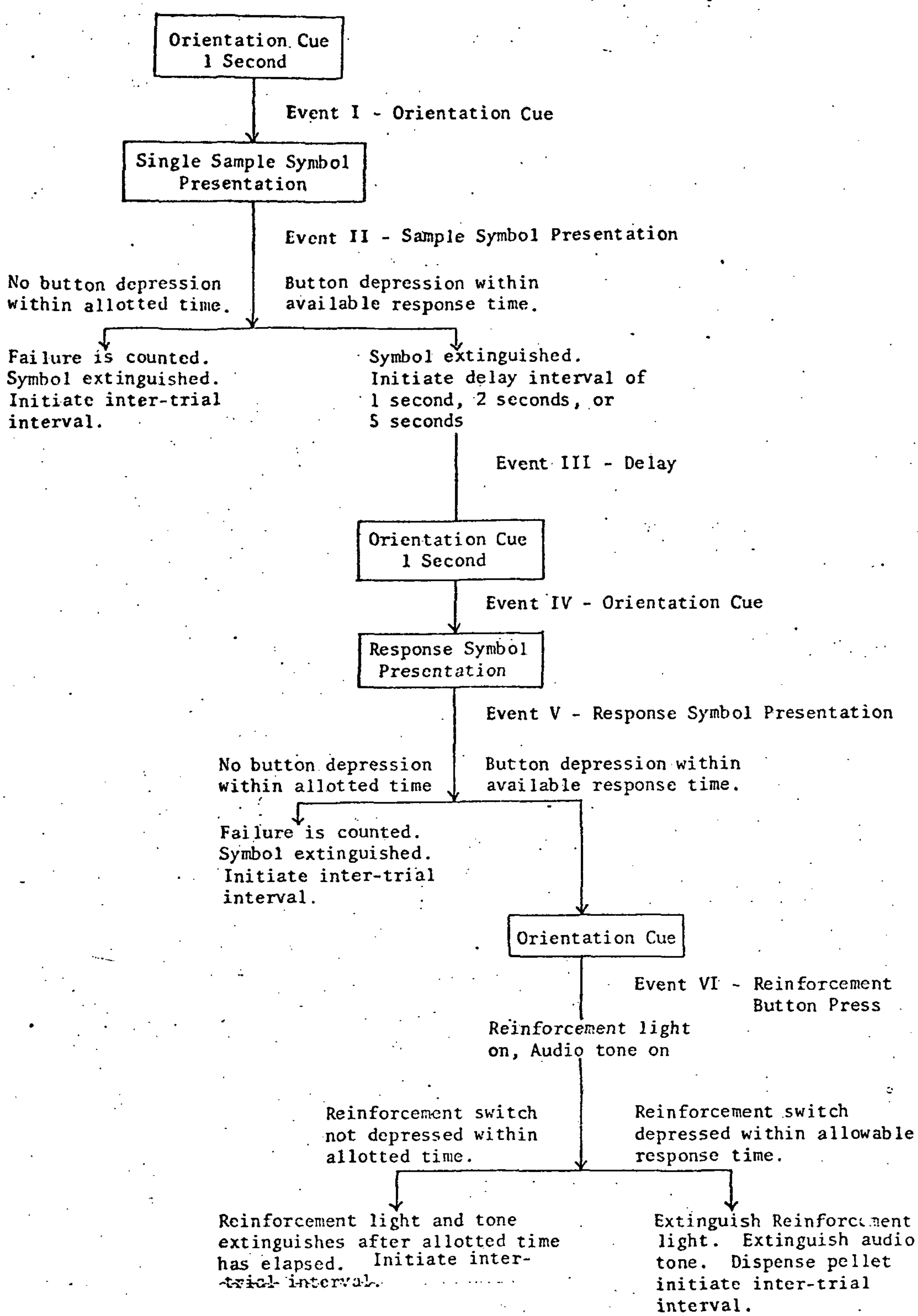


FIGURE 34

ONE SAMPLE, ONE CHOICE RANDOM
BEHAVIORAL TASK FLOW DIAGRAM

a) Failure in Event II
No Sample Symbol Switch Depression

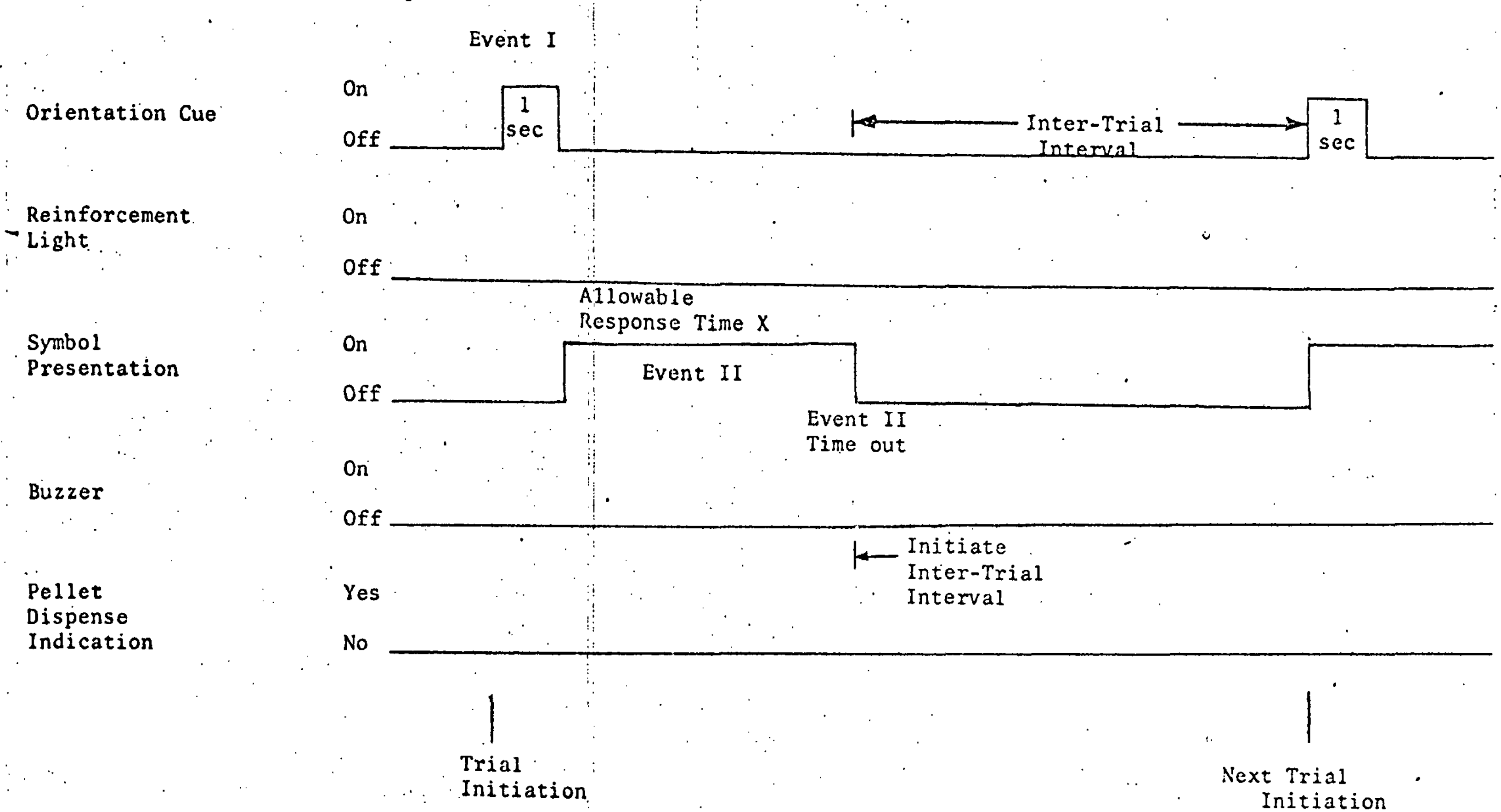


FIGURE 35a

ONE SAMPLE, ONE CHOICE RANDOM
BEHAVIORAL TASK TIME CHART

b) Failure in Event V
No Response Symbol Switch Depression

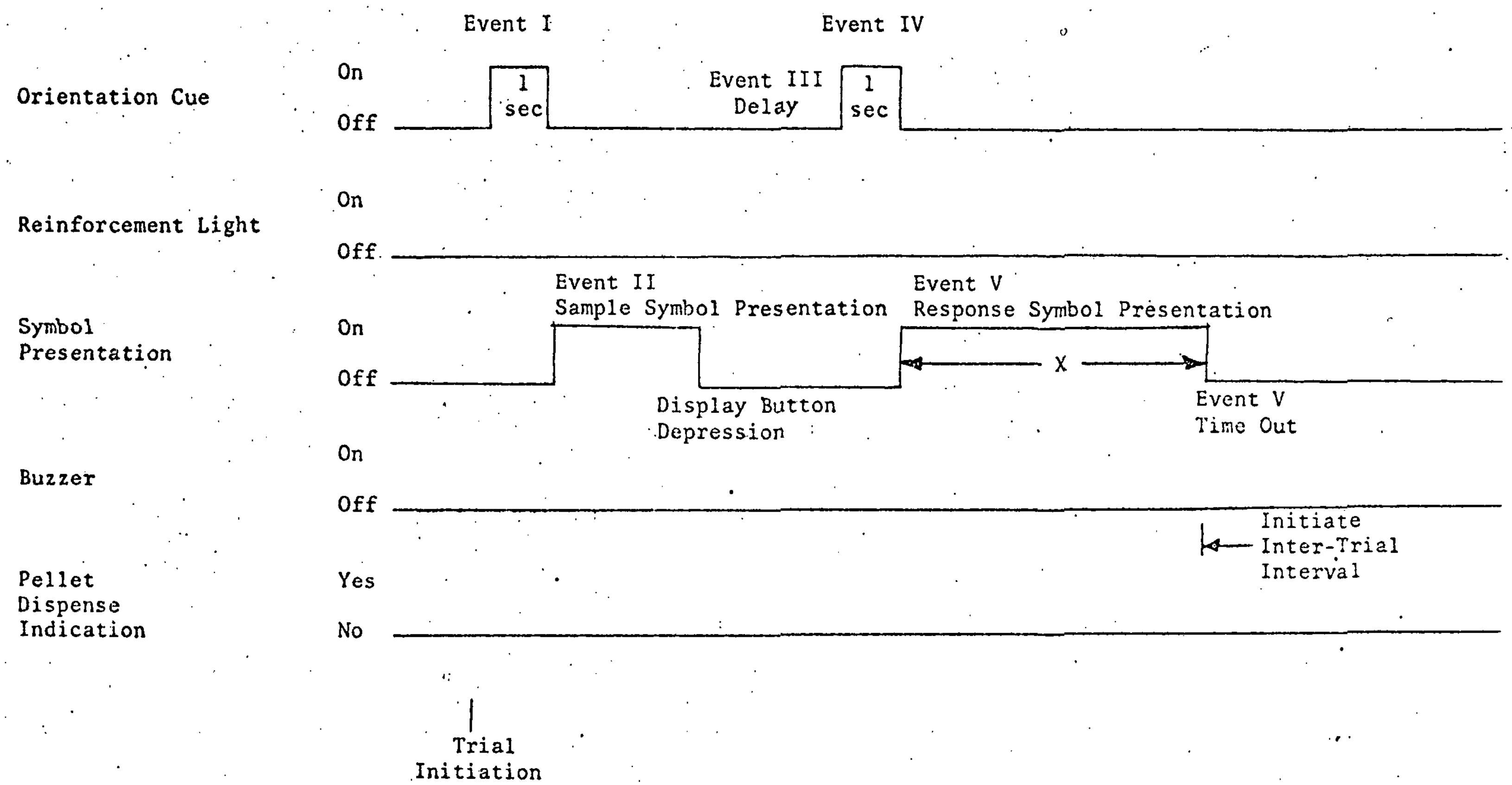


FIGURE 35b

ONE SAMPLE, ONE CHOICE RANDOM
BEHAVIORAL TASK TIME CHART

c) Failure in Event VI
No Reinforcement Button Depression

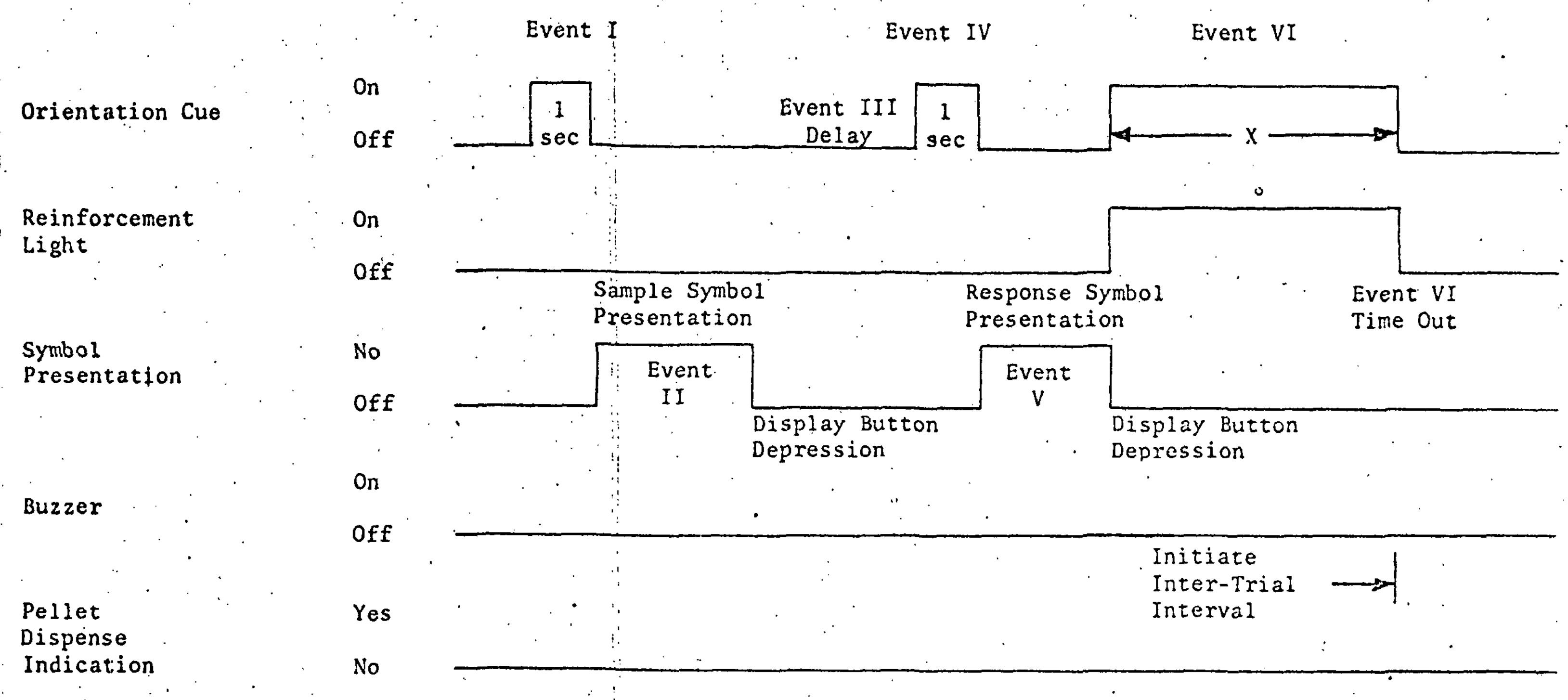


FIGURE 35c

ONE SAMPLE, ONE CHOICE RANDOM
BEHAVIORAL TASK TIME CHART

d) Success

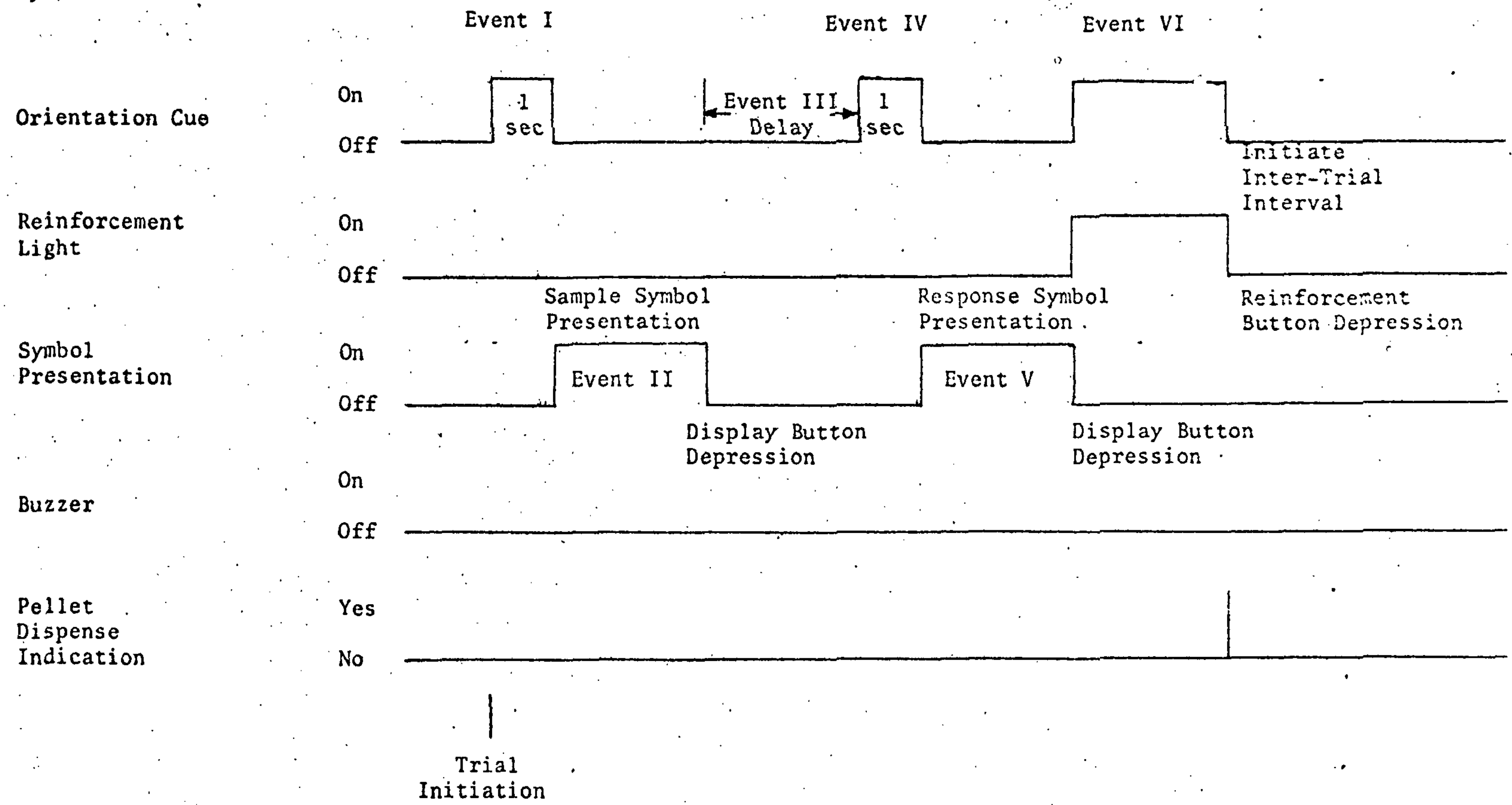


FIGURE 35d
ONE SAMPLE, ONE CHOICE RANDOM
BEHAVIORAL TASK TIME CHART

will test the primate's ability to perform sustained recognition of symbol sequences through memory.

The two sample, two choice random MSS behavioral task is initiated by a one sec in duration orientation cue. At the completion of the orientation cue, one of five possible symbols is selected randomly and presented in a random display window on the behavioral display panel. The primate has a specified response time to depress the symbol's associated display switch. Depression of the switch within the allotted time initiates a delay period referred to as the inter-sample interval. The inter-sample interval will be preselected to 0, 0.5 or 1 sec. Following the inter-sample interval, one of the remaining four symbols is selected randomly and presented in a randomly selected display switch on the behavioral display panel. The primate has a specified response time, X, to depress the illuminated display switch. No switch depression within the time limitation constitutes a failure, whereby the symbol is extinguished and the inter-trial interval is initiated. Successful switch depression of the second sample symbol initiates a preselected delay of 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10 secs. after which a second orientation cue of 1 sec duration is generated. At the completion of this orientation cue, the same two symbols that were previously presented to the primate reappear simultaneously as choice symbols in two of the five display switches chosen randomly. The primate is now given a total time of 2X (no. of symbols times the response time for each particular switch depression) to extinguish the symbols by depressing their associated display switch in the identical sequence as they were originally presented as samples. No switch depression within the time limitation constitutes a failure, extinguishing all symbols and initiating the inter-trial interval. Out of sequence switch depressions constitutes a failure, extinguishing all symbols and causing the one sec buzzer to sound. At the completion of the one sec buzzer, the inter-trial interval begins. Correct sequential response within the time constraints results in a third orientation cue whereby the reinforcement switch lights up simultaneously with a tone. The remainder of the task is identical to the reinforcement button task previously discussed. A flow diagram and time chart are shown in Figs 36 through 37b respectively.

The delayed matching to two samples task is expanded in subsequent behavioral sessions. The trial progression is identical to that just described with the only exception being the number of symbols illuminated during choice time.

a) Success - Three Symbol MSS Task

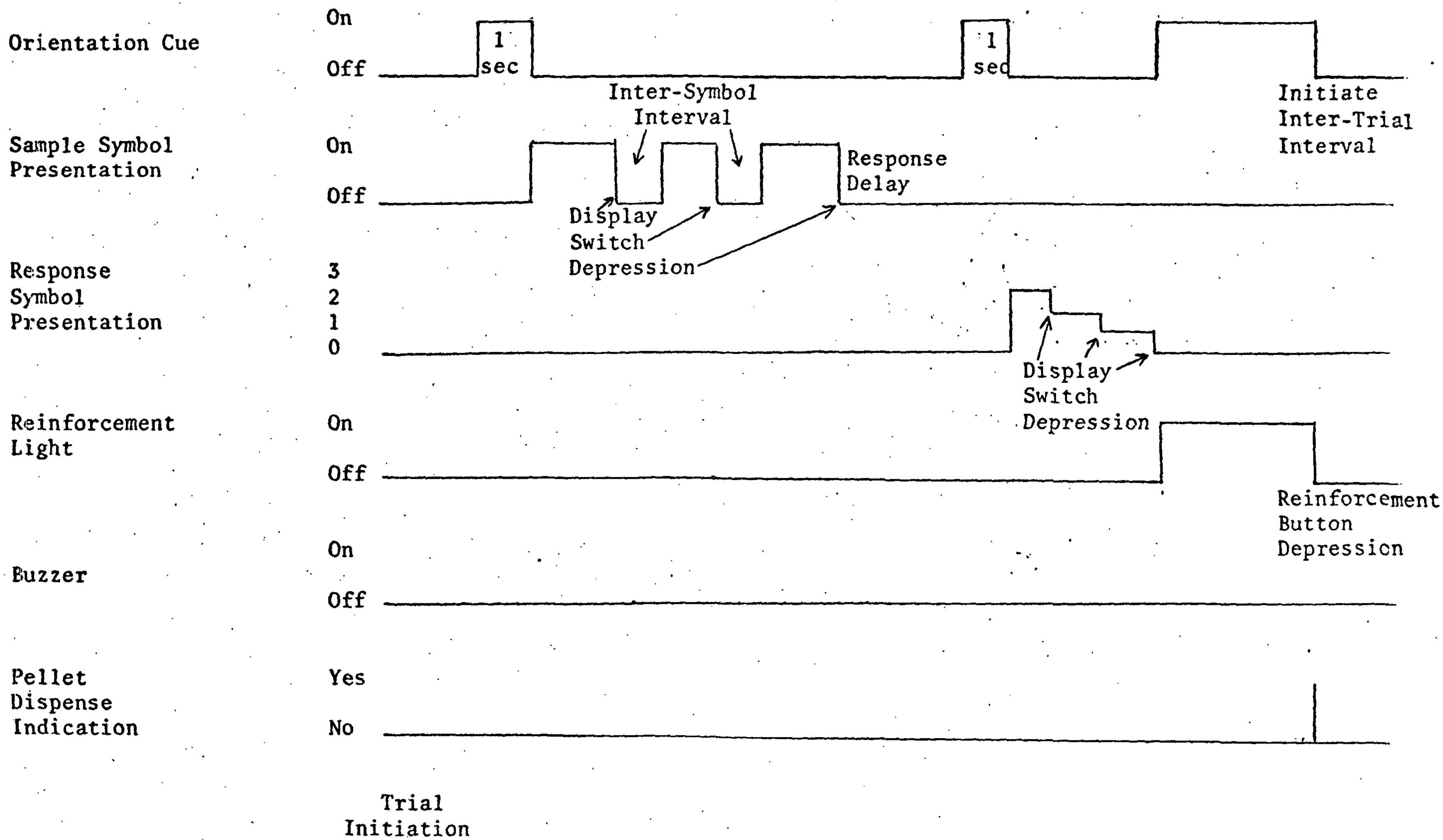


FIGURE 36

THREE SYMBOL MSS TIME CHART

b) Success - Four Symbol MSS Task

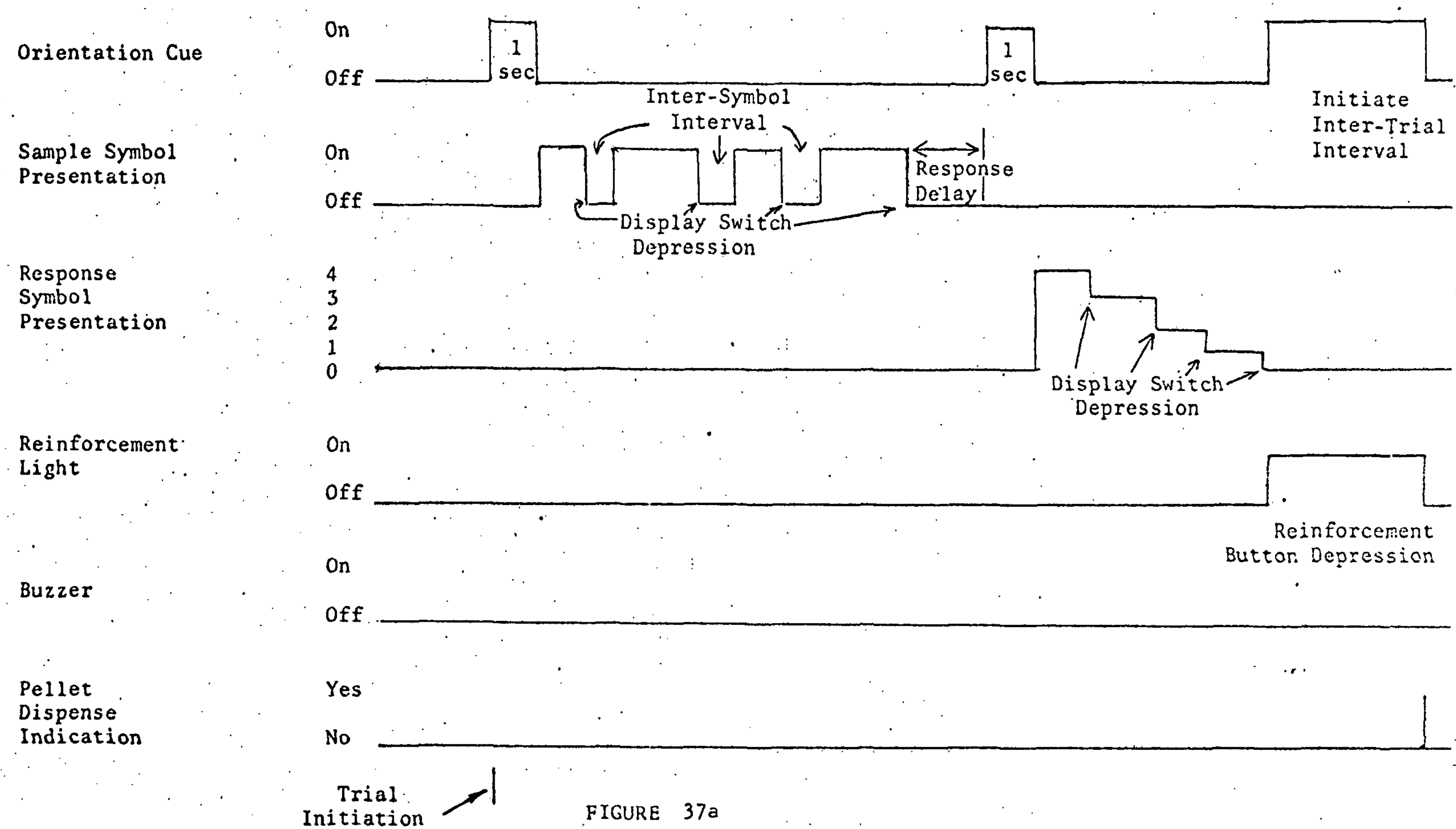


FIGURE 37a

FOUR SYMBOL MSS TIME CHART

c) Success - Five Symbol MSS Task

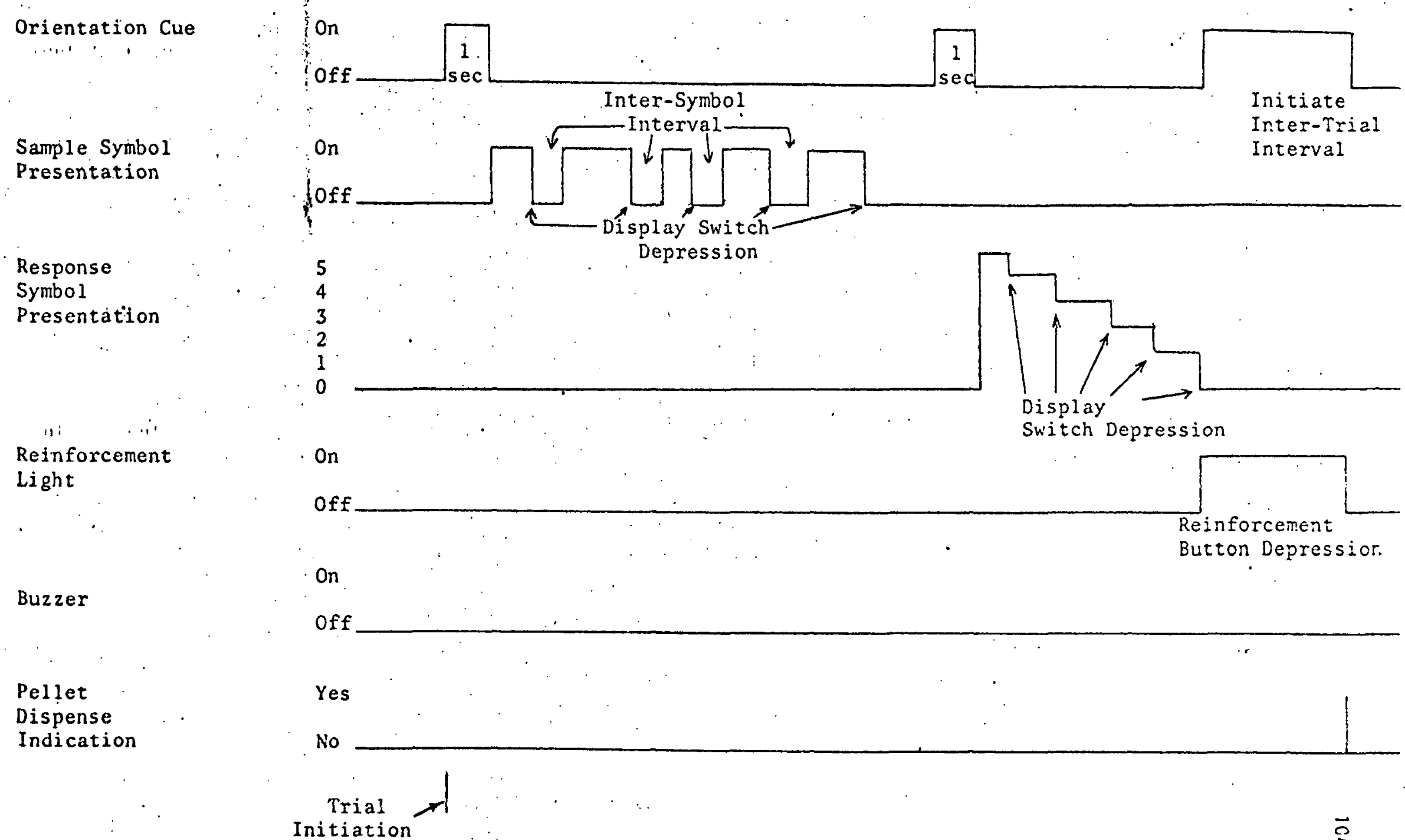
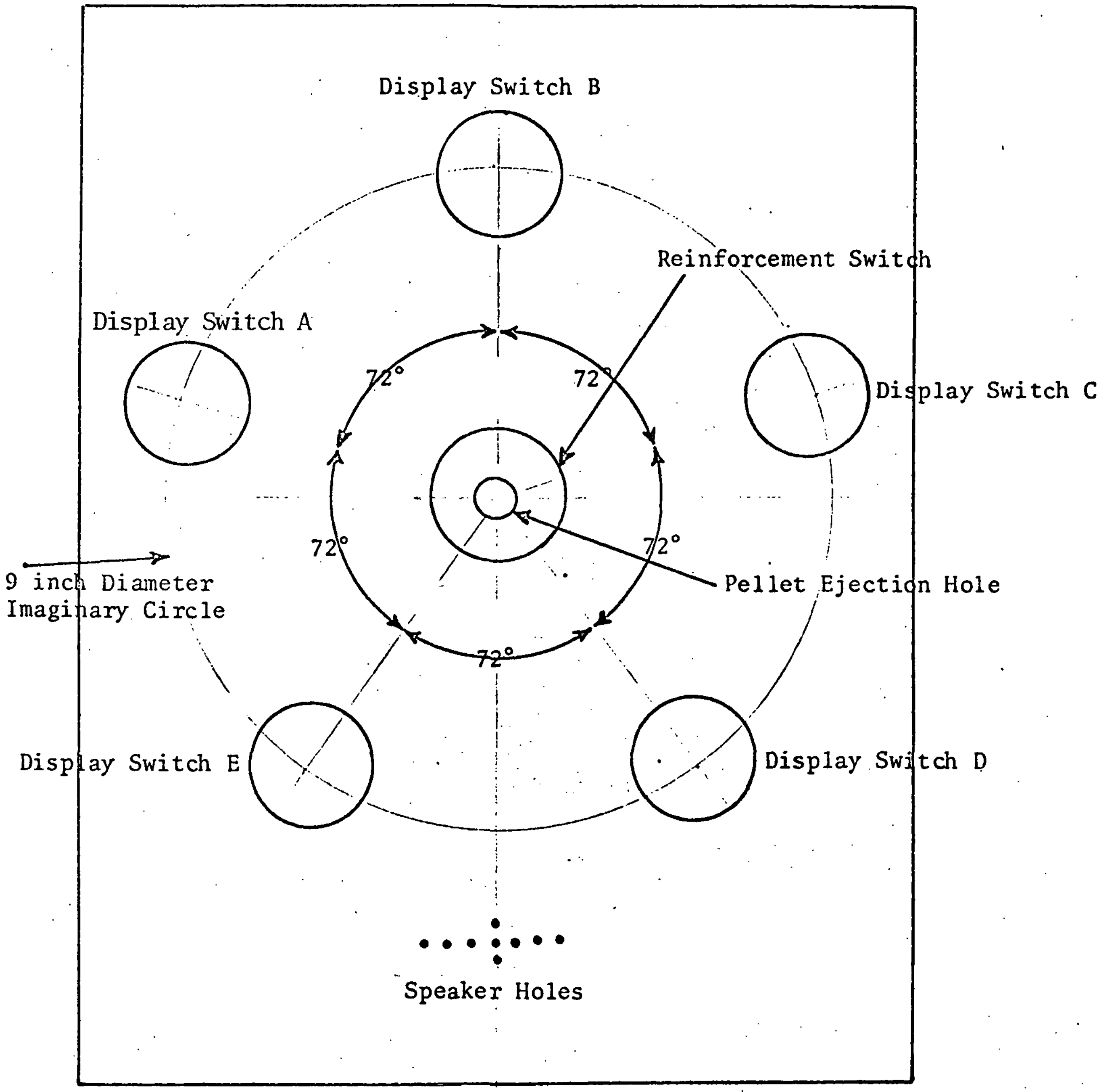


FIGURE 37b

FIVE SYMBOL MSS TIME CHART



Surface Color : Black

On back side of behavioral panel mount 1-45 pin male connector part no. FK-46-32S

FIGURE 38

FLIGHT CONFIGURATION BEHAVIORAL PANEL

C. FLIGHT TRAINING

C.1 PURPOSE

Training to the most difficult flight behavioral tasks ranging from one sample through five sample matching successive sample tasks are presented in this phase of the training program. The training is conducted in sound-retarded light controlled booths to provide minimum interference. The techniques utilized shall be a combined use of operant schedules and multiple attention schemes which emphasize stimulus control to the learning subject and minimize the probability of error.

C.2 BEHAVIORAL PANEL

The flight behavioral panel, (figure 38) is fabricated of black lucite. Smoothly integrated into the surface of the panel and visible to the subject are six proximity switches, speaker holes and a pellet holder. Internal to the panel are five IEEE display projectors positioned directly behind each display switch, light bulbs positioned directly behind the reinforcement switch, associated lamp drivers, an 8 ohm speaker, and a pellet storage and dispensing unit. The switch dimensions and symbol projectors are identical to the secondary behavioral panel.

C.3 BEHAVIORAL ELECTRONICS

Behavioral task contol was accomplished by two independent systems; (1) SDS 930 computer utilizing an interface decode logic unit, (2) a stand alone unit referred to as "SAM" (stand alone matching to Successive Samples Display).

C.3.1 STAND ALONE MSSD DESCRIPTION

The SAM system consists of a self-contained control unit and the presently flight configured behavioral panel.

The control unit contains 4 power supplies ($\pm$10 volts, +5 volts, and + 24 volts), 3 memories, 7 electronic counters, 6 mechanical counters, status indicator lamps and control switches, and measures approximately 25" W x 64" H x 26" D.

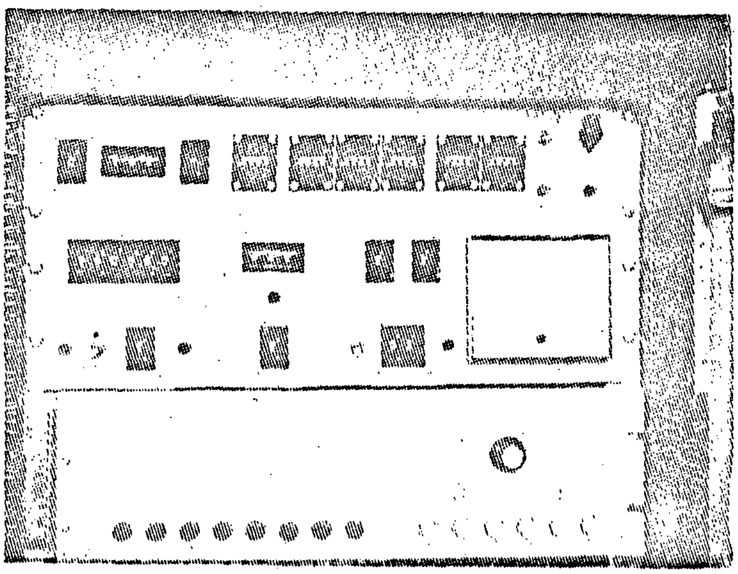


Figure 39

STAND ALONE MSSD

One may consider the SAM control unit as an 8 bit/word digital machine. At the present, only 8 words are required and available. These words are used to determine the time interval for the various phases of the MSSD program.

Two of the three memories are used to store the randomly selected symbols and the randomly selected display units. These memories consist of a 6 x 6 flip-flop matrix.

Five mechanical counters are used to indicate the number of discrete void conditions. The sixth mechanical counter indicates the trial number in progress. The electronic counters are generally used as timing elements.

The red status lamps indicate the trial phase in progress. The white lamps indicate the intensity step level during the automatic intensity controlled mode.

The switches and controls are used to set the initial operating conditions.

<u>Capability Description</u>:

I. Symbol Selection Options

A. Operator to select "n" number of symbols ($1 \leq n \leq 6$).

B. Operator must select which of six available symbols are to be employed. (Refer to Symbol Selection Code.)

C. Mode 1 (Fixed Mode)

1) Random order of symbol presentation during sample time.

2) Selected symbol/symbols displayed on pre-assigned display unit during choice time.

D. Mode 2 (Random Mode)

1) Random order of symbol presentation during sample time.

2) Selected symbol/symbols randomly assigned to any of six display units during choice time.

II. Symbol Illumination

A. Sample time. Symbol to be displayed at maximum intensity.

B. Response time. Correct symbol to be displayed at maximum intensity, all others, at relative dim. For each correct trial, all dimly illuminated symbols will be incremented by n_μ steps ($1 \leq n_\mu \leq 6$) and for each incorrect trial the illumination is decremented by n_d steps ($1 \leq n_d \leq 6$) when in stepping mode of operation. The operator has three initiating options:

1) Level of relative minimum intensity.

2) Starting step between absolute maximum and relative minimum.

3) Manual override switch (non-stepping mode) to hold at any level.

III. Time Intervals

A. All time intervals can be varied from 50 ms. to 12.75 sec. in steps of 50 ms. All time intervals are within ± 100 ms. of selected values.

B. Time Interval Definitions (Refer to Figure 40)

1) T.O.T. = Trial Orientation Tone Time (400 Hz ± 10%). Also referred to as Tone "A" (ta). Initial activation

by Demand signal and subsequent activation occurs at completion of I.T.I. for "n" trials ($1 \leq n \leq 255$). Where "n" is number of trials per session.

T.O.T. = $t_o - t_1$.

2) S.T. = Sample Time (ts). First symbol to be displayed upon completion of Trial Orientation Tone (T.O.T.). Each succeeding symbol is to be displayed upon completion of Inter Sample Interval (I.S.I.). Symbol to be displayed for selected time duration but will be extinguished immediately upon sample switch depression by primate, at which time the system immediately goes to the next phase of the trial.

S.T. = $t_1 - t_2$.

3) I.S.I. = Inter Sample Interval (tl) entered upon successful sample switch depression by primate. Repeated n - 1 times per trial, where n = number of symbols utilized. $1 \leq n \leq 6$.

I.S.I. = $t_2 - t_3$.

4) Delay = Delay Time. Also referred to as pause time (tw). Immediate entry to delay time upon response to the last sample symbol.

Delay = $t_2' - t_4$.

5) C.O.T. = Choice Orientation Tone Time (800 Hz ± 10%). Also referred to as Tone "B" (t_B). Entered upon completion of delay time.

C.O.T. = $t_4 - t_5$.

6) C.T. = Choice Time. Also referred to as response time (tr). The time interval allotted for the primate to complete all switch responses in the correct chronological order. Upon the last switch depression, the system enters the reward phase. If the allotted time elapses before all switch responses are made, the system enters into the Time Out phase.

   $C.T. = t_5 - t_6$.

7) T.O. = Time Out Interval (buzzer time). Also referred to as void time (tv). Refer to Section VI, Parts B and C for void conditions.

   $T.O. = t_n - t_7'$ where t_n can occur anywhere within t_o and t_6.

8) I.T.I. = Inter-Trial Interval (ti).

   $I.T.I. = t_7' - t_8$ for voided trial.

   $I.T.I.^* = t_R - t_8$ for a normal trial.

   * See Figure 41

   Completion of I.T.I. re-initiates subsequent trial until n trials are completed. $1 \leq n \leq 255$.

C. Time Constraint.

1) 5 sec. $\leq$ T.O.T. + I.S.I. + Delay + C.O.T.

IV. Reward Cycle

A. At every sample or choice switch press, a click is heard.

B. Negative reinforcement: Each incorrect trial activates a buzzer during the "Time Out" interval (void time).

C. Reinforcements (See Figure 1A)

1) Secondary reinforcement: $\frac{1}{2}$ second of RED symbols and Tone "C" (1200 Hz ± 10%) for every correct trial.

2) Primary reinforcement: Executed on the nth correct trial ($1 \leq n \leq 12$). $\frac{1}{2}$ second of RED symbols and Tone "C", $\frac{1}{2}$ second of delay, 5 seconds of RED symbols and Tone "C" at which time feeders are enabled. The 5 second interval is terminated when the animal depresses one of the feeder switches at which time the system enters a 2 second delay prior to entry into Inter-Trial Interval.

V. Analog Output (Refer to Figure 42)

A. The unit provides 8 different voltage levels between ± 1.4 v for the following conditions:

1) Trial in progress

2) Trial orientation tone

3) Sample time

4) Sample switch depressed

5) Choice orientation tone

6) Choice time

7) Choice switch depressed

8) 'Time out" interval (void).

VI. Mechanical Counters (Refer to Figure 43)

A. Counter #1 - indicates the nth trial of the session that is in progress.

B. Selection voids.

1) Counter #2 - indicates trial voids due to choice switch being depressed during sample symbol display time.

2) Counter #3 - indicates trial voids due to wrong selection during choice time.

3) Counter #4 - indicates trial voids due to switch depression during T.O.T., I.S.I., Delay or C.O.T. time intervals only.

C. Time voids.

1) Counter #5 - indicates trial voids during sample time due to no response from animal in allotted time interval.

2) Counter #6 - indicates trial voids during choice time due to incomplete responses from animal in the allotted time interval.

VII. Manual Override Switches

A. System start and stop switches are provided.

B. Operator feeder actuate switch is also provided.

VIII. Limitations and Constraints

A. Absolute minimum intensity is obtained when meter reads 5%.

B. Absolute maximum intensity is obtained when meter reads 100%.

C. 5 sec. $\leq$ T.O.T. + I.S.T. + Delay + C.O.T.

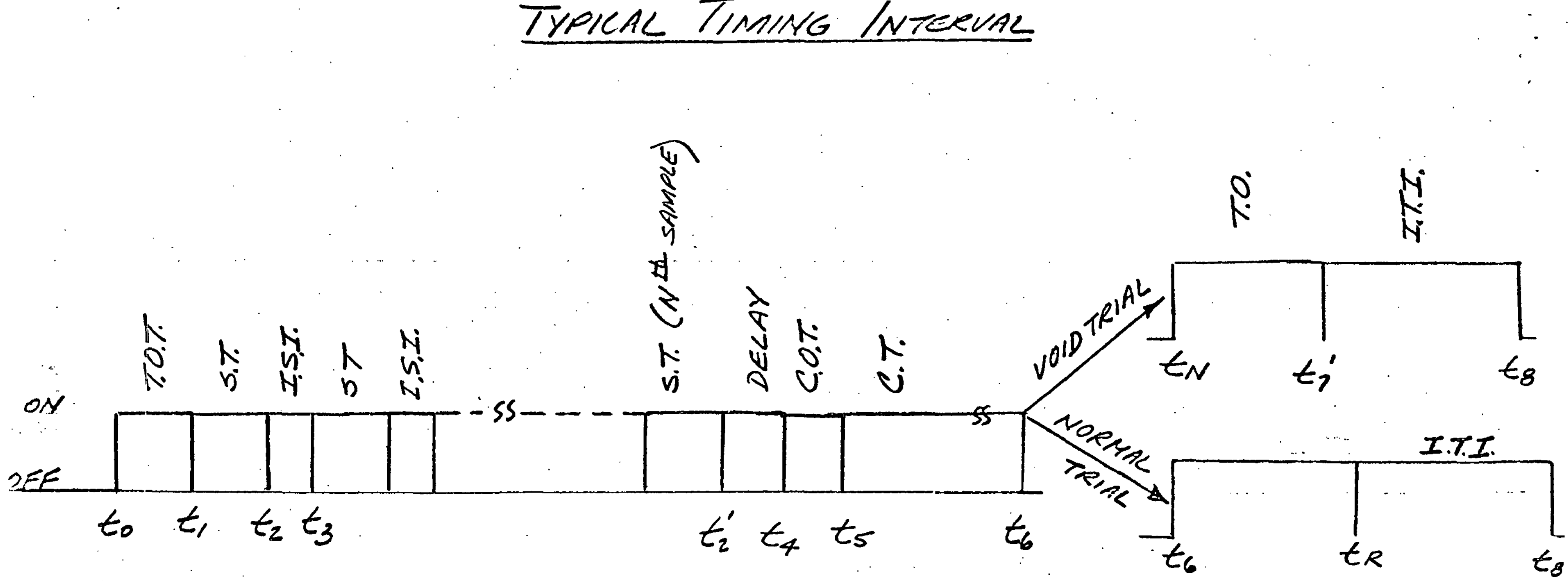
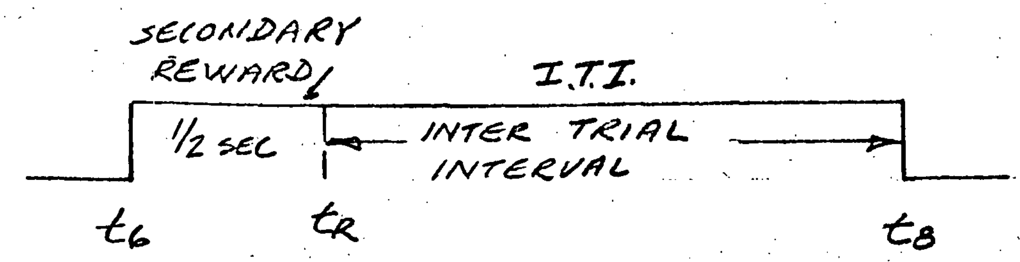
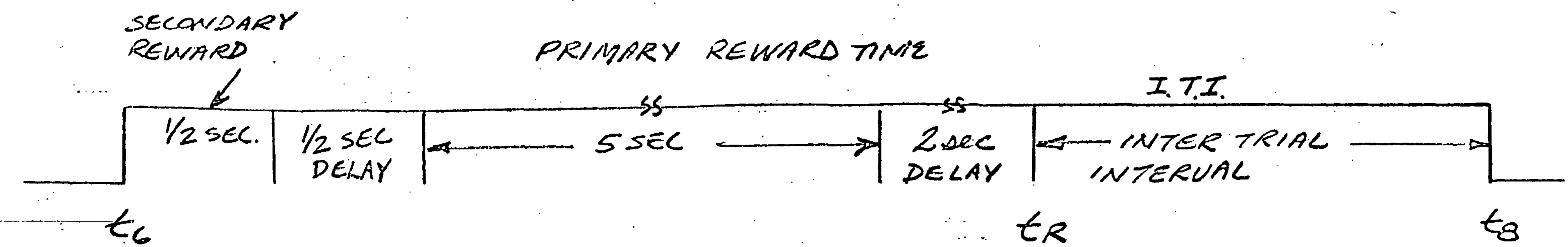

TYPICAL TIMING INTERVAL
T.O.T.
S.T.
I.S.I.
S.T.
I.S.I.
SS
S.T. (Nth SAMPLE)
DELAY
C.O.T.
C.T.
SS
ON
OFF
t_0
t_1
t_2
t_3
t_2'
t_4
t_5
t_6
VOID TRIAL
NORMAL TRIAL
T.O.
I.T.I.
t_N
t_7'
t_8
I.T.I.
t_6
t_R
t_8

Figure 40

NORMAL TRIAL REWARD TIMING



SECONDARY REWARD TIMING CYCLE



PRIMARY REWARD TIMING CYCLE

Figure 41

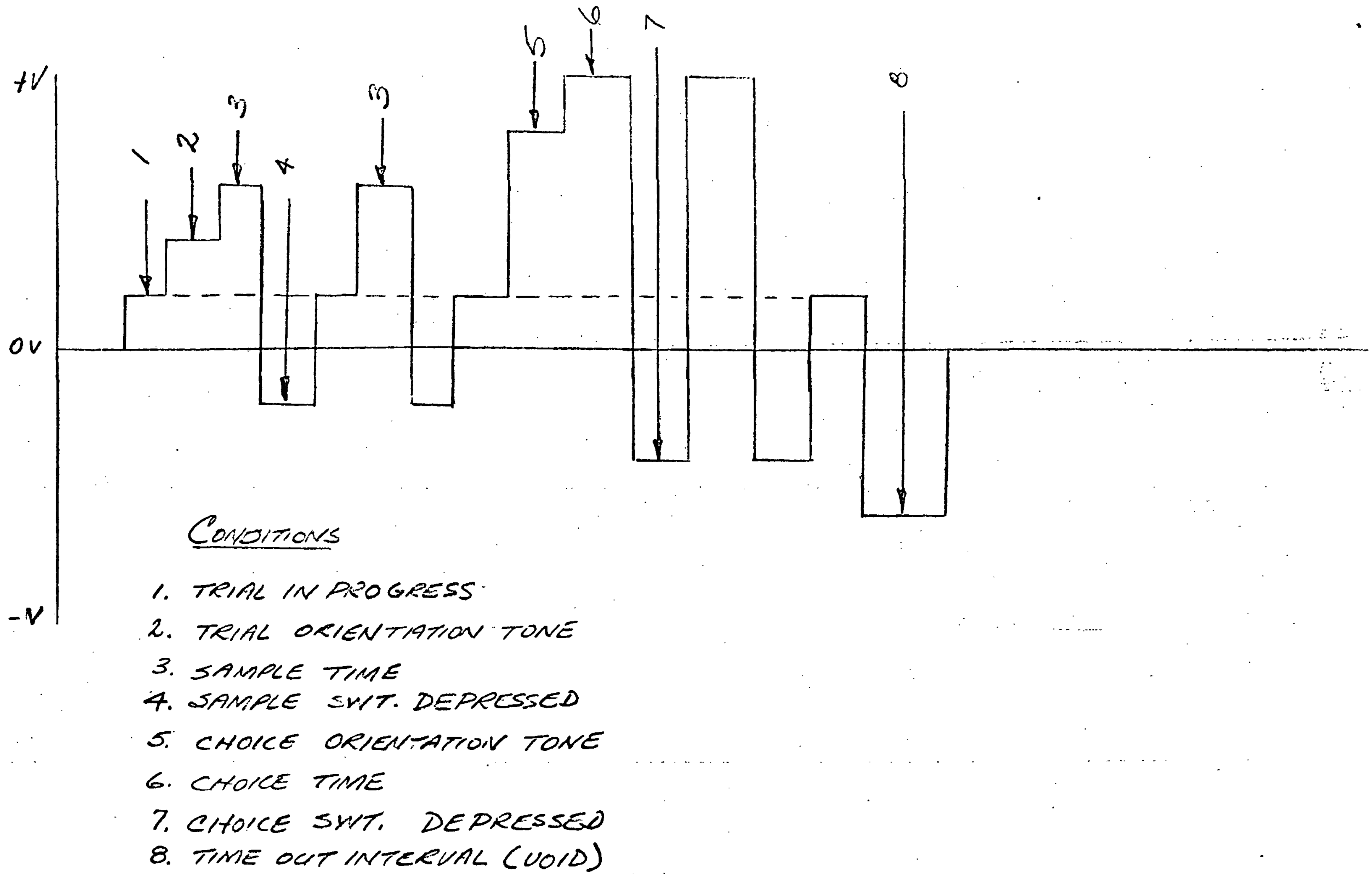

+V
0V
-V
1
2
3
4
3
5
6
7
8
CONDITIONS
1. TRIAL IN PROGRESS
2. TRIAL ORIENTIATION TONE
3. SAMPLE TIME
4. SAMPLE SWT. DEPRESSED
5. CHOICE ORIENTATION TONE
6. CHOICE TIME
7. CHOICE SWT. DEPRESSED
8. TIME OUT INTERVAL (VOID)

Figure 42

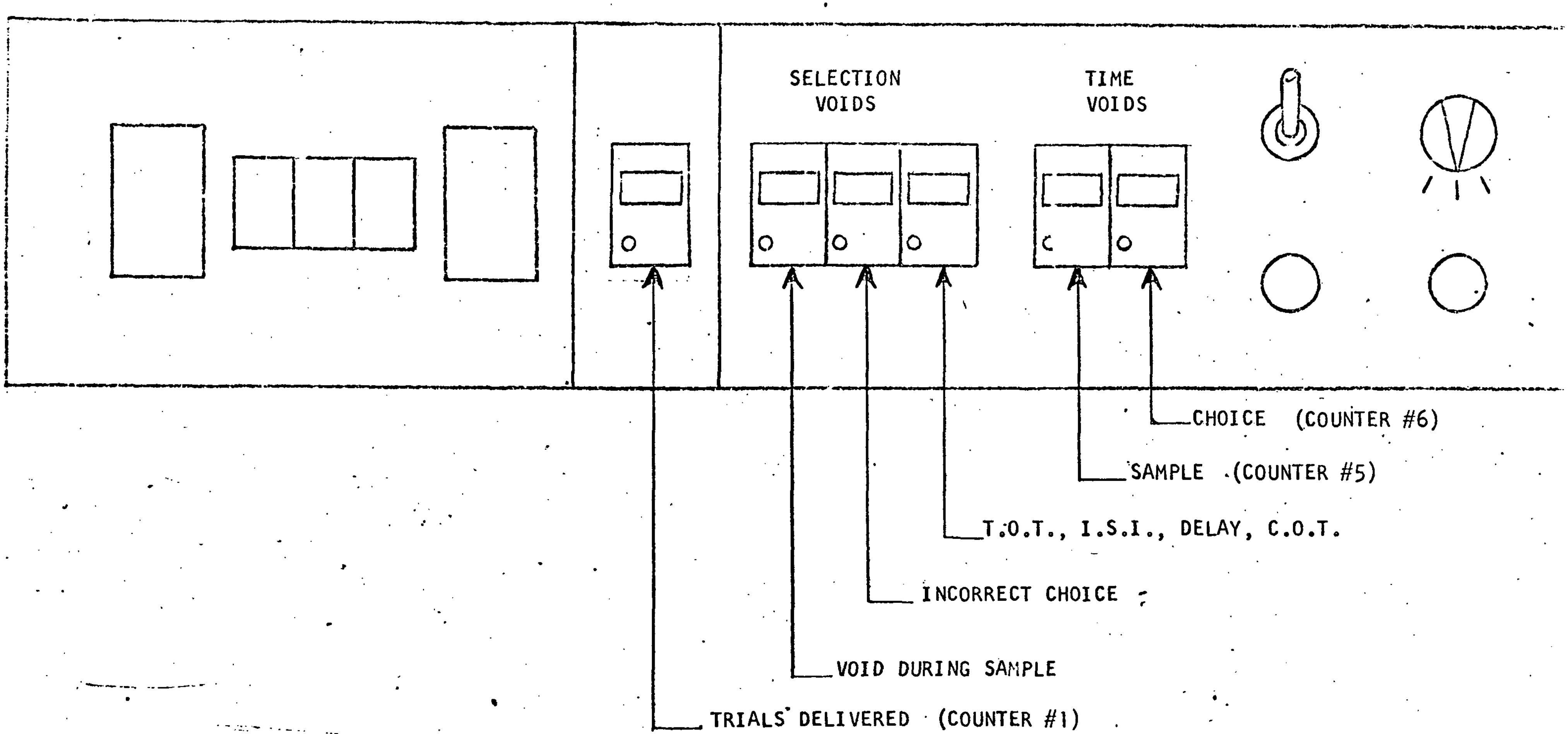

SELECTION
VOIDS
TIME
VOIDS
CHOICE (COUNTER #6)
SAMPLE (COUNTER #5)
T.O.T., I.S.I., DELAY, C.O.T.
INCORRECT CHOICE
VOID DURING SAMPLE
TRIALS DELIVERED (COUNTER #1)

Figure 43

C.4 FLIGHT TRAINING PROGRAMS

The subject advances to the flight training program after criterion performance is displayed for all symbol pairs of the two symbol matching to successive sample tasks. Flight training includes two symbol through five symbol matching to successive sample.

C.4.1 MULTIPLE SYMBOL MSS TASK

The three symbol through five symbol MSS tasks will not be presented in detail since they are just a logical extension of the two symbol MSS task, the only difference being the presentation of addition samples prior to choice time. For the sake of completeness, a timing diagram of a successful completion of each task is presented in Figures 44, 45 and 46.

C.5 FLIGHT TRAINING PROTOCOL

The paradigms for the flight training program will follow the same logical progression as the secondary training paradigms; however, lower criterion performance requirements, as shown below, will be used. Criteria for advancement from two through five symbol MSS without sample redisplay are as follows:

two to three MSS	40/50
three to four MSS	37/50
four to five MSS	35/50

Any candidate who can sustain three daily sessions of five MSS at 65% or better shall begin the delay phase of training. This entails gradually increasing the time delay between extinction of a)

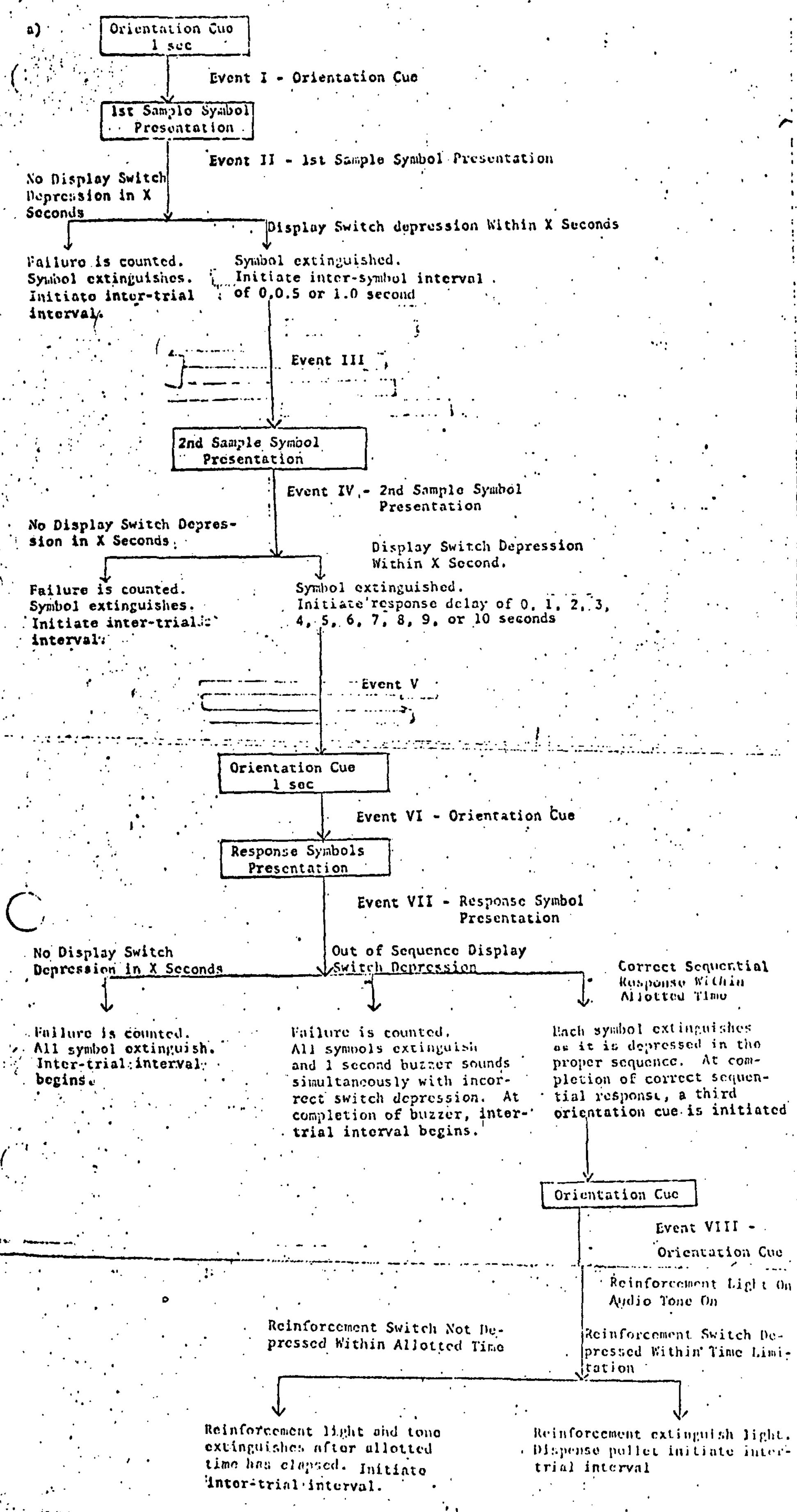


FIGURE 44

TWO SAMPLE, TWO CHOICE RANDOM, MSS
BEHAVIORAL TASK FLOW CHART

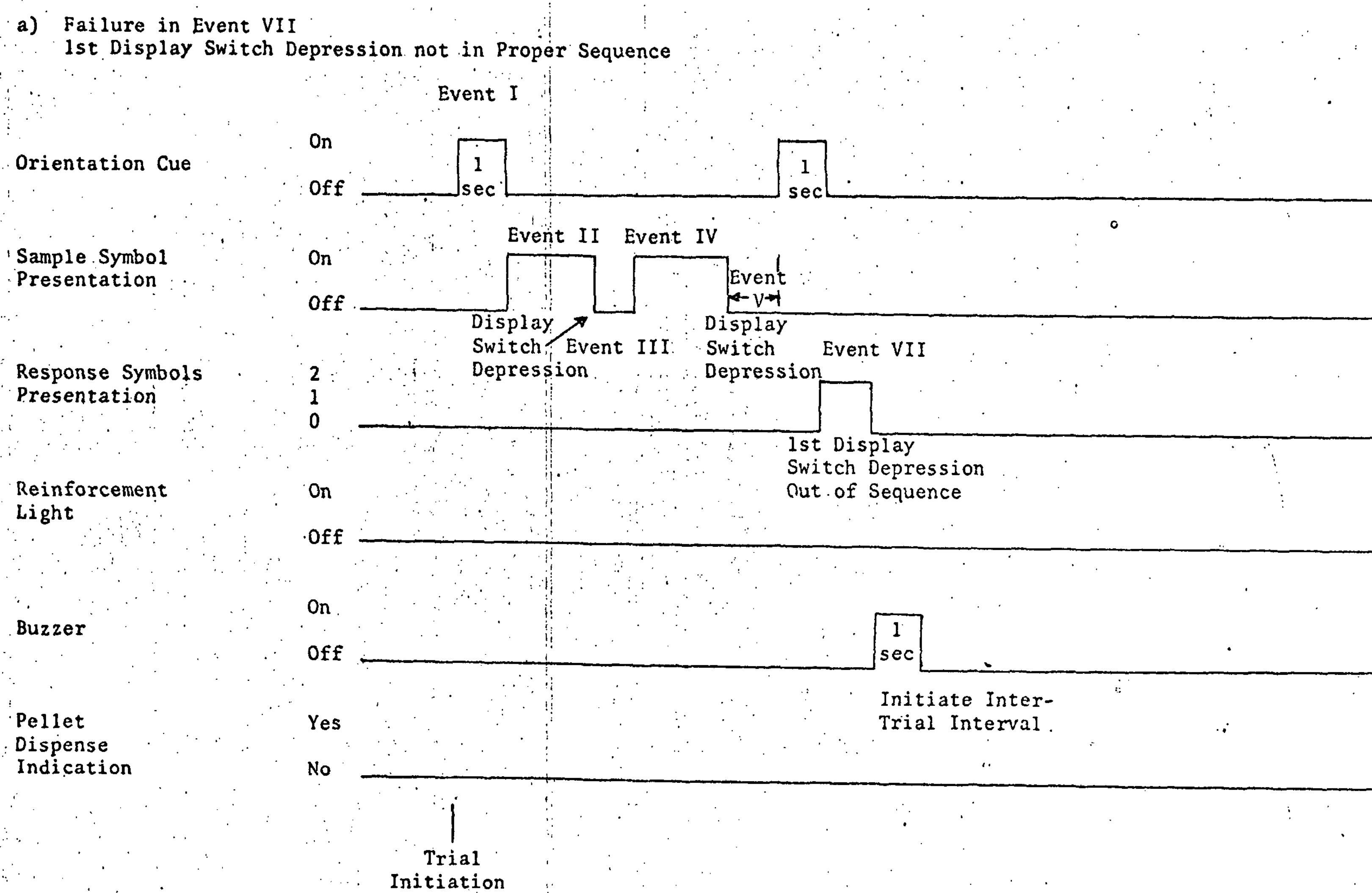


FIGURE 45

TWO SAMPLE, TWO CHOICE RANDOM, MSS BEHAVIORAL TASK FLOW-CHART

b) Success

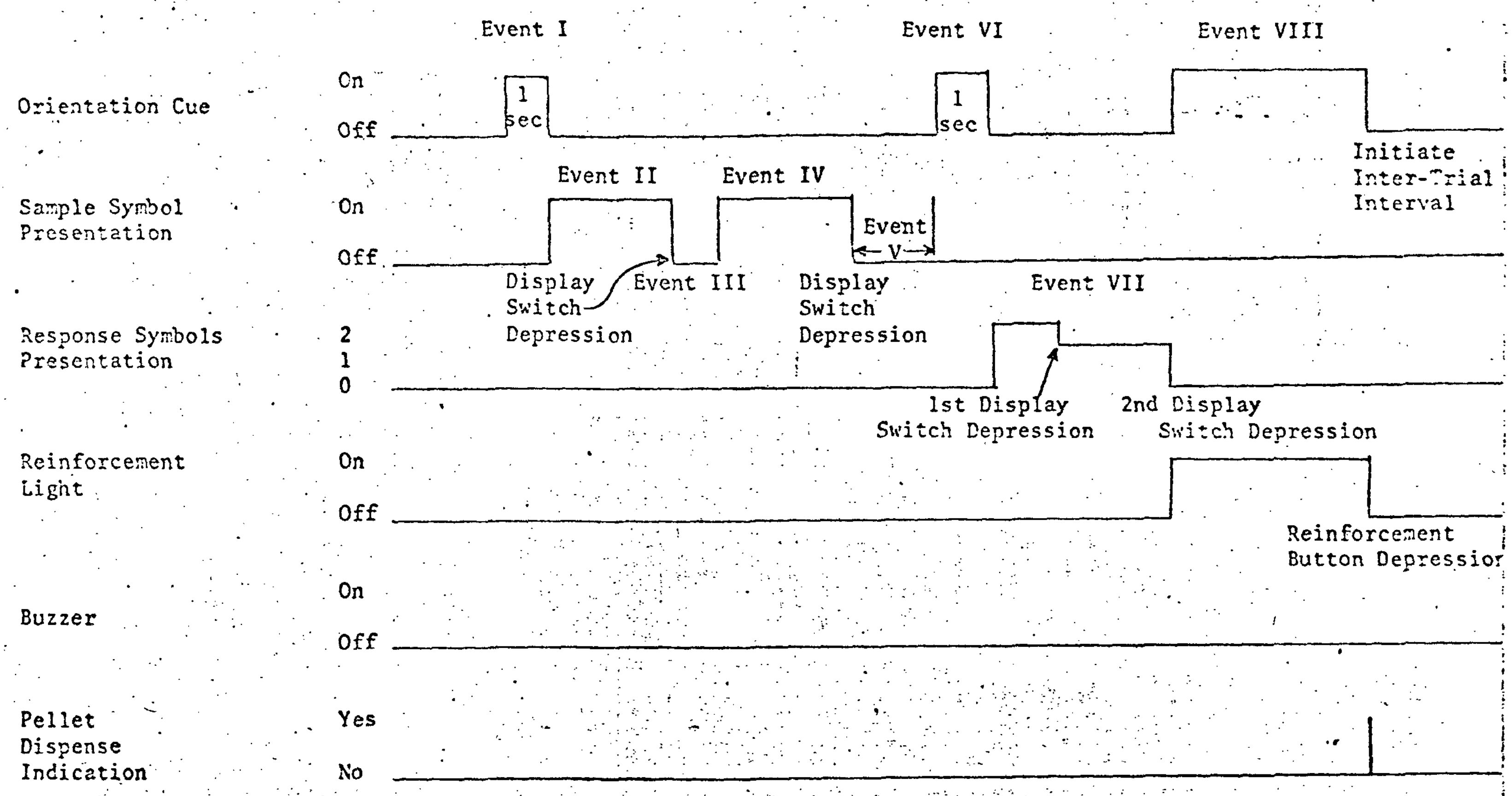


FIGURE 46
TWO SAMPLE, TWO CHOICE RANDOM, MSS
BEHAVIORAL TASK FLOW CHART

the fifth sample and the onset of the five symbol choice display. These delay increments shall be instituted in 250 msec steps so as not to strain high performance levels.

At any time the experimenter feels that certain additional reinforcement schedules should help the candidate differentiate the order of his responses to the samples, these schedules can be swiftly programmed into the training sessions.

D. ENVIRONMENTAL TRAINING

1. PURPOSE

To determine the feasibility of primate control of life cell lighting intensity, life cell temperature and auditory reinforcement.

2. BEHAVIORAL PANEL

The behavioral panel was made up of 18 proximity switches smoothly integrated into one wall of the isolation training cage. The description and function of each switch is tabulated in Figure 47.

D.4 ENVIRONMENTAL CONTROL TRAINING PROTOCOL

1.0 Houselight Control Training

1.1 Animal will have previous primary training experience and will have undergone adaptation to behavioral booth.

1.2 Set environmental parameters.

1.3 Arm dark blue (decrement) and yellow (increment) proximity switches and set decrement and increment steps at maximum.

1.4 Set light control switch schedules at CRF.

1.5 Set houselight at minimum.

1.6 Allow subject free operant control of light changes in both directions for maximum of 2 hours; then reset houselight level to minimum and reset increment, decrement step to 1/2 maximum size.

1.7 Reset houselight level to minimum and reset increment, decrement step setting to 1/2 maximum size, and allow S free operant control of light changes in both directions for maximum of 1 hour.

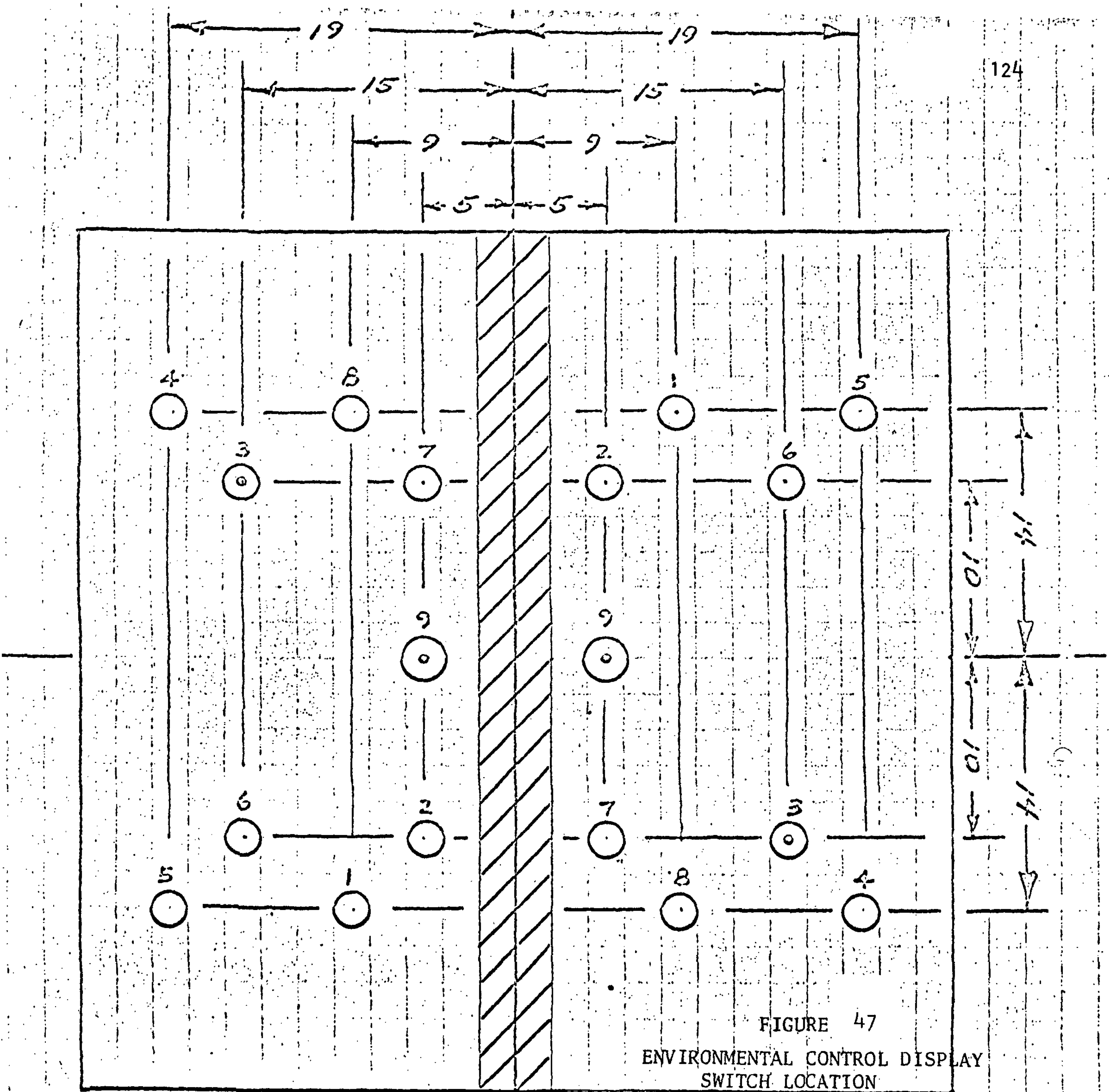


FIGURE 47
ENVIRONMENTAL CONTROL DISPLAY
SWITCH LOCATION

Dimensions in inches

Switch Designation	Function	Color	Diameter	Shinkolite A Color Number
1	Decrease lighting intensity	Dark Blue	2.00 inches	302*
2	Increase lighting intensity	Yellow	2.00 inches	993*
3	Water dispenser	White	2.25 inches	432
4	Auditory enrichment	Purple	2.00 inches	375
5	Decrease temperature	Light Blue	2.00 inches	300*
6	Increase temperature	Orange	2.00 inches	264
7	Behavioral session initiate	Green	2.00 inches	343*
8	Not connected	Black	2.00 inches	502
9	Food reinforcement**	Red	2.25 inches	136

* Colors are transparent and require the addition of a white translucent background
** To be non-operative during system test

1.8 Reset houselight level to minimum and rest increment, decrement step setting to 1/4 step setting; allow free operant control of light changes in both directions for 1/2 hour.

1.9 Reset houselight level to minimum and reset increment, decrement setting to 1/3 maximum step setting and allow free operant control of light changes for 1/2 hour. Record all intensity changes.

1.10 Reset houselight level to minimum and reset increment, decrement setting to 1/16 maximum step setting and allow free operant control of light changes for 1/2 hour. Record all intensity changes.

1.11 Reset houselight level to minimum and reset increment, decrement setting to 1/16 maximum step setting and set light control switch settings at FR4. Allow free operant control of light changes for 48 hours. Record all intensity changes. S will perform on MSS tasks and obtain food and H_2O during this period.

1.12 Repeat 1.2 to 1.11 with houselight setting initially at maximum rather than minimum.

1.13 In the event that the subject has indicated a near zero operant level, or has responded earlier but ceased responding for the greater portion of his booth isolation, the protocol utilizing a CRF feeder schedule in chained association with concurrent light control schedules should be put into effect.

2.0 Ambient Temperature Control Training

2.1 Animal will have previous primary training experience and will have undergone adaptation to behavioral booth.

2.2 Set environmental parameters.

2.3 Arm light blue (decrement) and orange (increment) proximity switches and set decrement and increment steps at maximum ($10^{\circ}F$).

2.4 Set temperature control switch schedules at CRF.

2.5 Set ambient temperature at minimum.

2.6 Allow subject free operant control of temperature changes in both directions for maximum of 2 hours; then reset ambient temperature level to minimum and reset increment, decrement step to 1/2 maximum size.

2.7 Reset ambient temperature level to minimum and reset increment, decrement step setting to 1/2 maximum size, and allow S free operant control of temperature changes in both directions for maximum of 1 hour.

2.8 Reset ambient temperature level to minimum and reset increment, decrement step setting to 1/4 step setting; allow free operant control of temperature changes in both directions for 1/2 hour.

2.9 Reset ambient temperature level to minimum and reset increment, decrement setting to 1/3 maximum step setting and allow free operant control of temperature changes for 1/2 hour. Record all intensity changes.

2.10 Reset ambient temperature level to minimum and reset increment, decrement setting to 1/16 maximum step setting and allow free operant control of temperature changes for 1/2 hour. Record all intensity changes.

2.11 Reset ambient temperature level to minimum and reset increment, decrement setting to 1/16 maximum step setting and set temperature control switch settings at FR4. Allow free operant control of temperature changes for 48 hours. Record all intensity changes. S will perform on MSS tasks and obtain food and H_2O during this period.

2.12 Repeat 2.2 and 2.11 with ambient temperature setting initially at maximum rather than minimum.

2.13 In the event that the subject has indicated a near zero operant level, or has responded earlier but ceased responding for the greater portion of his booth isolation, the protocol utilizing a CRF feeder schedule in chained association with concurrent temperature control schedules should be put into effect.

3.0 Auditory Reinforcement Training

3.1 S will have undergone subsequent adaptation to behavioral booth adaptation and training on primary, MSS, light control, and temperature control tasks.

3.2 The purple reinforcement switch will be armed so that a button press will be followed by 5 sec of sound recording of vivarium sounds (a mixture of chimpanzee and animal trainer vocalizations along with cage noise contingent on chimpanzee activity).

3.3 The auditory reinforcement switch will remain armed during the auditory reinforcement epoch. Each button press (CRF) will reset the 5 sec timer, allowing 5 sec of auditory reinforcement to follow.

3.4 Following stable baseline and evaluation of motivational performance characteristics, FR and DRH contingencies along with evaluation of various quality of auditory reinforcement parameters will be explored.

D.5 ALTERNATE ENVIRONMENTAL CONTROL PROTOCOL

1.0 Houselight Control

1.1 Food deprive <u>S's</u> for two days prior to commencement of booth training. During initial button pressing and simple operant schedule phases of this training, up to 20% of the subject's daily k/cal requirement shall be earned through performance on other tasks (e.g., MSS or primary trainer tasks). Following criterion phases of self control of environmental tasks, a selective decrease in the amount of deprivation will proceed to a point where no food is earned by performance on environmental control tasks.

1.2 Set environmental parameters and feeder schedule.

1.3 Arm dark blue (decrement) and yellow (increment) proximity switches and set decrement and increment steps at maximum.

1.4 Set light control proximity switch schedules at CRF.

1.5 Set houselight level at minimum.

1.6 Set feeder schedule at CRF and arm reinforcement switch for 2 immediate reinforcements.

1.7 Allow subject to perform light/feeder task chain CRF/CRF. A response to either light-control switches arms the feeder switch (red light on). A response to the red feeder switch dispenses a pellet.

1.8 Once the subject has traversed the house light range 4 times or has elected to alternate between light levels to arm the feeder, the increment/decrement steps should be reduced to 1/2 maximum step setting. This schedule requires that any combination of two responses on one or both light switches arms the feeder light. One press to the feeder switch dispenses a pellet.

1.9 Twenty reinforcements from this schedule advances the subject to 1/4 maximum step setting on the light schedule and alters the schedule to chained FR4/CRF.

1.10 Complex schedules: The next schedule following 20 reinforcements from the schedule (1.9) is a concurrent schedule on the light control switches chained to a CRF schedule on the reinforcement switch (FR4/FR10 ch CRF). Four presses to a light control switch will increment/decrement accordingly the light intensity one step. A total of ten presses on one or both switches arm the reinforcement switch. Increment/decrement step setting for this schedule is at 1/8 maximum step setting.

1.11 Following 20 reinforcements on schedule (1.10), advance subject to a concurrent FR4/V110 sec ch CRF schedule, step setting at 1/16 maximum.

1.12 Following 20 reinforcements on schedule (1.11), advance subject to a concurrent FR4/V130 sec ch CRF schedule, step setting at 1/16 maximum.

1.13 Following 20 reinforcements on schedule (1.12), advance subject to a concurrent FR4/VI 1 min ch CRF schedule, step setting at 1/16 maximum.

1.14 Houselight readjustment following stable baseline.

1.15 If within schedule (1.13) the subject has maintained a light level within 30% of the full light range, the E will manually reduce the light level to minimum and change schedule to concurrent FR4/VI 2 min ch CRF schedule and allow S to readjust to its desired baseline level for at least 10 reinforcements.

1.16 After two such operations (1.15), the E will manually switch the house light level to maximum on the same feeder schedule and again allow the subject to return to baseline.

1.17 Feeder schedule phase out.

1.18 After S has completed a satisfactory baseline of 10% of light range on the foregoing schedules, he will be advanced to a concurrent FR4/VI 5 min ch to CRF.

1.19 If light baseline is still nominal for 20 min, the concurrent feeder schedule and feeder switch should be inhibited, giving an FR4 schedule for light increment and decrement.

1.20 This (1.19) program should prevail for repeat operations of 1.15 without feeder arming schedule.

2.0 Temperature Control Schedules

2.1 Concurrent schedules and temperature control switches chained to CRF schedule on feeder switch.

2.2 Concurrent FR4 (temperature increment/decrement)/VI 1 min (reinforcement switch arming); increment/decrement step setting at 10^{o}F; temperature initially at minimum; after 10 reinforcements advance to 2.3.

2.3 Concurrent FR4/VI 1 min; step setting 6^{o}F, temperature initially at minimum; after 10 reinforcements, advance to 2.4.

2.4 Concurrent FR4/VI 1 min; step setting 4^{o}F, temperature initially at minimum; after 10 reinforcements, advance to 2.5.

2.5 Concurrent FR4/VI 1 min; step setting 2^{o}F, temperature initially at minimum; after 10 reinforcements, advance to 2.6.

2.6 Concurrent FR4/VI 2 min; step setting at 1^{o}F. After 4 reinforcements, advance to 2.7.

2.7 The S should precede from this point to section 1.4 of houselight control procedure with the replacement of light changes by temperature changes. This should follow to the end of section 1.20.

III. SYSTEM TESTS

Primate inserted system tests were envisioned to be conducted throughout the POCO program. System Test No. 1 was conducted in September-November, 1969, and has been well documented in previous progress reports (POCO-PMH-70-014, Progress Report, September 1969 to March 1970). Preparations for a second primate inserted system test were completed; however, notification of program cancellation resulted in the cancellation of the system test in order to perform higher priority close out functions.

The specifications and facilities developed for the subject system test are presented in this section of the report.

A. TEST DESCRIPTION

The primary purpose of the test is to determine primate adaptability to the proposed experimental conditions while demonstrating the feasibility of each available flight configured support subsystem. For this purpose, one complete trimester of the flight will be simulated, adhering as closely as possible to the experiment definition and mission sequence specified in the interface document.

B. TEST LOCATION

The test will be conducted in the isolation chamber located in the basement of Slichter Hall. Total primate isolation throughout the system test is planned.

C. TEST DURATION

The duration of the test is scheduled to be no less than 30 days. If conditions exist to allow test continuation, the test will be extended on a day by day basis contingent upon approval by the Project Scientist, Project Engineer and Research Manager.

D. PRIMATE INTERFACE

D.1 TEST SUBJECT

The chimpanzee named Charlie has been designated as the test subject (head electrode implantation and headcap structure are complete). This chimpanzee was also the subject of the system test conducted in October of 1969.

D.2 FOOD

There will be a singular diet formulation supplied in the form of dry pellets to the primate. At the successful completion of a behavioral task, one pellet will be dispensed to the primate. The diet to be utilized in this test will be Purina Monkey Chow: the ingredients of which are presented below:

<u>Ingredients</u>

Ground wheat

Dehydrated alfalfa meal preserved with ethoxyquin

Ground yellow corn

Dried skimmed milk

Soybean meal

Sucrose

Animal fat preserved with BHA

Fish meal

Brewers' dried yeast

Vitamin B_{12} supplement

Riboflavin supplement

Methionine hydroxy analogue calcium

Calcium pantothenate

Niacin

Folic acid

Pyridoxine hydrochloride

Thiamin

Ascorbic acid

Vitamin A supplement

D activated animal sterol (source of Vitamin D)

Steamed bone meal

Vitamin E supplement

Calcium carbonate

Dicalcium phosphate

Iodized salt

Iron oxide

Manganous oxide

Copper oxide

Cobalt carbonate

Zinc oxide

<u>Guaranteed Analysis</u>

Crude protein not less than.	15.0%
Crude fat not less than	5.0%
Crude fiber not more than	3.0%
Added minerals not more than	3.0%

The pellets shall conform to the following specifications:

Weight: 1.3 grams

Caloric Content: 5.4 Kcals/pellet

Dimensions: 0.62 inch, spherical diameter

The feeder capacity shall be no less than 12,000 pellets.

D.3 WATER

The only liquid to be available for primate consumption during the test shall be water. Water will be presented on an ad lib basis requiring primate switch depression and suction for delivery. Water may be obtained by the primate only for the duration of the water switch depression.

The quantity of water consumed by the primate will be monitored hourly to within ± 5 ml. In addition, the water activation event signal will be recorded continuously.

The temperature of the water delivered to the primate shall be between $55^{o}F$ and $80^{o}F$. The suction required for operation of the water dispenser shall be between 22 and 40 torrs. The water flow rate over the range of required suctions will be no less than 0.2 ml/sec and no greater than 0.7 ml/sec.

D.4 ATMOSPHERE

The test will be conducted in a controlled, open, non-recirculated atmosphere. The environmental control limits shall be as follows:

1. Relative Humidity: 35 - 70 percent
2. Temperature in Life Cell: $76^{o}F\ {}^{+5^{o}}_{-1}F$
   $76^{o}F\ \pm 5^{o}F$ when primate controlled
3. Gas Flow Rate into Life Cell: 160 ft^3/min

D.5 BEHAVIORAL TASKS

A variety of behavioral tasks will be presented to the primate of varying degree of difficulty. Behavioral Task sessions on 100 trials each will be monitored and scored in banks of 25 trials to determine the particular task to be presented to the primate in the subsequent 25 trial bank. For detail task description, please refer to the interface document.

TABLE 9 - Behavioral Task Nomenclature*

Nomenclature	Description
R1	Reinforcement Button Task: Event I Duration = 60 secs
R2	Reinforcement Button Task: Event I Duration = 50 secs
R3	Reinforcement Button Task: Event I Duration = 40 secs
R4	Reinforcement Button Task: Event I Duration = 30 secs
R5	Reinforcement Button Task: Event I Duration = 20 secs
R6	Reinforcement Button Task: Event I Duration = 10 secs
OS1	One Symbol Random Task: Event III Duration = 1 sec
OS2	One Symbol Random Task: Event III Duration = 2 secs
OS3	One Symbol Random Task: Event III Duration = 5 secs

*MSS behavioral tasks may have one through five choice symbols; nomenclature in Table I refers to number of sample symbols in task.

TABLE 9 (cont)

Nomenclature	Description
TWS1	Two symbol Random, Matching to Successive Sample Task: Intersymbol Interval = 1/4 sec; Delay Between Sample Presentation "OFF" and Response Orientation Cue = 50 msecs
TWS2	Intersymbol Interval = 0.5 sec; Delay = 0.5 sec
TWS3	Intersymbol Interval = 1.0 sec; Delay = 1.0 sec
TWS4	Intersymbol Interval = 1.0 sec; Delay = 2.0 secs
TWS5	Intersymbol Interval = 1.0 sec; Delay = 3.0 secs
TWS6	Intersymbol Interval = 1.0 sec; Delay = 4.0 secs
TWS7	Intersymbol Interval = 1.0 sec; Delay = 5.0 secs
TWS8	Intersymbol Interval = 1.0 sec; Delay = 6.0 secs
TWS9	Intersymbol Interval = 1.0 sec; Delay = 7.0 secs
TWS10	Intersymbol Interval = 1.0 sec; Delay = 8.0 secs
TWS11	Intersymbol Interval = 1.0 sec; Delay = 9.0 secs
TWS12	Intersymbol Interval = 1.0 sec; Delay = 10.0 secs
THS1	Three Symbol Random, Matching to Successive Sample Task: Intersymbol Interval = 1/4 sec; Delay Between Sample Presentation "OFF" and Response Orientation Cue = 50 msecs
THS2	Intersymbol Interval = 0.5 sec; Delay = 0.5 sec
THS3	Intersymbol Interval = 1.0 sec; Delay = 1.0 sec
THS4	Intersymbol Interval = 1.0 sec; Delay = 2.0 secs
THS5	Intersymbol Interval = 1.0 sec; Delay = 3.0 secs
THS6	Intersymbol Interval = 1.0 sec; Delay = 4.0 secs
THS7	Intersymbol Interval = 1.0 sec; Delay = 5.0 secs
THS8	Intersymbol Interval = 1.0 sec; Delay = 6.0 secs

TABLE 9 (cont)

Nomenclature	Description
THS9	Intersymbol Interval = 1.0 sec; Delay = 7.0 secs
THS10	Intersymbol Interval = 1.0 sec; Delay = 8.0 secs
THS11	Intersymbol Interval = 1.0 sec; Delay = 9.0 secs
THS12	Intersymbol Interval = 1.0 sec; Delay = 10.0 secs
FOS1	Four Symbol Random, Matching to Successive Sample Task: Intersymbol Interval = 1/4 sec; Delay Between Sample Presentation "OFF" and Response Orientation Cue = 50 msecs
FOS2	Intersymbol Interval = 0.5 sec; Delay = 0.5 sec
FOS3	Intersymbol Interval = 1.0 sec; Delay = 1.0 sec
FOS4	Intersymbol Interval = 1.0 sec; Delay = 2.0 secs
FOS5	Intersymbol Interval = 1.0 sec; Delay = 3.0 secs
FOS6	Intersymbol Interval = 1.0 sec; Delay = 4.0 secs
FOS7	Intersymbol Interval = 1.0 sec; Delay = 5.0 secs
FOS8	Intersymbol Interval = 1.0 sec; Delay = 6.0 secs
FOS9	Intersymbol Interval = 1.0 sec; Delay = 7.0 secs
FOS10	Intersymbol Interval = 1.0 sec; Delay = 8.0 secs
FOS11	Intersymbol Interval = 1.0 sec; Delay = 9.0 secs
FOS12	Intersymbol Interval = 1.0 sec; Delay = 10.0 secs
FIS1	Five Symbol Random, Matching to Successive Sample Task: Intersymbol Interval = 1/4 sec; Delay Between Sample Presentation "OFF" and Response Orientation Cue = 50 msecs
FIS2	Intersymbol Interval = 0.5 sec; Delay = 0.5 sec
FIS3	Intersymbol Interval = 1.0 sec; Delay = 1.0 sec
FIS4	Intersymbol Interval = 1.0 sec; Delay = 2.0 secs
FIS5	Intersymbol Interval = 1.0 sec; Delay = 3.0 secs

TABLE 9 (cont)

Nomenclature	Description
FIS6	Intersymbol Interval = 1.0 sec; Delay = 4.0 secs
FIS7	Intersymbol Interval = 1.0 sec; Delay = 5.0 secs
FIS8	Intersymbol Interval = 1.0 sec; Delay = 6.0 secs
FIS9	Intersymbol Interval = 1.0 sec; Delay = 7.0 secs
FIS10	Intersymbol Interval = 1.0 sec; Delay = 8.0 secs
FIS11	Intersymbol Interval = 1.0 sec; Delay = 9.0 secs
FIS12	Intersymbol Interval = 1.0 sec; Delay = 10.0 secs

D.5.1. BEHAVIORAL TASK PRESENTATION CRITERIA

The first behavioral task presented to the primate at the start of each phase of the test is the reinforcement button press task (R1). The task progression from task R1 through R6 to OS1C1 will be contingent on the primate's response latency scores, defined as the time from trial onset to reinforcement switch depression. During the initial bank of trials, task R1 will be presented to the primate (Event I, duration = 60 seconds). The criteria for determining the subsequent tasks are as follows:

a. If the primate performs successfully (latency scores equal to or less than Event I duration) on 22 or more of the 25 trials, he shall advance to the reinforcement task that has an Event I duration within which have occurred no less than 15 of 25 of his response latency scores.

b. If on any given R task the primate successully performs on 15 to 21 of 25 trials, then the same R task will be presented on the subsequent bank of trials.

c. If the primate performs successfully on less than 15 of of 25 trials for any R task, R2 through R6, then on the next bank of trials, he shall revert to an R task that has an Event I duration 10 seconds longer than the previous R task. (60 seconds is maximum Event I duration, 10 seconds is the minimum Event I duration).

d. The performance criterion to advance the task to OS1C1 with a switch depression opportunity time of 10 seconds will be 12 successive banks of 25 trials where the animal has averaged greater than 90 percent successful responses to the reinforcement switch on task R6. If the subject does not meet the above criterion within 108 banks then he will be presented successive banks of task R5. The subject will advance to task OS1C1 with a switch depression opportunity time of 20 seconds only if he averages on 12 successive banks greater than 90 percent successful responses and that his latency scores on 75 percent of the trials of the banks are equal to or less than 10 seconds. The subject will remain on task R5 until criterion is reached or unless performance is such to warrant the presentation of task R4 to R1.

Table 10 - Task Presentation Criterion

Behavioral Task	Performance - Subsequent Behavioral Task 22/25	17 to 21/25	0 to 16/25
OS1C1	OS1C2	OS1C1	OS1C1
OS1C2	OS1C3	OS1C2	OS1C1
OS1C3	OS5C1	OS1C3	OS1C2
OS2C1	OS2C2	OS2C1	OS1C3
OS2C2	OS2C3	OS2C2	OS2C1
OS2C3	OS5C1	OS2C3	OS2C2
OS5C1	OS5C2	OS5C1	OS2C1
OS5C2	OS5C3	OS5C2	OS5C1
OS5C3	TWS2C1	OS5C3	OS5C2

Behavioral Task	Performance - Subsequent Behavioral Task 21/25	16 to 20/25	0 to 15/25
TWS2C1	TWS2C3	TWS2C1	OS5C3
TWS2C2	TWS2C3	TWS2C2	TWS2C1
TWS2C3	TWS2C5	TWS2C3	TWS2C2
TWS2C4	TWS2C5	TWS2C4	TWS2C3
TWS2C5	TWS2C7	TWS2C5	TWS2C4
TWS2C6	TWS2C7	TWS2C6	TWS2C5
TWS2C7	TWS2C9	TWS2C7	TWS2C6
TWS2C8	TWS2C9	TWS2C8	TWS2C7
TWS2C9	TWS2C12	TWS2C9	TWS2C8
TWS2C10	TWS2C11	TWS2C10	TWS2C9
TWS2C11	TWS2C12	TWS2C11	TWS2C10
TWS2C12	TWS5C1	TWS2C12	TWS2C11
TWS3C1	TWS3C3	TWS3C1	TWS2C12
TWS3C2	TWS3C3	TWS3C2	TWS3C1
TWS3C3	TWS3C5	TWS3C3	TWS3C2
TWS3C4	TWS3C5	TWS3C4	TWS3C3
TWS3C5	TWS3C7	TWS3C5	TWS3C4
TWS3C6	TWS3C7	TWS3C6	TWS3C5
TWS3C7	TWS3C9	TWS3C7	TWS3C6
TWS3C8	TWS3C9	TWS3C8	TWS3C7
TWS3C9	TWS3C12	TWS3C9	TWS3C8
TWS3C10	TWS3C11	TWS3C10	TWS3C9

Behavioral Task	Performance - Subsequent Behavioral Task 21/25	16 to 20/25	0 to 15/25
TWS3C11	TWS3C12	TWS3C11	TWS3C10
TWS3C12	TWS5C1	TWS3C12	TWS3C11
TWS5C1	TWS5C3	TWS5C1	TWS3C12
TWS5C2	TWS5C3	TWS5C2	TWS5C1
TWS5C3	TWS5C5	TWS5C3	TWS5C2
TWS5C4	TWS5C5	TWS5C4	TWS5C3
TWS5C5	TWS5C7	TWS5C5	TWS5C4
TWS5C6	TWS5C7	TWS5C6	TWS5C5
TWS5C7	TWS5C9	TWS5C7	TWS5C6
TWS5C8	TWS5C9	TWS5C8	TWS5C7
TWS5C9	TWS5C12	TWS5C9	TWS5C8
TWS5C10	TWS5C11	TWS5C10	TWS5C9
TWS5C11	TWS5C12	TWS5C11	TWS5C10
TWS5C12	TWS3C1	TWS5C12	TWS5C11

Behavioral Task	Performance - Subsequent Behavioral Task 19/25	14 to 18/25	0 to 13/25
THS3C1	THS3C3	THS3C1	TWS5C12
THS3C2	THS3C3	THS3C2	THS3C1
THS3C3	THS3C5	THS3C3	THS3C2
THS3C4	THS3C5	THS3C4	THS3C3
THS3C5	THS3C7	THS3C5	THS3C4
THS3C6	THS3C7	THS3C6	THS3C5
THS3C7	THS3C9	THS3C7	THS3C6
THS3C8	THS3C9	THS3C8	THS3C7
THS3C9	THS3C12	THS3C9	THS3C8
THS3C10	THS3C11	THS3C10	THS3C9
THS3C11	THS3C12	THS3C11	THS3C10
THS3C12	THS5C1	THS3C12	THS3C11
THS4C1	THS4C3	THS4C1	THS3C12
THS4C2	THS4C3	THS4C2	THS4C1
THS4C3	THS4C5	THS4C3	THS4C2
THS4C4	THS4C5	THS4C4	THS4C3
THS4C5	THS4C7	THS4C5	THS4C4
THS4C6	THS4C7	THS4C6	THS4C5
THS4C7	THS4C9	THS4C7	THS4C6
THS4C8	THS4C9	THS4C8	THS4C7
THS4C9	THS4C12	THS4C9	THS4C8
THS4C10	THS4C11	THS4C10	THS4C9

Behavioral Task	Performance - Subsequent Behavioral Task 19/25	14 to 18/25	0 to 13/25
THS4C11	THS4C12	THS4C11	THS4C10
THS4C12	THS5C1	THS4C12	THS4C11
THS5C1	THS5C3	THS5C1	THS4C12
THS5C2	THS5C3	THS5C2	THS5C1
THS5C3	THS5C5	THS5C3	THS5C2
THS5C4	THS5C5	THS5C4	THS5C3
THS5C5	THS5C7	THS5C5	THS5C4
THS5C6	THS5C7	THS5C6	THS5C5
THS5C7	THS5C9	THS5C7	THS5C6
THS5C8	THS5C9	THS5C8	THS5C7
THS5C9	THS5C12	THS5C9	THS5C8
THS5C10	THS5C11	THS5C10	THS5C9
THS5C11	THS5C12	THS5C11	THS5C10
THS5C12	FOS4C1	THS5C12	THS5C11

Behavioral Task	Performance - Subsequent Behavioral Task 16/25	10 to 15/25	0 to 9/25
FOS4C1	FOS4C3	FOS4C1	THS5C12
FOS4C2	FOS4C3	FOS4C2	FOS4C1
FOS4C3	FOS4C5	FOS4C3	FOS4C2
FOS4C4	FOS4C5	FOS4C4	FOS4C3
FOS4C5	FOS4C7	FOS4C5	FOS4C4
FOS4C6	FOS4C7	FOS4C6	FOS4C5
FOS4C7	FOS4C9	FOS4C7	FOS4C6
FOS4C8	FOS4C9	FOS4C8	FOS4C7
FOS4C9	FOS4C12	FOS4C9	FOS4C8
FOS4C10	FOS4C11	FOS4C10	FOS4C9
FOS4C11	FOS4C12	FOS4C11	FOS4C10
FOS4C12	FOS5C1	FOS4C12	FOS4C11
FOS5C1	FOS5C3	FOS5C1	FOS4C12
FOS5C2	FOS5C3	FOS5C2	FOS5C1
FOS5C3	FOS5C5	FOS5C3	FOS5C2
FOS5C4	FOS5C5	FOS5C4	FOS5C3
FOS5C5	FOS5C7	FOS5C5	FOS5C4
FOS5C6	FOS5C7	FOS5C6	FOS5C5
FOS5C7	FOS5C9	FOS5C7	FOS5C6
FOS5C8	FOS5C9	FOS5C8	FOS5C7
FOS5C9	FOS5C12	FOS5C9	FOS5C8
FOS5C10	FOS5C11	FOS5C10	FOS5C9
FOS5C11	FOS5C12	FOS5C11	FOS5C10
FOS5C12	FIS5C1	FOS5C12	FOS5C11

Behavioral Task	Performance - Subsequent Behavioral Task 12/25	6 to 11/25	0 to 5/25
FIS5C1	FIS5C3	FIS5C1	FOS5C12
FIS5C2	FIS5C3	FIS5C2	FIS5C1
FIS5C3	FIS5C5	FIS5C3	FIS5C2
FIS5C4	FIS5C5	FIS5C4	FIS5C3
FIS5C5	FIS5C7	FIS5C5	FIS5C4
FIS5C6	FIS5C7	FIS5C6	FIS5C5
FIS5C7	FIS5C9	FIS5C7	FIS5C6
FIS5C8	FIS5C9	FIS5C8	FIS5C7
FIS5C9	FIS5C12	FIS5C9	FIS5C8
FIS5C10	FIS5C11	FIS5C10	FIS5C9
FIS5C11	FIS5C12	FIS5C11	FIS5C10
FIS5C12	FIS5C12	FIS5C12	FIS5C11

At the completion of each test phase, the behavioral task program will re-cycle and start again at task R1. The automatic task progression criteria will be supplemented by an overriding capability of the test control center to initiate any of the tasks or terminate any behavioral session.

D.6 ENVIRONMENTAL TASKS

At select periods during the test, certain environmental controls will be given to the subject as specified in the test sequence. These controls are summarized below:

1. Life Cell Temperature: 71°F to 81°F (fixed ratio to initiate)
2. Lighting Intensity: 0 to 35 foot-candles (fixed ratio to initiate)
3. Behavioral Session Self Initiate (fixed ratio to initiate)
4. Auditory Reinforcement (DRH to initiate)

D.7 PHYSIOLOGICAL DATA ACQUISITION REQUIREMENTS

1. Lt. Occ. - Rt. Occ. EEG
2. Lt. Occ. - Lt. Par. EEG
3. Lt. Red Nucl. EEG
4. Rt. Hipp. EEG
5. RCM EEG
6. Rt. Amyg. EEG
7. EOG
8. EMG
9. Core Temp.
10. Heart Rate

Totally implantable telemetry systems will be used to gather information from the central and peripheral nervous system and cardiovascular system. The telemetry system will be divided into two separate independent units; one attached to the subject's existing headcap to obtain nervous system data, and the other surgically implanted in the animal to obtain cardiovascular data. The University of Southern California will be responsible for the cardiovascular telemetry unit.

D.8 ACOUSTIC CONSIDERATIONS

The primate inserted system test will be conducted in a totally isolated environment. The primate will be subjected to only those sounds associated with the behavioral tasks and life support equipment.

The total continuous sound pressure level during the test at any point within the life cell shall not be greater than 75 dB (not including behavioral task tones). Excursions not lasting more than 30 seconds may reach a sound pressure level of 100 dB during the "day" cycle only.

D.9 TEST SEQUENCE

The test sequence will follow the proposed mission sequence as specified in Revision I of the interface document with a time scaling of one-half (60 day trimester to be simulated in 30 days).

The simulated flight trimester is divided into 3 phases as summarized below:

<u>Phase A</u> <u>(Day 1 through 10)</u>

Day 1 through 5: a) 12 hours light, 12 hours dark

b) three behavioral sessions of 100 trials each presented at scheduled times during the "day"

Day 1 through 5: c) temperature controlled by experimenter $76^{o}F$ to $81^{o}F$

Day 6 through 10: a) 12 hours light, 12 hours dark

b) behavioral sessions primate initiated during light (100 trials/session)

c) temperature controlled by experimenter

<u>Phase B (Day 11 through 20)</u>

Day 11 through 15: a) primate lighting control

b) behavioral sessions primate initiated

c) temperature controlled by experimenter

Day 16 through 20: a) primate lighting control

b) behavioral sessions primate initiated

c) primate temperature control - $71^{o}F$ to $81^{o}F$

<u>Phase C (Day 21 through 30)</u>

Day 21 through 25: a) 24 hours continuous light (at primate's desired intensity

b) behavioral sessions primate initiated

c) primate temperature control

Day 26 through 30: a) 24 hours continuous light

b) behavioral sessions primate initiated

c) temperature controlled by experimenter (at primate's desired temperature)

Figure 48 represents the test sequence.

Should the test duration be extended beyond 30 days, the second trimester of the flight will be simulated beginning with Phase A of trimester II. A more detailed description of the test sequence is shown below:

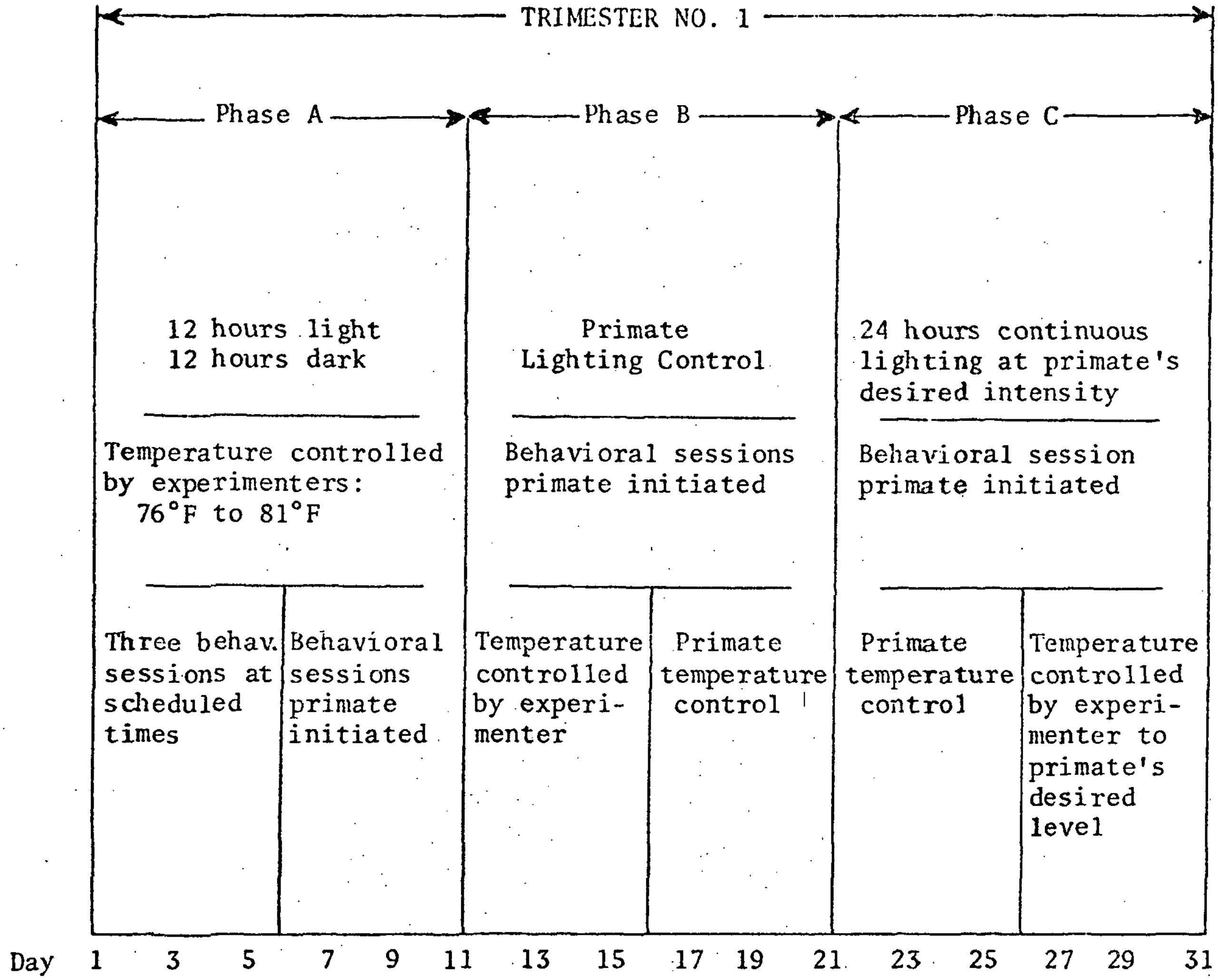


Figure 48

TEST SEQUENCE

Day 1 through 5

PDT	
0700	Lights on
0900	Behavioral session #1
	Waste management flush, 5 minutes after behavioral session completion
1200	Behavioral session #2
1500	Behavioral session #3
1900	Lights off

Day 6 through 10

0700	Lights on; primate behavioral session initiate switch on Waste management flush, 5 minutes after completion of first behavioral session during which behavioral session initiate switch is off
1900	Lights off; primate behavioral session initiate switch off (behavioral session initiate switch is automatically turned off at beginning of third behavioral session). If three sessions are not initiated by 1900, then switch is extinguished at 1900.

Day 11 through 15

0700*	Primate lighting control switches on; primate behavioral session initiate switch on (no longer limited to three sessions/day). Waste management flush; 5 minutes after completion of first behavioral session during which behavioral session initiate switch is off

Day 16 through 20

**	At onset of 16th circadian day, defined as subject's mid-activity point plus one-half of the circadian cycle, primate temperature control switches on

*Day 11 only
**Day 16 only

Waste management flush: 5 minutes after completion of first behavioral session during which behavioral session initiate switch is off

Day 21 through 25

PDT

* At onset of 21st circadian day, lights on; primate lighting control switches off

Waste management flush; 5 minutes after completion of first behavioral task during which behavioral session initiate switch is off

Day 26 through 30

** At onset of 26th circadian day, temperature controlled by experimenter; primate temperature control switches off

Waste management flush; 5 minutes after completion of behavioral session during which behavioral session initiate switch is off

In addition to the automatic data acquisition system, the following items will be manually recorded as described below:

1. Water intake - hourly
2. Subject position
3. Gross subject activities
4. Behavioral session times

*Day 21 only
**Day 26 only

E. HARDWARE & INSTRUMENTATION

E.1 LIFE CELL

A cubical housing chamber with sides of 4 feet will be used for the test, providing an enclosed volume of 64 feet. One wall of the life cell contains environmental control switches and water dispensers; an adjacent wall contains a flight configured behavioral panel and feeder, the bottom of the life cell consists of a supporting grate below which is located the waste management system, incorporated in the ceiling of the cell is the lighting and camera system (see Figure 49).

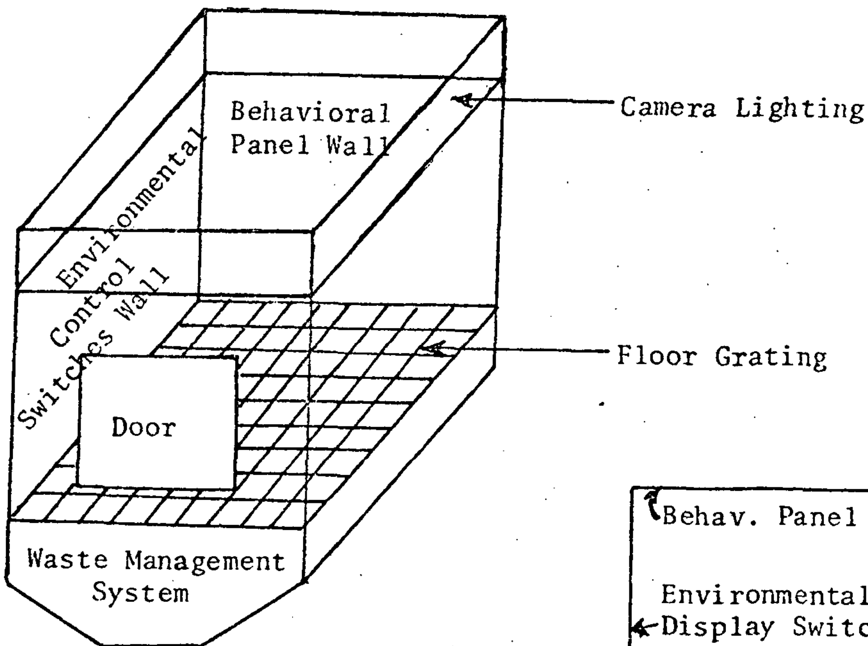
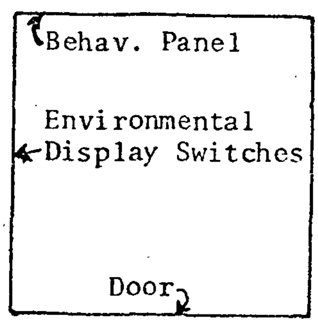


Figure 49

LIFE CELL



Top View

E.2 ENVIRONMENTAL CONTROL DISPLAY SWITCHES

One wall of the life cell (see Figure 50) will be utilized to mount the environment display switches. There shall be 18 circular switches, 2 for each of the 9 environmental control functions positioned on the mounting wall as shown in Figure 51 The switches functions, dimensions, and color are presented in Table 11.

Table 11

Switch Designation	Function	Color	Diameter	Shinkolite A Color Number
1	Decrease lighting intensity	Dark Blue	2.00 inches	302*
2	Increase lighting intensity	Yellow	2.00 inches	993*
3	Water dispenser	White	2.25 inches	432
4	Auditory enrichment	Purple	2.00 inches	375
5	Decrease temperature	Light Blue	2.00 inches	300*
6	Increase temperature	Orange	2.00 inches	264
7	Behavioral session initiate	Green	2.00 inches	343*
8	Not connected	Black	2.00 inches	502
9	Food reinforcement**	Red	2.25 inches	136

*colors are transparent and require the addition of a white translucent background
**to be non-operative during system test

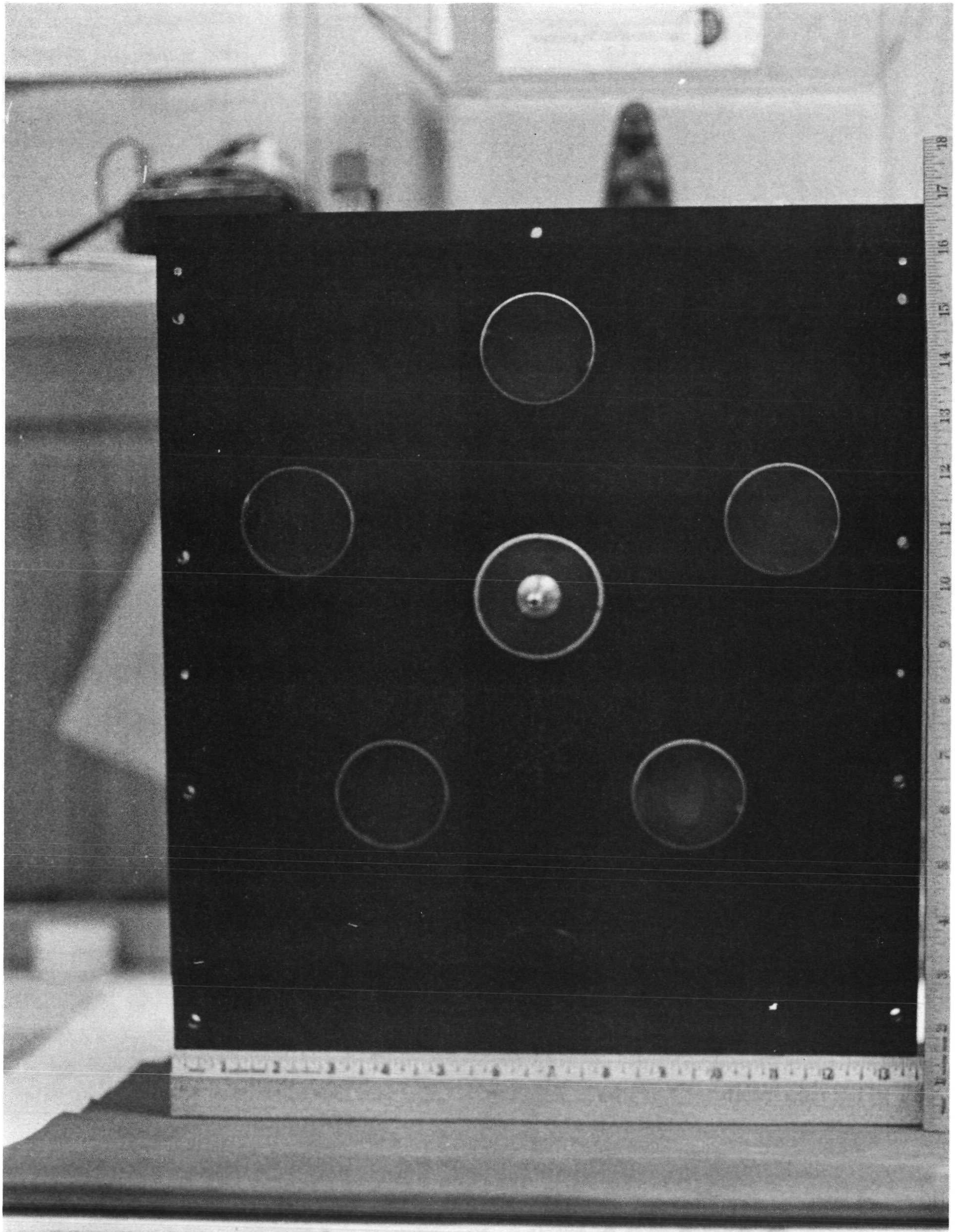


Fig. 50
One wall of life cell

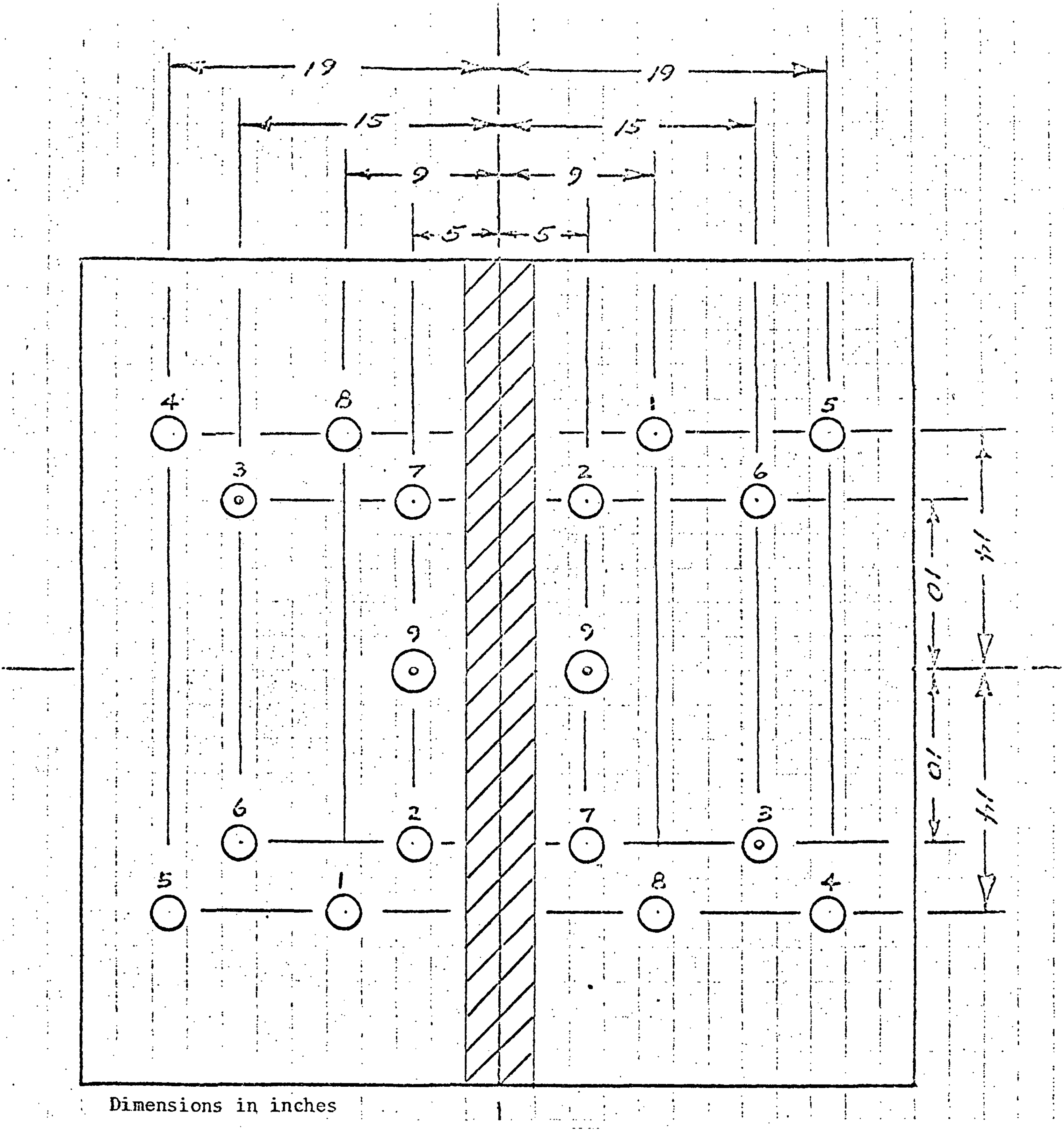


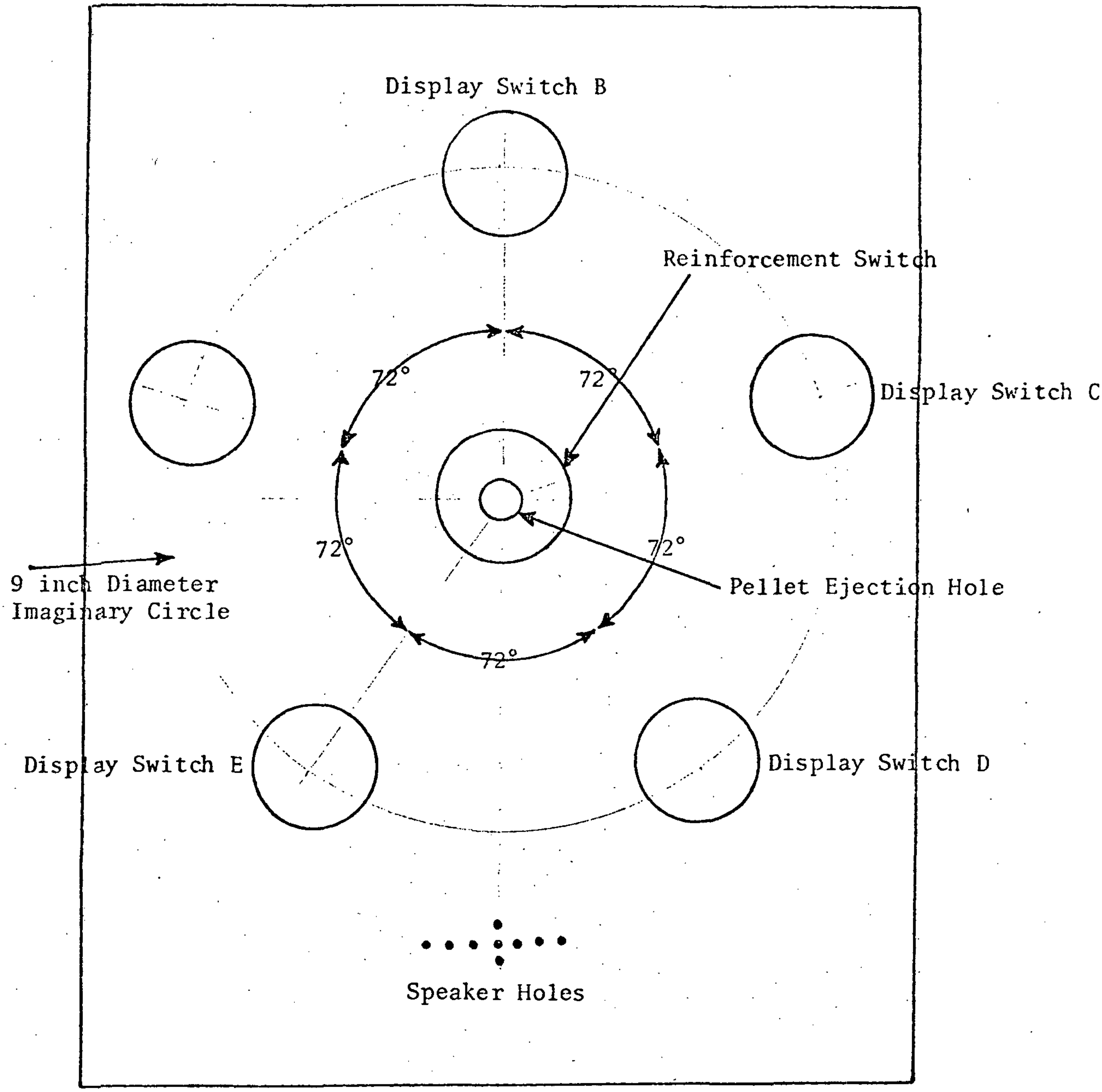
Figure 51

ENVIRONMENTAL CONTROL DISPLAY SWITCH LOCATION

E.3 BEHAVIORAL DISPLAY & FEEDER

The mechanical configuration of the behavioral display panel is shown in Figure 52. The panel consists of five circular symbol display switches equally spaced along the circumference of an imaginary 9 inch diameter circle. A pellet ejection hole is located at the center of the imaginary 9 inch diameter circle and is surrounded by a circular reinforcement switch.

1. Switch size (non-displacement proximity)
   a. Display switch: 5.08 cm $\pm$.051 cm
   b. Reinforcement switch: 5.715 cm $\pm$.051 cm
2. Switch color
   a. Display switches: Clear (symbol projector to mount behind display switch)
   b. Reinforcement switch: Red (same as primary trainer)
3. Pellet ejection hole
   a. 2.0 cm $\pm$0.1 cm diameter
4. Display symbols
   a. Symbol size: 1 inch - IEE Projection Symbols
5. Panel mounting
   a. The panel shall be mounted in the life cell in place of the existing behavioral panel



Surface Color : Black

On back side of behavioral panel mount 1-45 pin male connector part no. FK-46-32S

Figure 52

BEHAVIORAL PANEL CONFIGURATION

E.4 WATER DISPENSER

Water will be available for primate consumption on an ad lib basis in response to a depression of either "water dispensation" switch. Water shall be available to the primate for the duration of switch depression.

There will be three containers for drinking water storage; a 5 gallon primary storage container and two 250 ml secondary storage containers. From primary storage, water enters the secondary via gravity feed from which the water is delivered to the two dispensing devices.

Once each hour, a test attendant will observe and document the water level in the two secondary containers (graduated cylinders), and fill the cylinders by opening a valve from the primary storage container. The primary and secondary containers will be located outside the isolation chamber so that acoustical isolation is maintained. The water from the secondary storage will be delivered to the dispensing nipples via tygon tubing. A solenoid valve will be actuated when the primate touches the "water dispensation" switch which will allow water to be delivered to the dispenser. The water level in the graduated cylinders will be slightly lower than the elevation of the two dispensers requiring suction from the animal for water delivery. (See Figure 53).

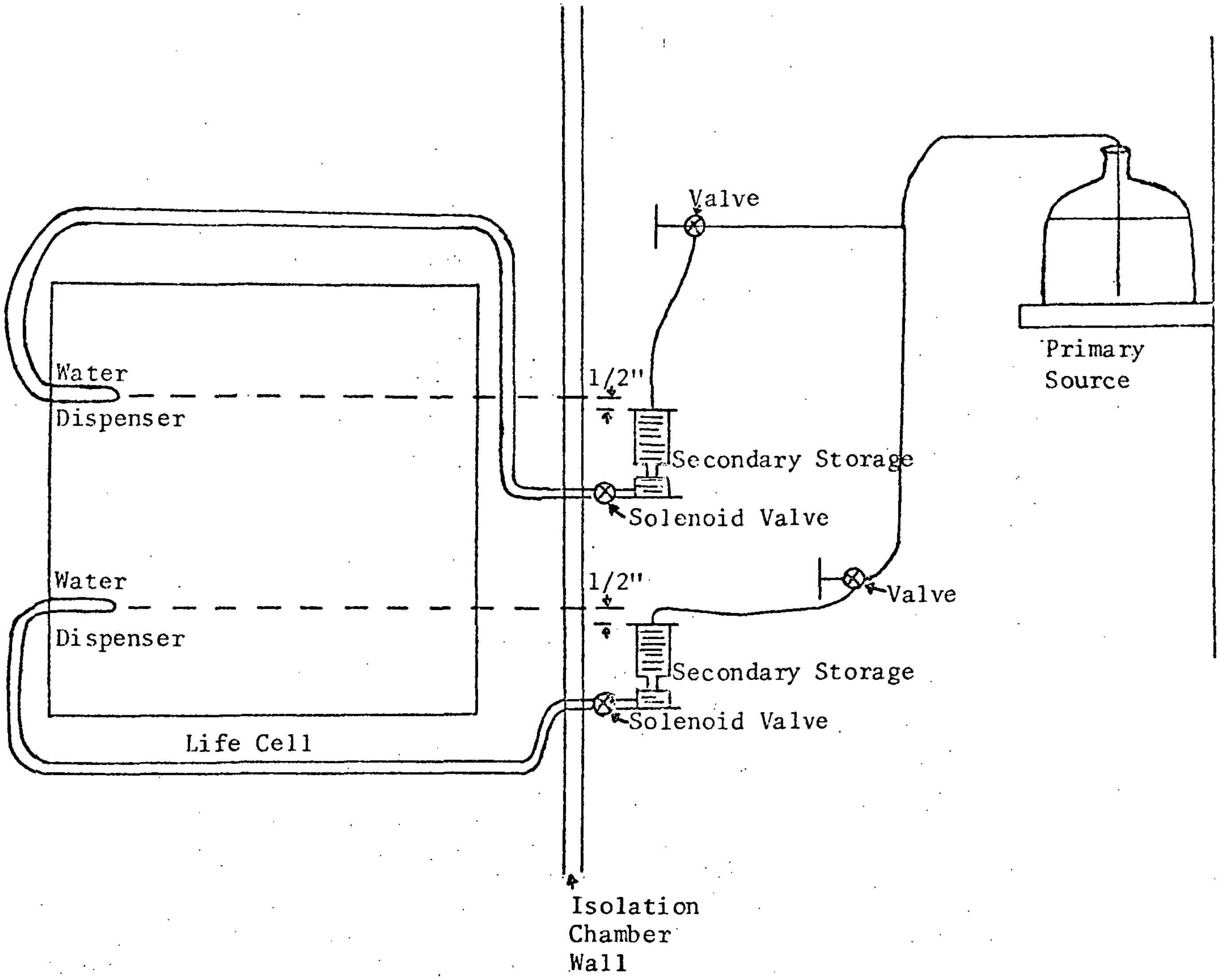


Figure 53

WATER DISPENSATION SYSTEM

E.5 IMPLANTABLE TELEMETRY

E.5.1 NERVOUS SYSTEM

An eight channel micropowered PAM/TIME SHARED/FM TELEMETRY SYSTEM shown in block diagram form in Figure 54 will be used for nervous system data acquisition.

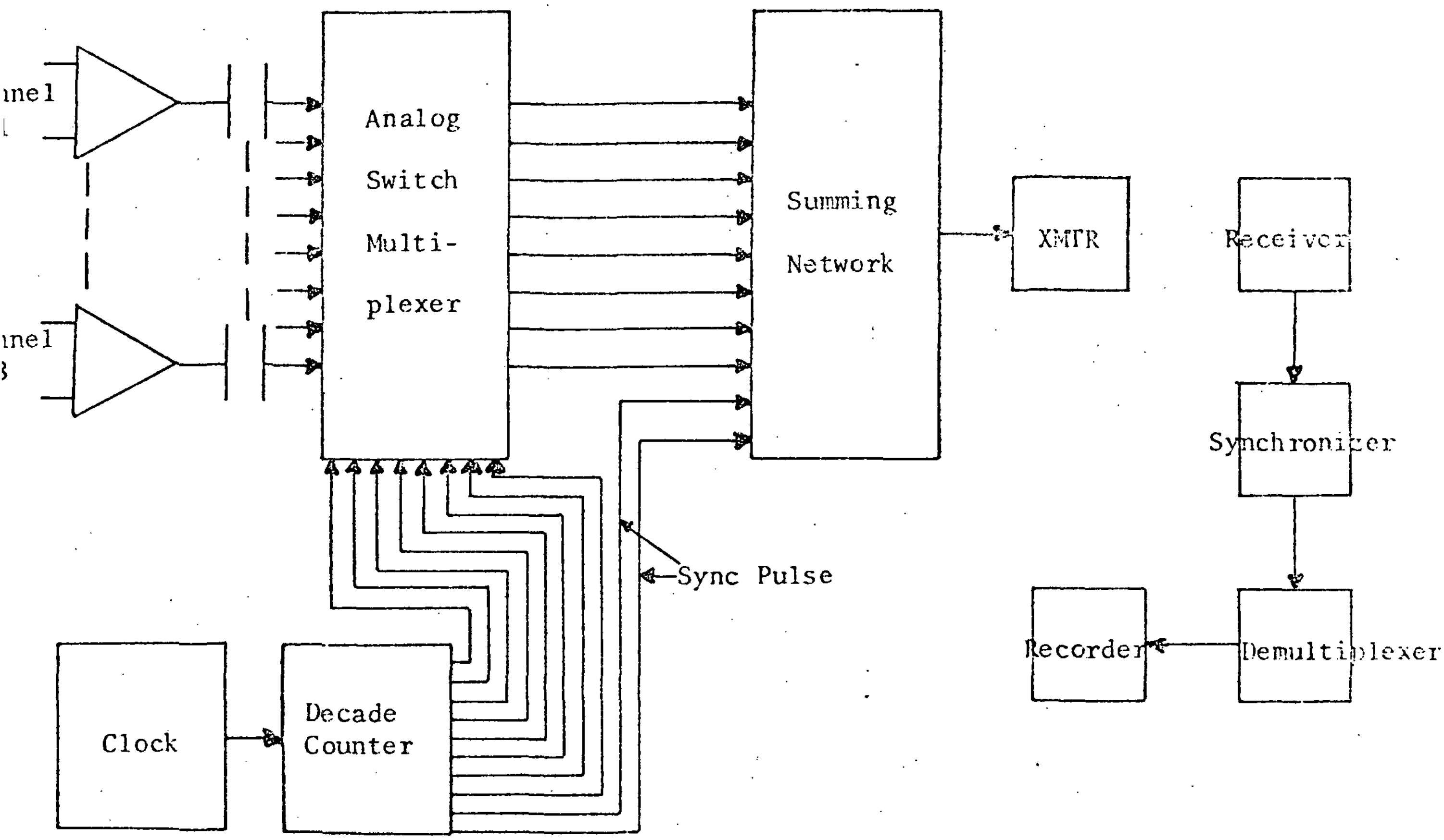


Figure 54

SYSTEM CONFIGURATION

Each differential amplifier is comprised of two Fairchild μA735 operational amplifiers connected in a voltage follower configuration, providing unity gain whose outputs are connected to a third Fairchild μA735 operational amplifier to provide the required channel amplification. The amplified outputs are AC coupled into an analog multiplexing unit being switched at a rate of 256 samples/second/channel via clock and decade counter. The multiplexer, clock and decade counter are micro-powered complimentary metal oxide semiconductors manufactured by RCA. The outputs of the multiplexer are summed and fed into an FM transmitter. The signal is then received, synchronized, demultiplexed and recorded. The telemetry system fabricated for the system test shall conform to the following specifications:

1.	Gain	: 1000 (variable)
2.	Frequency Response	: 3 dB cutoff $\leq$0.65 Hz to 50 Hz (limited by sampling rate of 256 sps)
3.	Output Noise Referenced to Input (input shorted)	: $\leq$3 μv peak-to-peak
4.	Common Mode Rejection Rate	: $\geq$82 dB
5.	Input Impedance	: $\geq$50 MΩ
6.	Power Consumption	: $\leq$550 μwatts from -2.5 v; $\leq$1550 μwatts from +2.5 v (220 μA @ neg. supply, 620 μA @ pos. supply)
7.	Supply Voltage	: ±2.5 VDC (transmitter: +2.5 VDC only)
8.	Frequency of Transmission	: 86 MHz

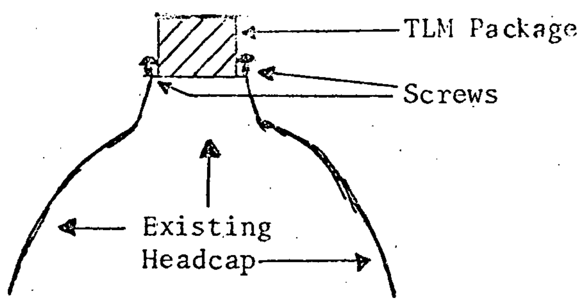
9. Transmitted Field Intensity

(1 meter referred to $1 \mu v$, 50 Ω) : ≥ 60 dB

10. Transmitter Deviation Sensitivity : 15 μv/kHz

11. Adjacent Channel Crosstalk Isolation : ≥ 40 dB

The telemetry unit will be packaged to mate with the headcap configuration existing on the test subject (see Figure 55). The package configuration and dimensions are to be determined at a later date.



Telemetry Package Configuration

Figure 55

E.5.2 CARDIOVASCULAR SYSTEM

The data acquisition from the cardiovascular system is the responsibility of the University of Southern California and will be integrated into the test specification at a later date. The system will be surgically implanted and will monitor heart rate and core temperature.

E.6 WASTE REMOVAL SYSTEM

The waste removal system will be a gravity feed, water-disinfectant flushed unit. The existing floor grates in the isolation test booth will be replaced with a new grate having sufficiently wide spacing to allow solid fecal matter to drop through and fall upon the sloping sides of the waste collector. Two waste collector canisters will be located below the grate. At the bottom of the canisters will be 3 inch holes. Directly below these holes will be a stainless steel sheet metal funnel; the small end of which is connected to a 3 inch diameter plastic (vinyl) soil pipe.

The pipe will penetrate the wall of the isolation booth with a downward slope. A rubber stopper will be used to plug the soil pipe.

A sprinkler-type flushing system will be activated once a "day", synchronized with completion of the first behavioral session. Around the perimeter of the waste collection canisters, immediately below the floor grate will be a metal tube with an array of holes placed approximately an inch apart. The holes will be located so that the water emerging from them (under pressure) will impinge upon the surfaces of the waste collection canisters and carry feces and residual urine down the sloping sides and into the soil pipe.

During system flushing, the stopper will be removed from the soil pipe and the waste will be collected.

E.7 CAMERA SUBSYSTEM

A television camera will be located above the life cell ceiling looking down at a rotatable mirror. The mirror shall be capable of rotating in two perpendicular axes so that all four walls and the floor may be observed, depending upon the position of the mirror. Camera operation is planned 24 hours per day.

E.8 HOUSELIGHTING

Houselighting for the primate inserted system test will consist of four evenly spaced 50 watt incandescent bulbs. Below each bulb is a lucite window mounted on the ceiling of the life cell. The four lamps are to be connected in parallel and powered by a variac (variable transformer) to provide a variable level of illumination. The variac shaft is belt driven to a DC gear-motor which is driven by signals from the control console.

E.9 BEHAVIORAL ELECTRONICS

E.9.1 BEHAVIORAL TASKS

A combination of two existing major systems, the MSS console and the logic rack, plus additional interface hardware are required to present the full complement of behavioral tasks.

The logic rack will be used primarily for the following functions:

a. Reinforcement task presentation (task R1 through R6) with automatic progression.

b. Test timer.

c. Behavioral task success monitor.

d. Test equipment status monitor and event coder.

The MSS console will be used to present behavioral tasks OS1C1 through FIS5C12 without automatic task progression, that is, an 100 trial behavioral session will be divided into four 25 trial "sessions" with the subsequent behavioral task definition manually entered into the MSS console after which the next session is immediately initiated. This will cause approximately a 1 minute delay between banks of 25 trials within the 100 trial session.

Design changes to the MSS console plus some additional interface hardware will be necessary to make the electronics compatible with the flight configured behavioral panel.

The system is shown in block diagram form in Figures 56 and 57.

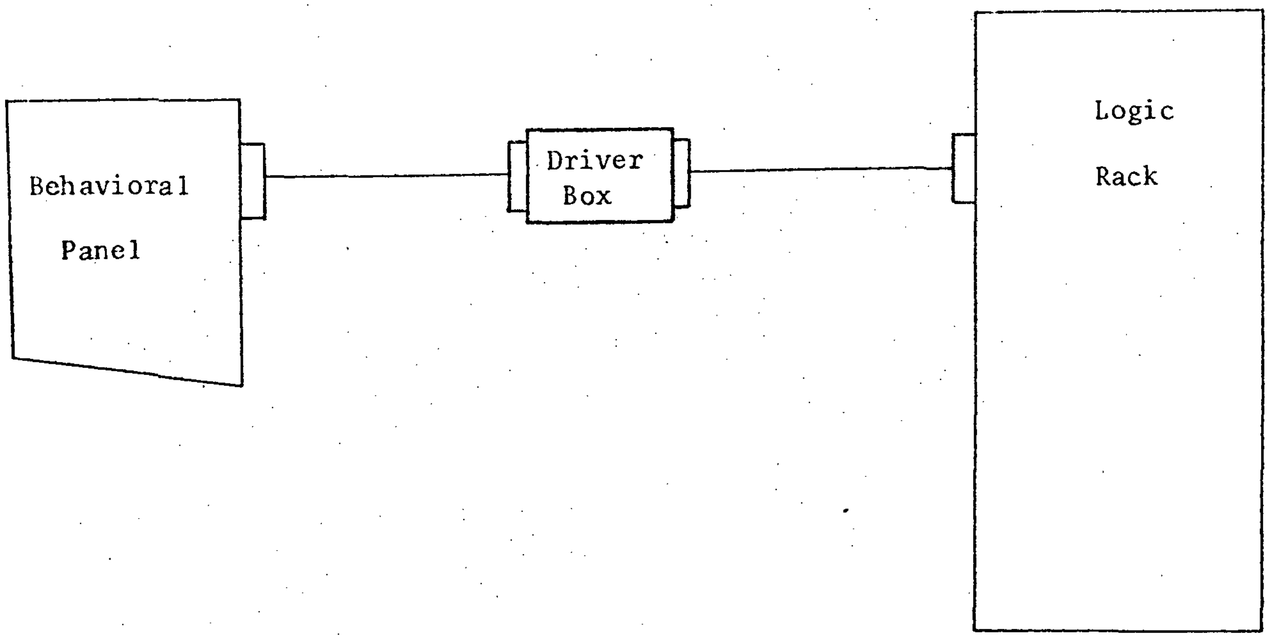


Figure 56

BEHAVIORAL ELECTRONICS

BLOCK DIAGRAM TASKS R1 THROUGH R6

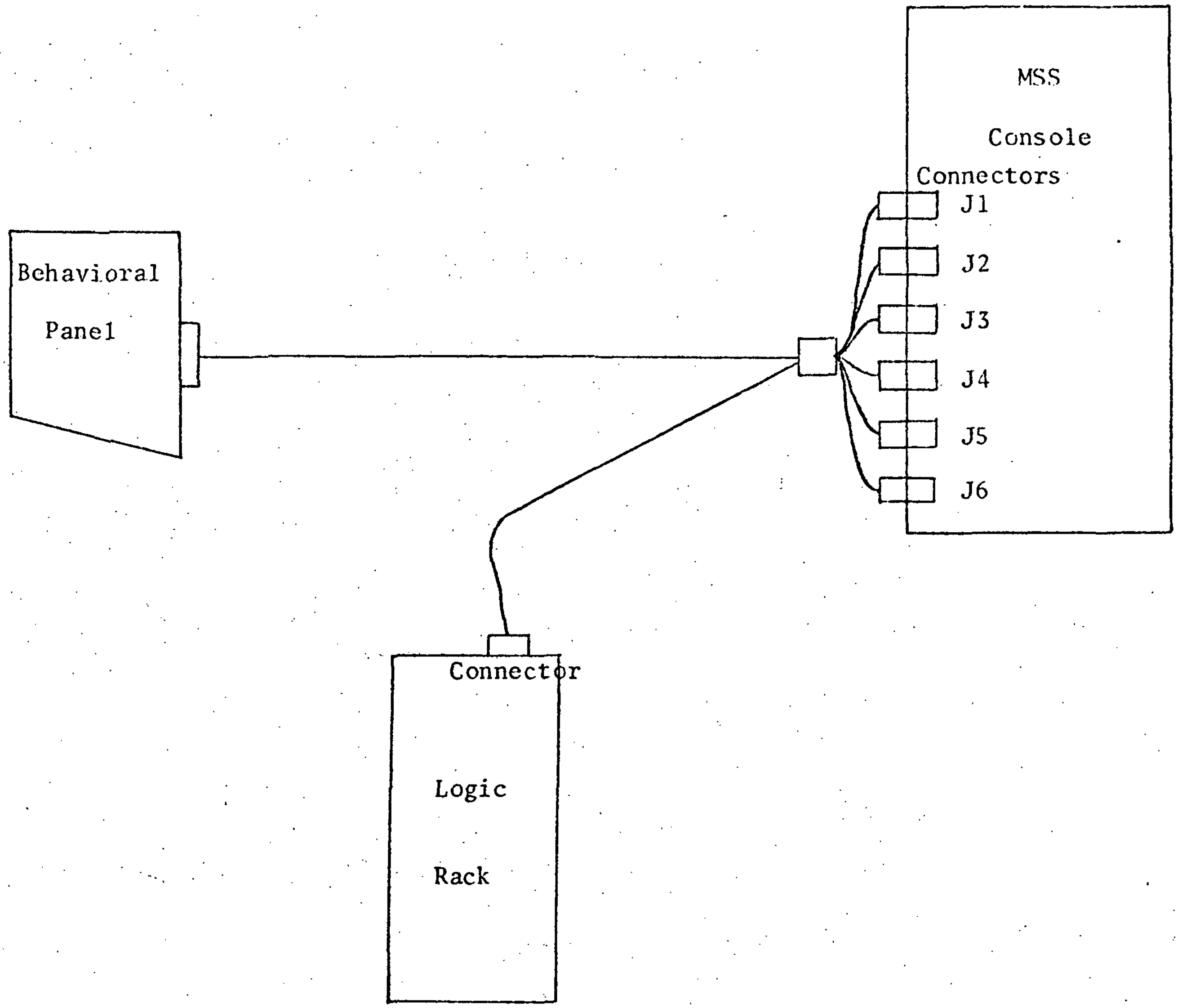


Figure 57

BEHAVIORAL ELECTRONICS

BLOCK DIAGRAM TASKS OS1C1 THROUGH FIS5C12

E.9.2 ENVIRONMENTAL TASKS

A separate independent unit known as the Environmental Console will be utilized to offer the primate temperature, lighting intensity and audio control. The events occurring in the environmental electronics as well as events from other support subsystems will be monitored by use of the logic rack.

F. DATA ACQUISITION

F.1 DATA ACQUISITION PARAMETERS

F.1.1 TELEMETRY

a. Lt. Occ. - Rt. Occ. EEG

b. Lt. Occ. - Lt. Par. EEG

c. Lt. Red Nucl. EEG

d. Rt. Amyg. EEG

e. Rt. Hipp. EEG

f. RCM EEG

g. EOG

h. EMG

i. Heart Rate

*j. Core Temp

F.1.2 HARDWIRE

a. Time Code

b. Life Cell Temperature

c. Life Cell Lighting Intensity

d. Water Intake (hourly)

e. Life Cell Humidity

f. Urination Occurrence/Duration

*Optional - may not be implemented for this sytem test

g. Behavioral Task Event Code

h. Life Cell Auditory Level

i. Environmental Task Event Code

  1. Temperature "Up" Change

  2. Temperature "Down" Change

  3. Light Intensity "Up" Change

  4. Light Intensity "Down" Change

  5. Self Behavioral Task Initiate

  6. Auditory Reinforcement Initiate

  7. Water Intake Initiate

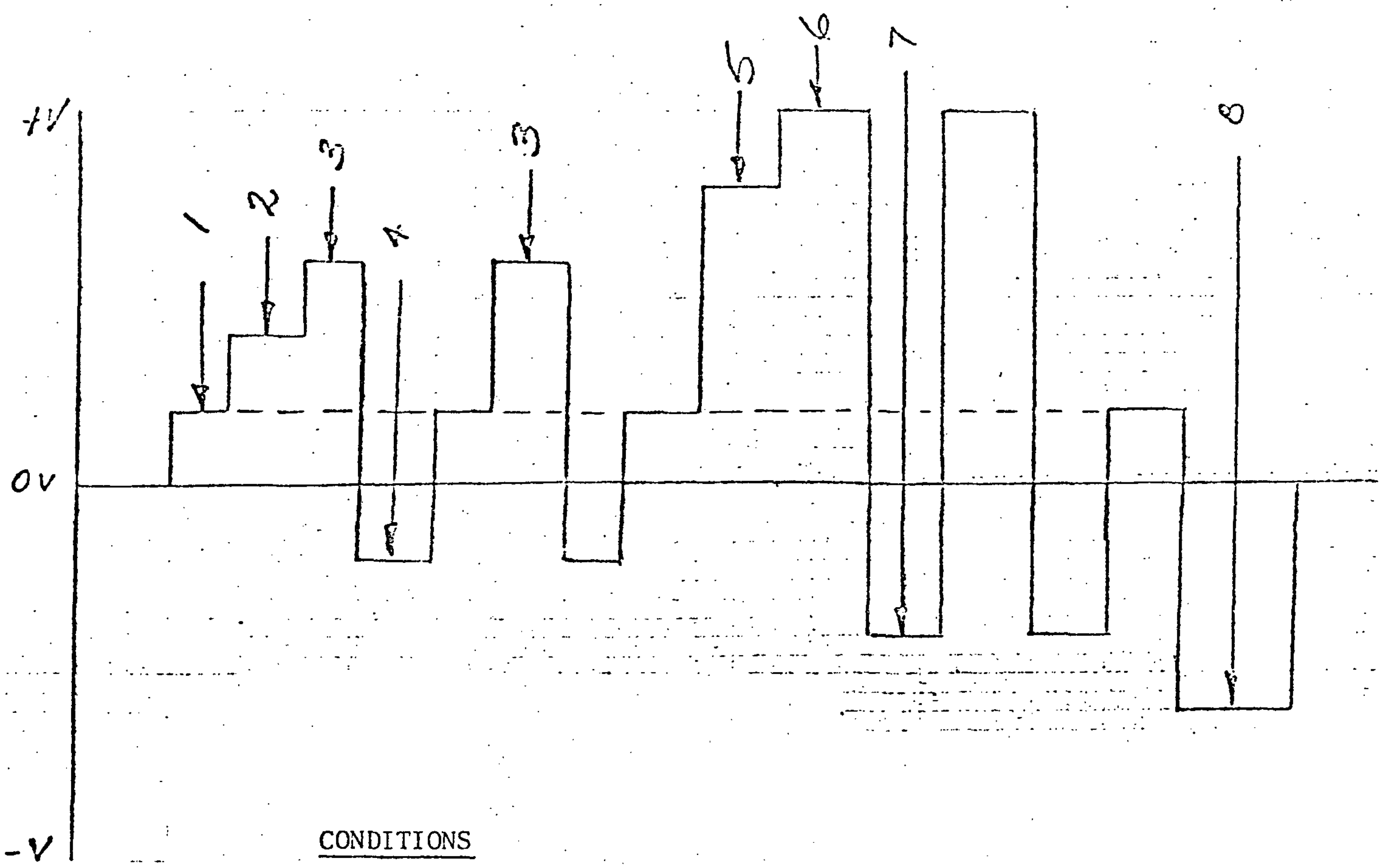
F.2 BEHAVIORAL TASK EVENT CODE

The behavioral task event code is shown in Figure 58. The code provides eight different voltage levels between ±1.4 VDC to indicate the following conditions:

1. Trial in progress: +0.28 V
2. Trial orientation tone: +0.56 V
3. Sample time: +0.84 V
4. Sample switch depressed: -0.28 V
5. Choice orientation tone: +1.12 V
6. Choice time: +1.40 V
7. Choice switch depressed: -0.56 V
8. Time our interval (void): -0.84 V

F.3 DATA ACQUISITION FACILITY

The data acquisition facility is shown in block diagram form in Figure 59 . The proposed facility features both oscillograph and magnetic tape recording of physiological and life support



CONDITIONS

1. Trial In Progress
2. Trial Orientation Tone
3. Sample Time
4. Sample Switch Depressed
5. Choice Orientation Tone
6. Choice Time
7. Choice Switch Depressed
8. Time Out Interval (Void)

Figure 58

BEHAVIORAL TASK EVENT CODE

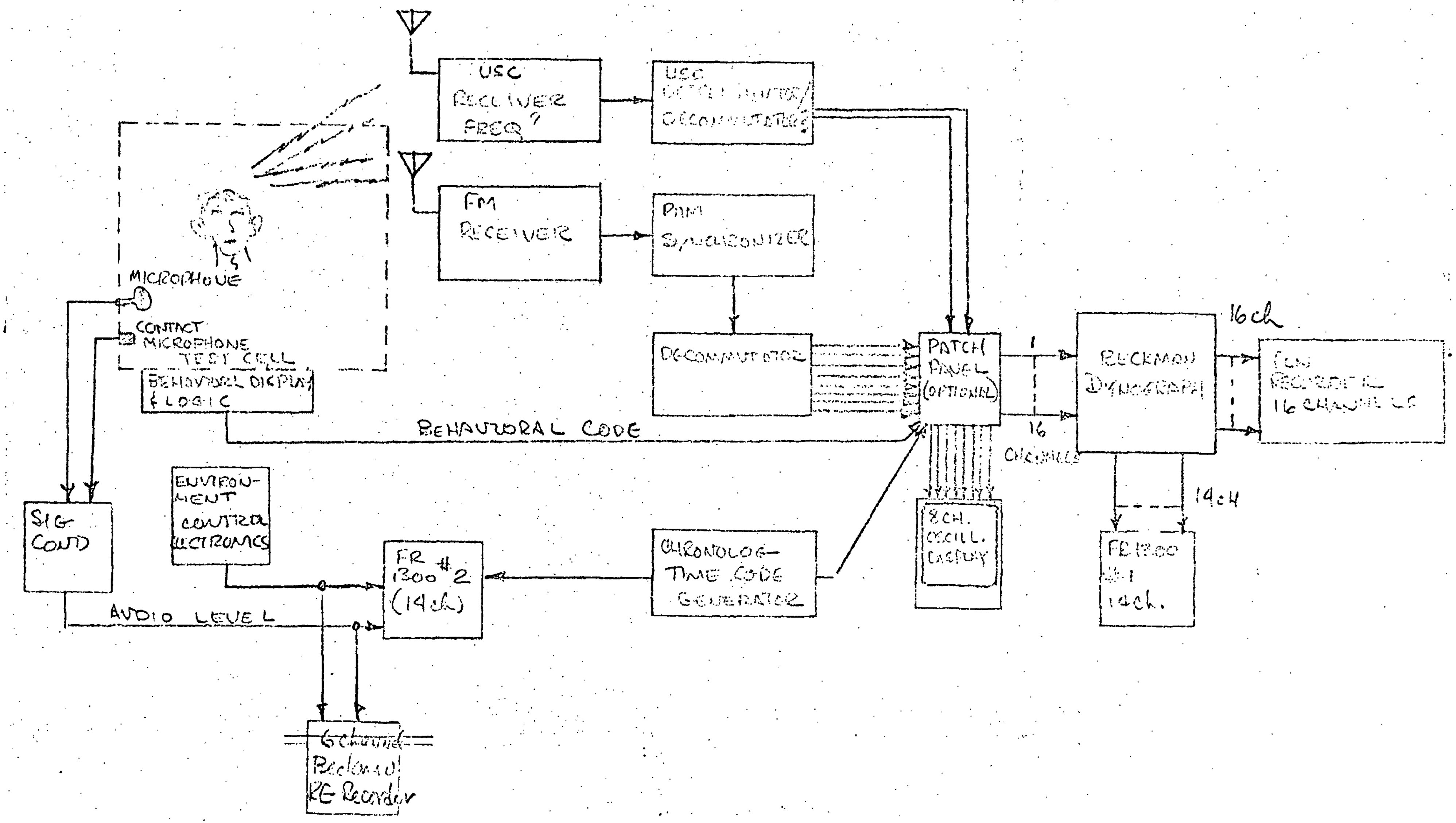


Figure 59

BLOCK DIAGRAM 30 DAY TEST DATA ACQUISITION FACILITY system parameters using Beckman 16 channel and 6 channel oscillograph recorders and two FR 1300 magnetic tape recorders.

The physiological signals to be displayed on the 16 channel dynograph are to be recorded on FR 1300 #1. The FR 1300 inputs are thus derived from the oscillograph preamp outputs. This avoids coupling the decommutator and other signals to the relatively low input impedance of the FR 1300. The FR 1300 will be run at a speed of 1 7/8 ips.

F.4 DATA ACQUISITION SCHEDULE

The recording times and durations relating to the chart recordings and magnetic tape recordings are to be determined at a later date.

IV LIFE SUPPORT SUBSYSTEMS

A. WASTE MANAGEMENT

A number of waste removal concepts were investigated as described in section III.G. of the POCO Interface Document (POCO-04-071-006, Final Revision). Of these concepts, the water jet concept was developed and tested.

A.1 WATER JET CONCEPT

When the cleaning process is initiated, swivel type water jets are positioned internally to the spherical cell shown in Fig 60. After the water jets are in place, a solution of water and an ingestible detergent, such as Dioctyl, are sprayed out of the swivel nozzles tangentially along the inner surface of the sphere wall to remove any waste material adhering to the wall. A continuous flow of filtered air will serve to scavenge the atmosphere by forced convection. This procedure would be repeated as required. Mechanical drawings of a prototype developed and tested in our laboratory are shown in Fig 61 through 64. Initial test results proved satisfactory as at least 80% of the defecation was removed using water only on both fresh and hardened fecal matter.

B. PRIMATE LIFE CELL

The life cell is the central element of the life support subsystem and serves as the living area for the primate. As the principal structural member of the spacecraft, it provides a shell which, in addition to the primate, encloses the food supply, waste management system, thermal and atmosphere control systems and other primate support equipment. Atmosphere, water and other tankage are mounted outside to the

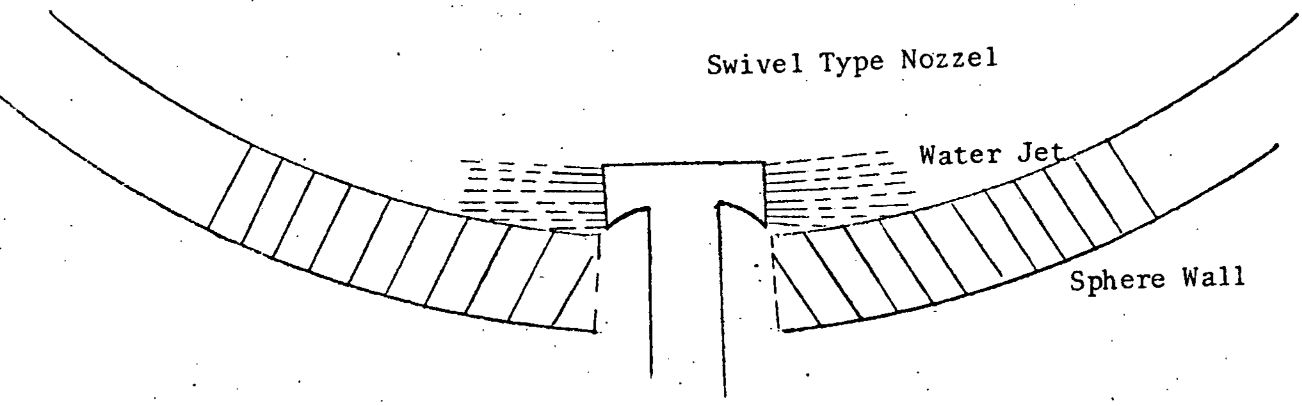
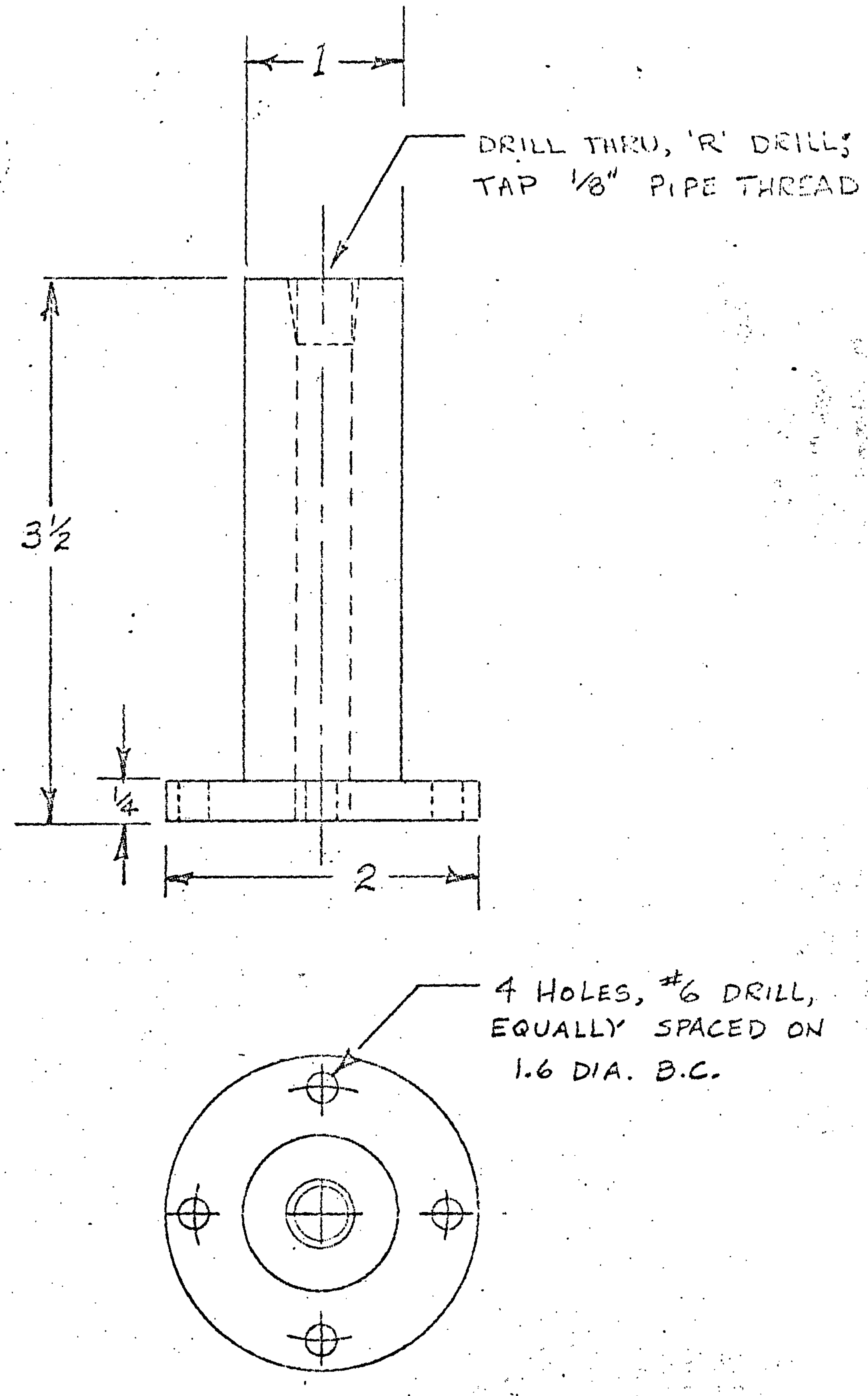


FIGURE 60

WATER JET CONCEPT



POCO WATER JET CLEANER —
SUPPORT SHAFT FIGURE 61 1 REQ'D

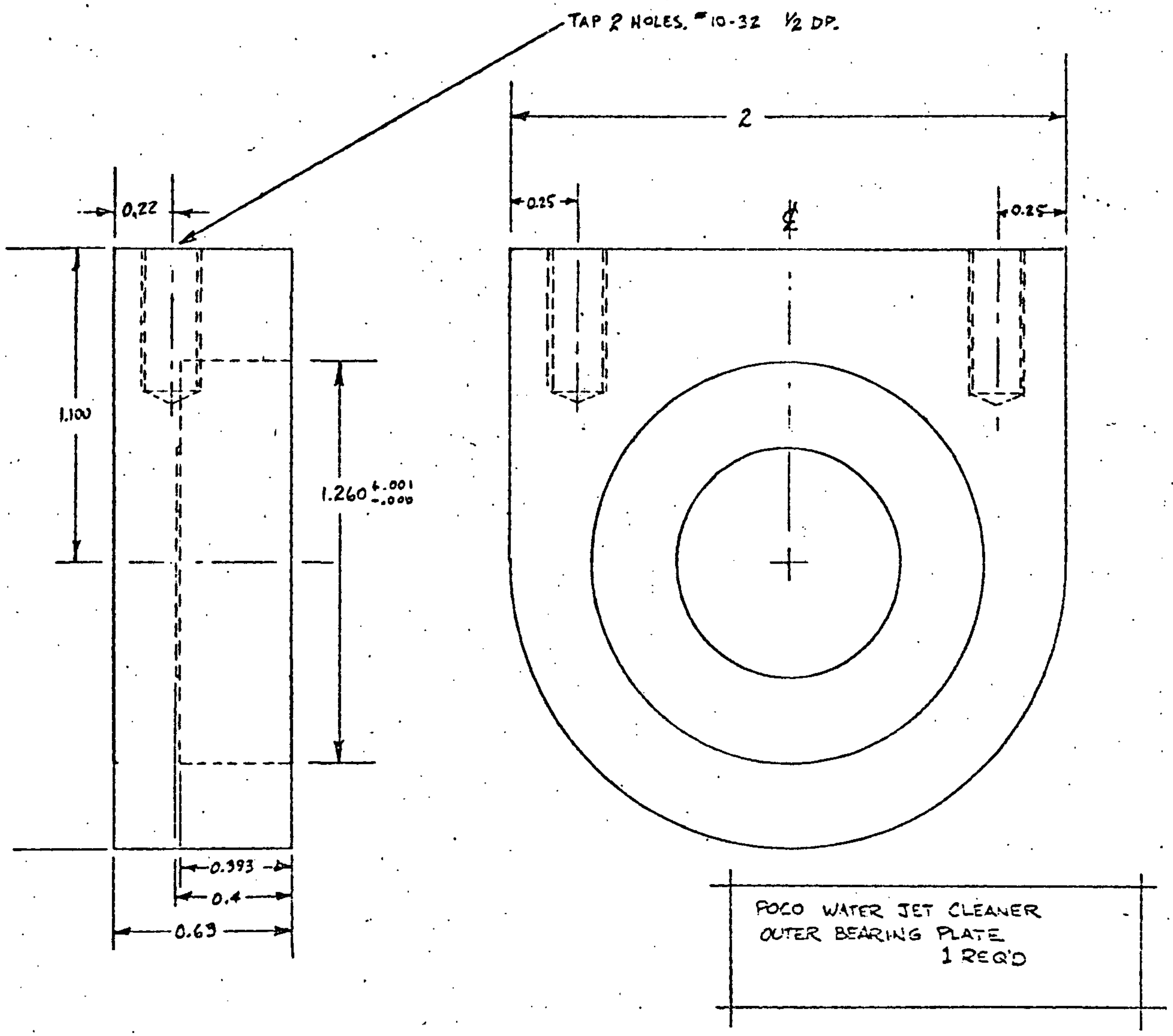


FIGURE 62
WATER JET PROTOTYPE

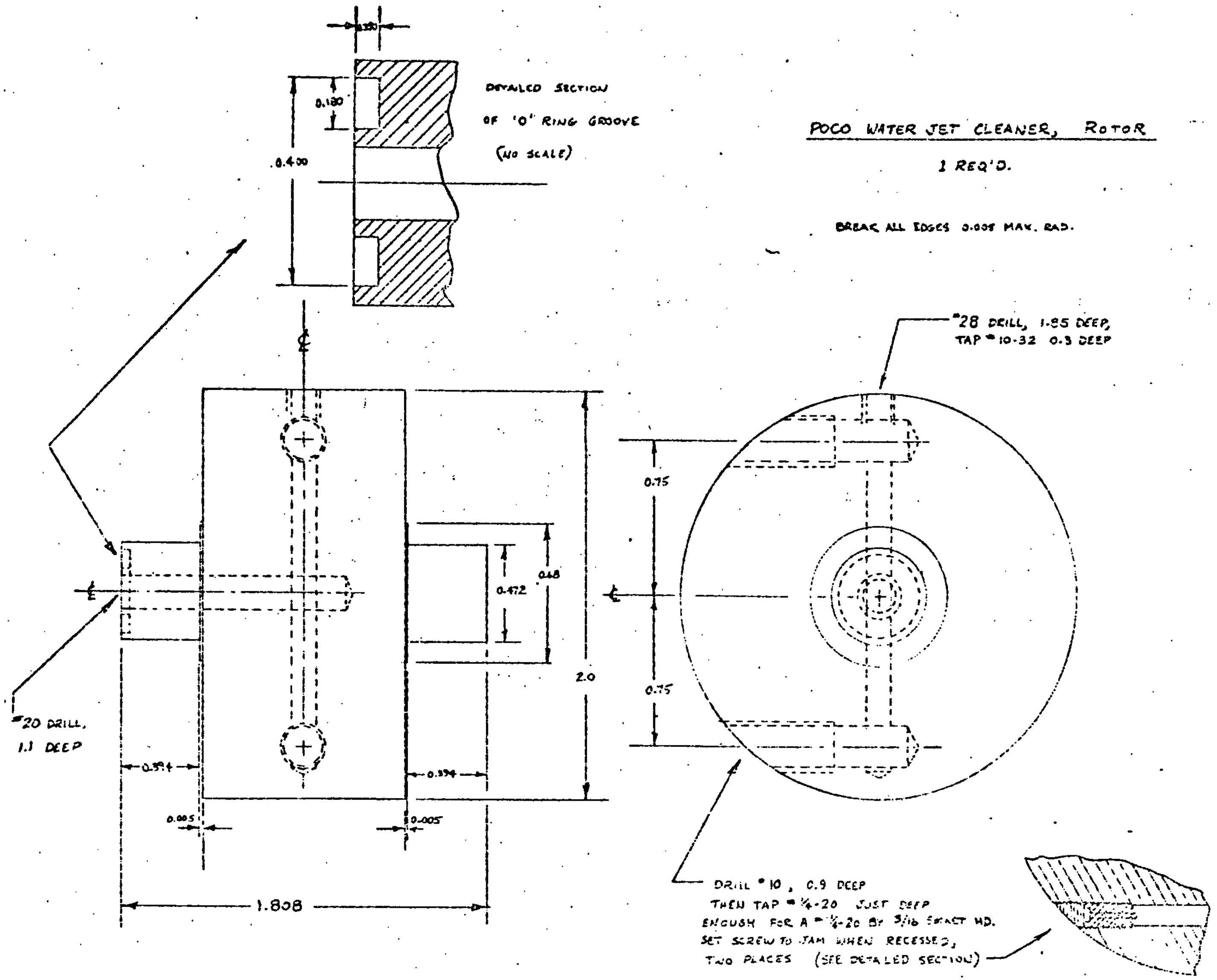


FIGURE 63

WATER JET PROTOTYPE

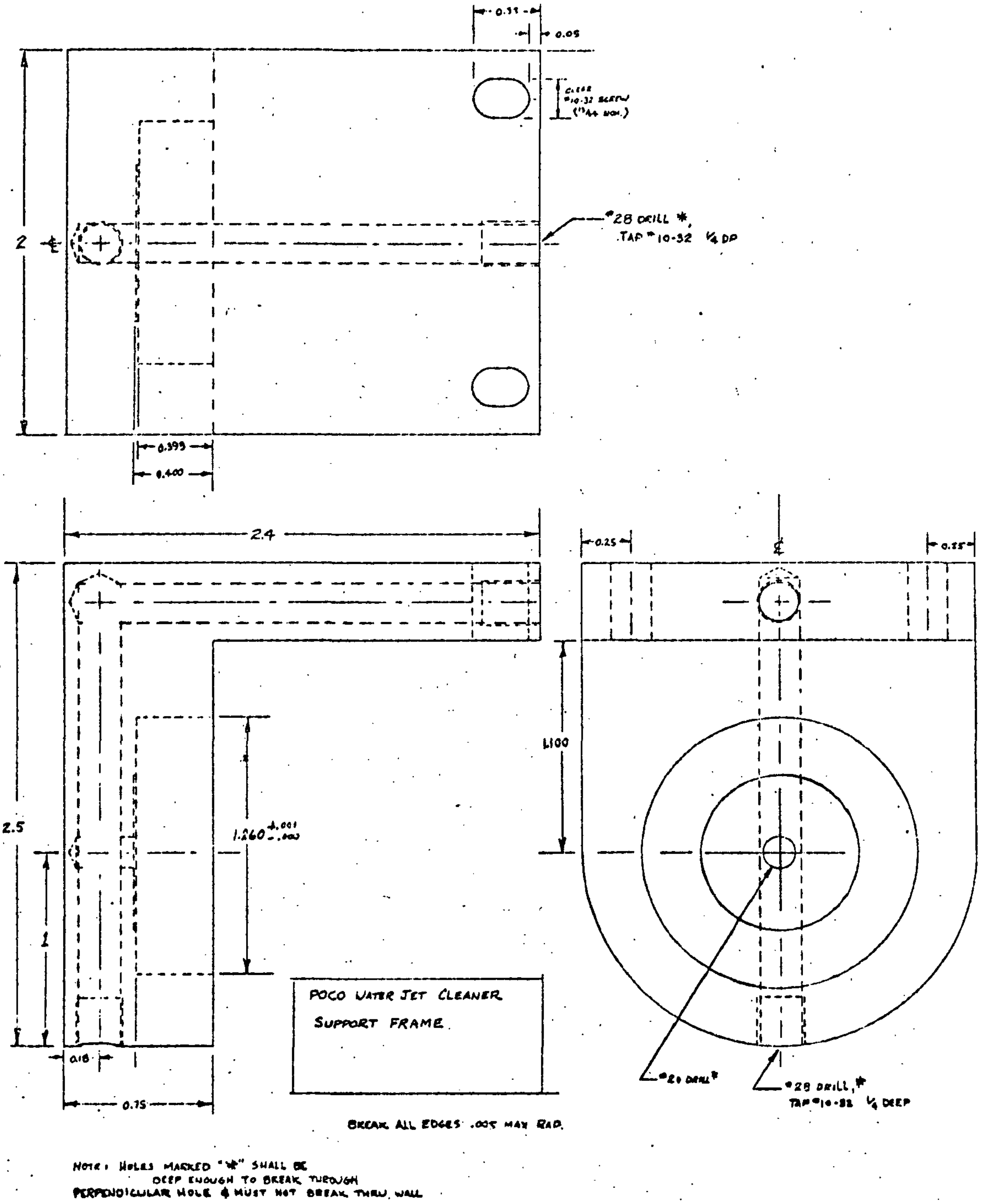


FIGURE 64

WATER JET PROTOTYPE

shell structure. The life cell is a pressure vessel which provides structural support for the internal equipment which is integrated into the spherical housing chamber.

To provide adequate living area for the primate while subjecting him to an orientation cueless environment, a spherical housing chamber of 1.524 meters inside diameter has been selected, providing an enclosed volume of 1.852.

The sphere will be made by injection molding sixty identical triangular spherical segments (Fig 65) when fitted together form a complete sphere. Holes will be cast into the ribs on all three apexes of the triangular segments so that dowel pins may be inserted to precisely locate the relative positions of the sections during assembly. The segments will be fitted together with removable fasteners and will have a thin layer of compliant material between them to provide a gas and water tight gasket and to allow for material expansion due to temperature variations.

The modular segments are to be fabricated so that they are interchangeable to facilitate exchange and repair.

B.1 MISSION REQUIREMENTS

1. Dimensions: 1.524 meters $\pm$ 0.2 cm inside diameter.
2. The sphere must have sufficient structural integrity to withstand the forces imposed at launch.
3. The sphere must have sufficient structural integrity to withstand forces of up to 60 kg applied by the primate at any point and in any direction.

4. The triangular segments must be of the following planar dimensions:

Long side:	57.61 cm	+.000 -.01 cm
Short sides:	51.36 cm	+.000 -.01 cm

5. The sphere must have sufficient structural integrity to withstand a continuous pressure differential of 16.2 psia.
6. The sphere must have an easily removable hatch (6 triangular segments) to facilitate primate insertions.

B.2 LIFE CELL WALL SEGMENT DISPOSITION

In order to present an orientation cueless environment to the primate, the various components visible to the primate have been placed symmetrically about the sixty triangular wall segments. The geometrical constraints of a Solid Pentakis Dodecahedron (60 sided geodesic figure) necessitated the following quantity of components in order to establish an orientation cueless environment:

Behavioral Display Panels:	6
Feeder:	6
Water Dispenser:	6
Temperature Control Switch:	6
Light Intensity Control Switch:	6
Task Initiate Switch:	6
Camera Lens:	1
Tracking System Lens:	5
House Lighting Panel:	24

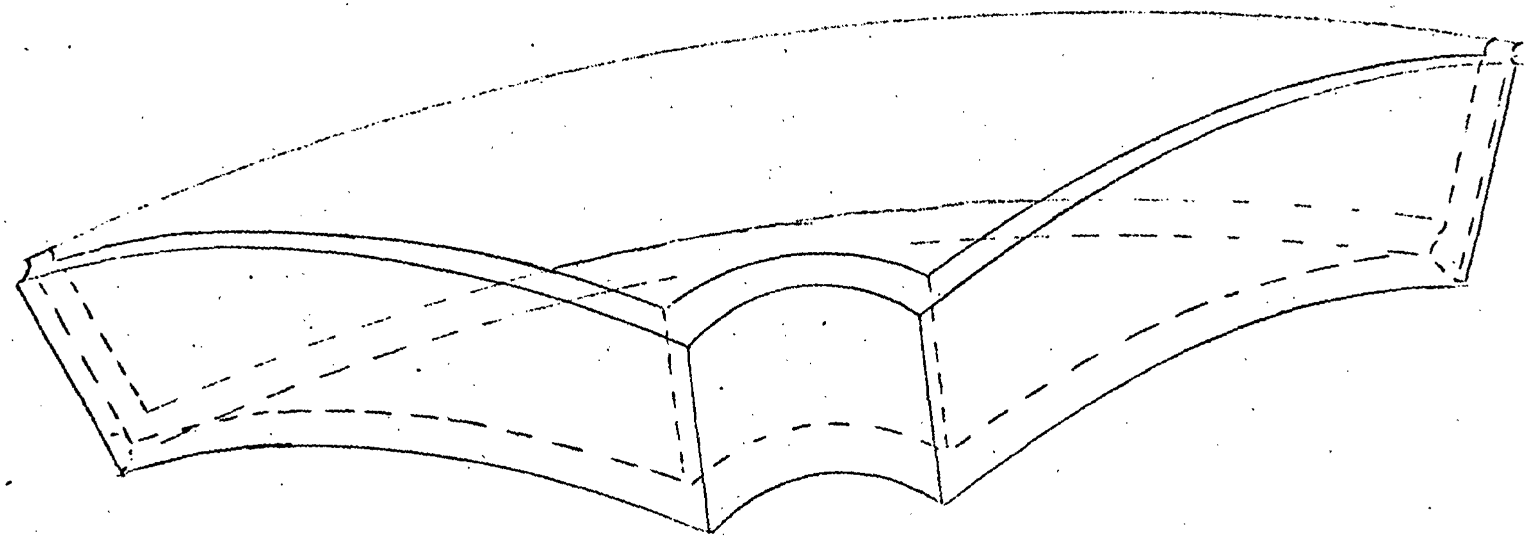


FIGURE 65

TRIANGULAR SHAPED WALL SEGMENT

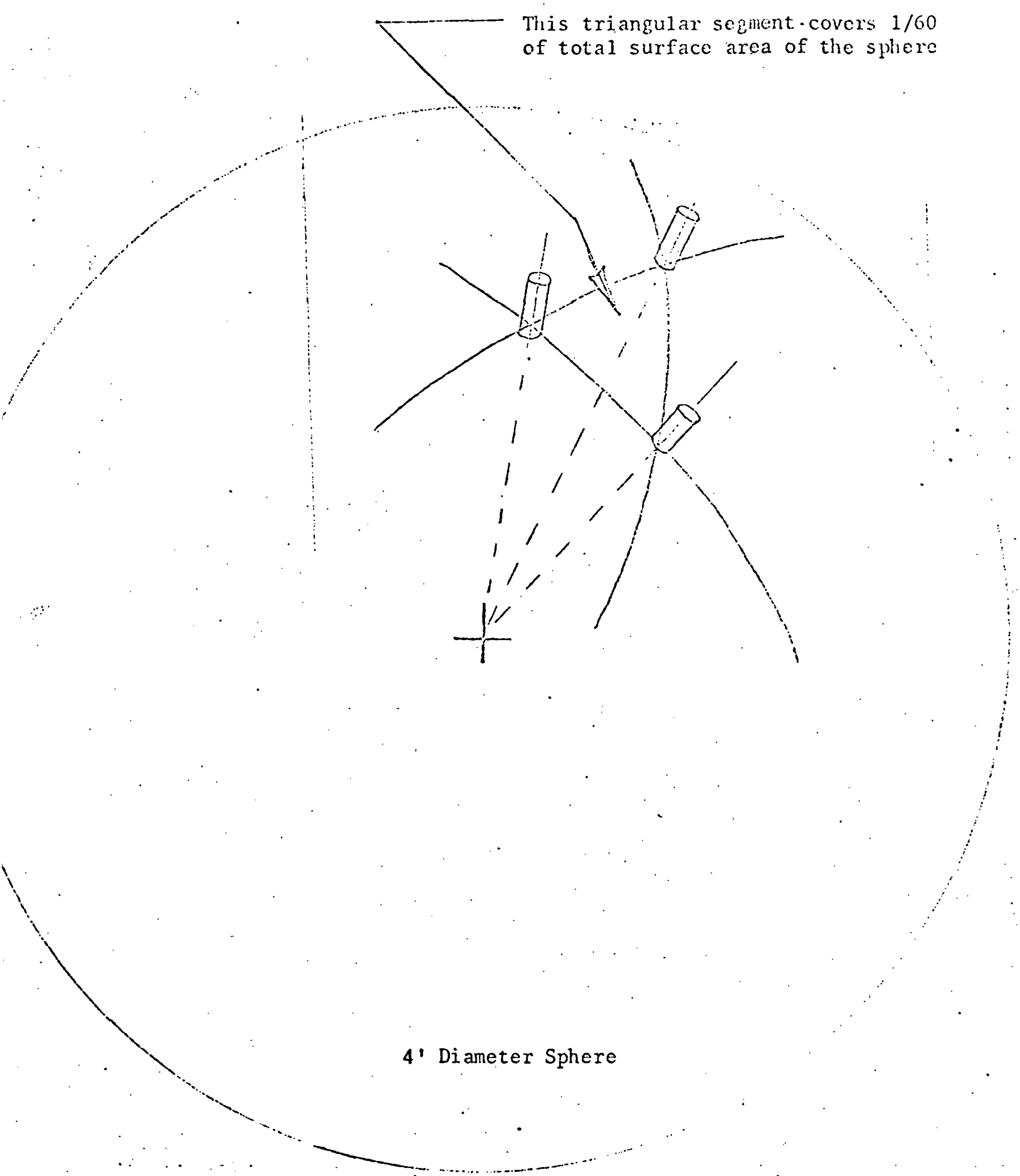


FIGURE 66

RELATIVE POSITION OF TRIANGULAR SEGMENT

IN RESPECT TO SPHERE AND CYLINDERS

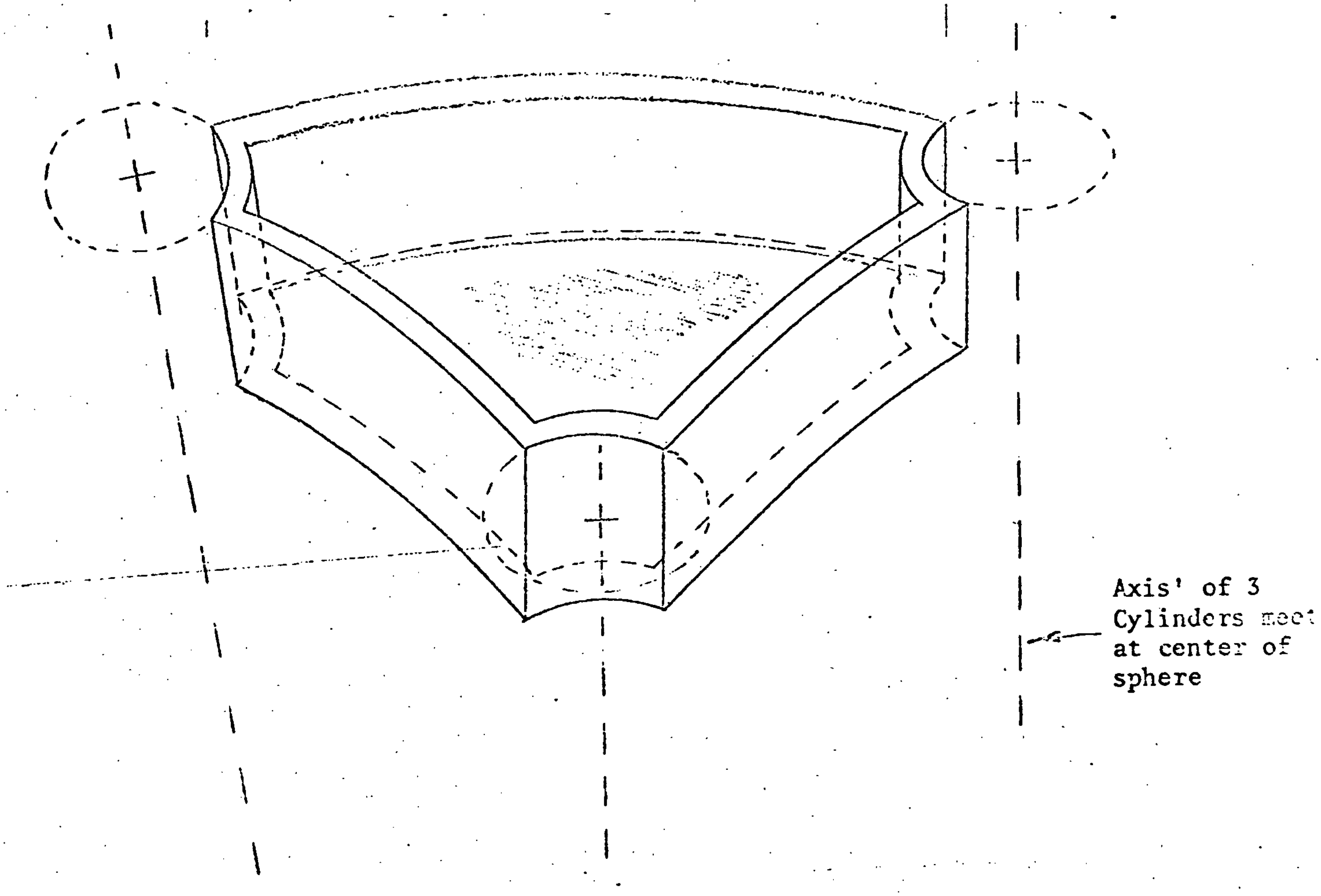


FIGURE 67

MOLDED POLYCARBONITE

TRIANGULAR SPHERICAL SEGMENT

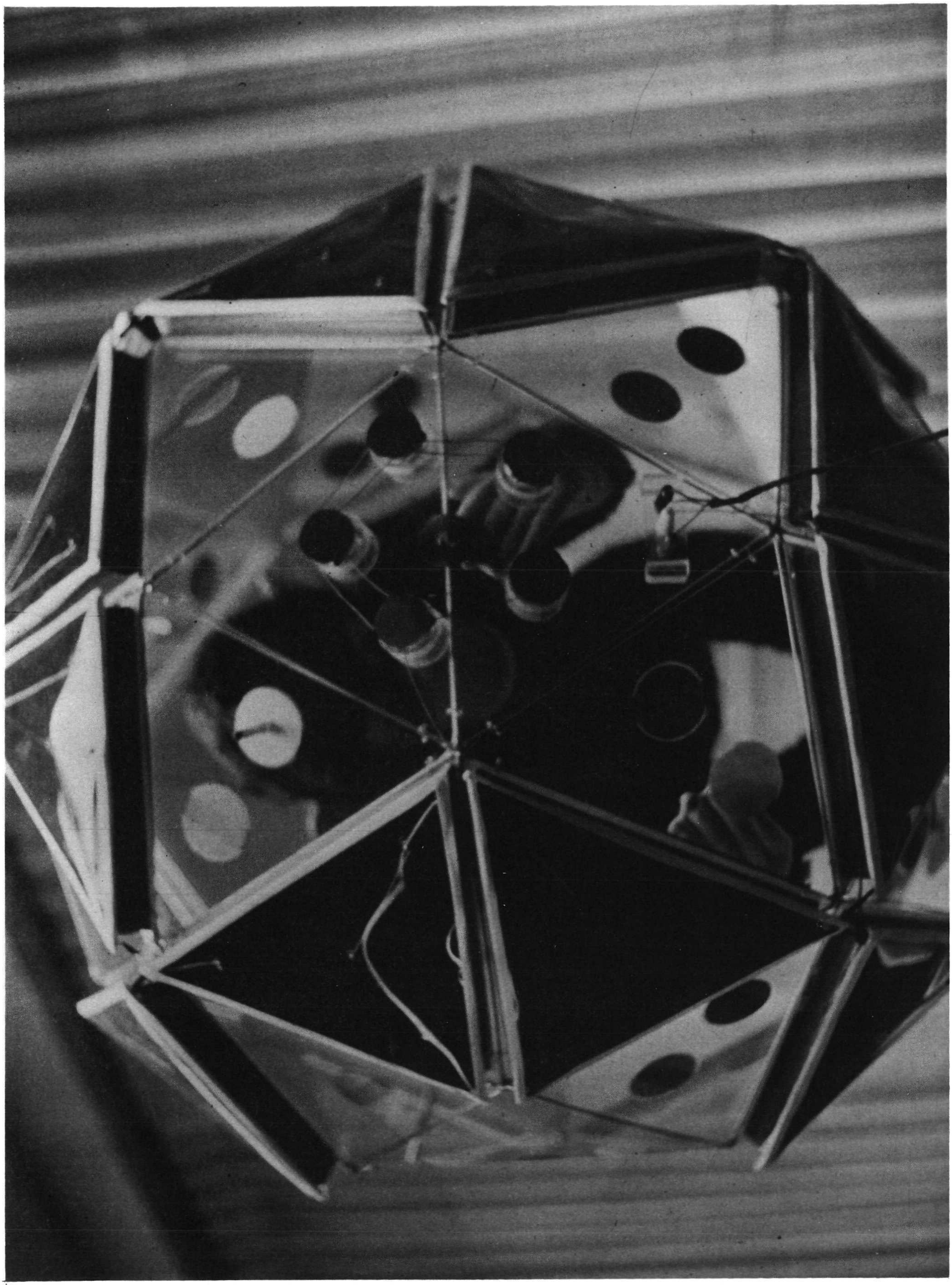


Fig. 68
A one-half size mockup was fabricated
for visual display purposes

Each of sixty triangular shaped wall segments contain one or more of the above components. Presented in Table 12 is the disposition of these segments.

TABLE 12

WALL SEGMENT DISPOSITION

Quantity of Triangular Wall Segments	Function
12	Behavioral display panel (including secondary reinforcement switch and feeder)
24	House lighting
6	House lighting on/off control switches
6	Water dispenser, dummy switch
1	Camera lens, task initiate switch
5	Tracking System lens, task initiate switch
60	TOTAL

A one-half size mockup was fabricated for visual display purposes (Figure 68).

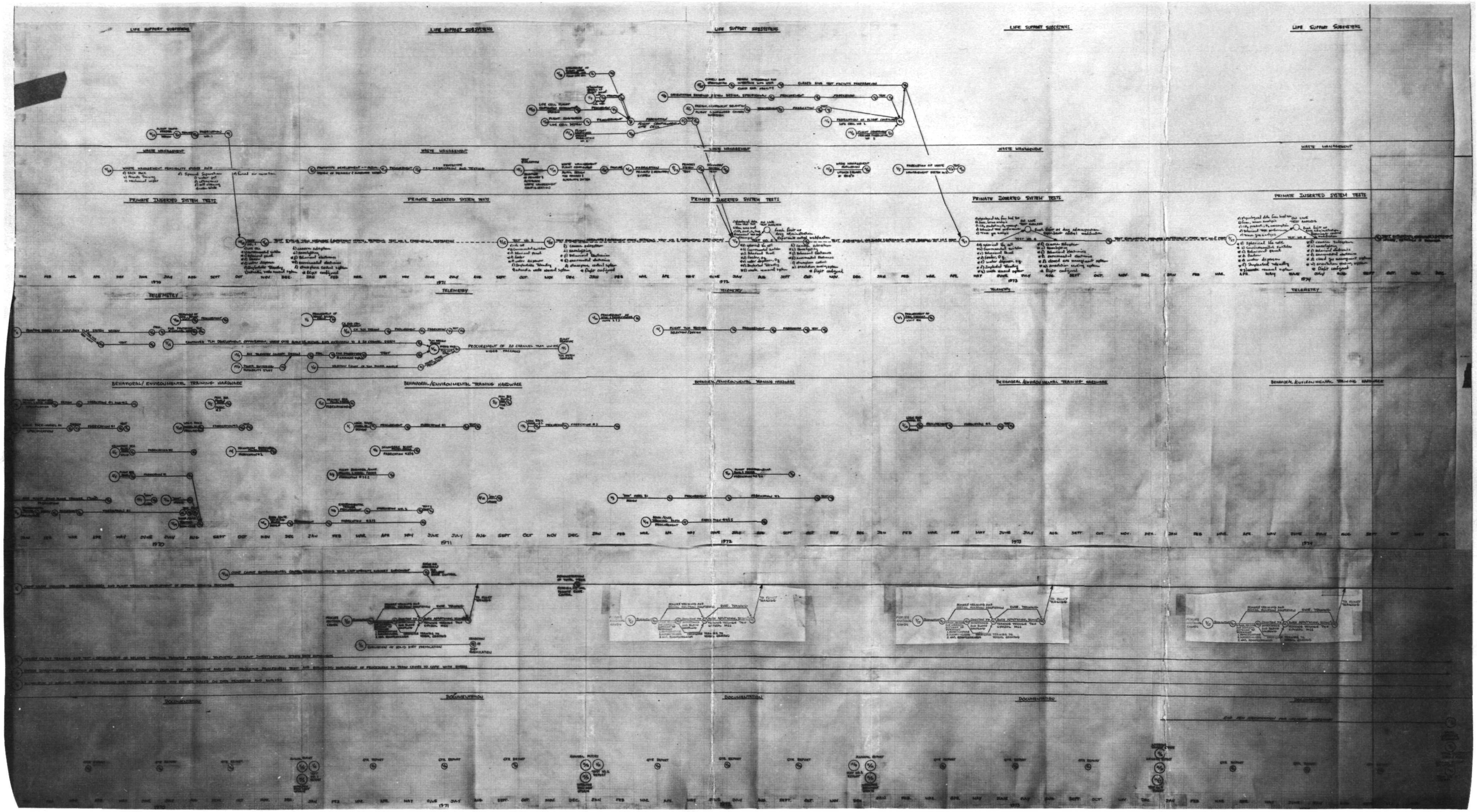


FIGURE 69
5 YEAR FLOW CHART FOR POCO DEVELOPMENT

V PROGRAM PLAN

Prior to program termination, a five year program plan encompassing the hardware development, experiment definition, primate training and system tests. For reference, this program plan is included with hash marks indicating completed tasks. A vertical line labeled "Termination" displays the time at which the program plan was no longer followed in order to perform higher priority close-out functions.

A. TELEMETRY

A.1 MISSION REQUIREMENTS

A totally implantable telemetry system to continuously condition and transmit the physiological data requirements of Table I throughout the duration of this mission was the objective of our design consideration. The telemetry system is envisioned to be divided into two independent units; one to transmit data from the central and peripheral nervous system, mounted on the bones of the Calvaria and the other to transmit data from the cardiovascular system implanted in the abdominal or pleural cavity (See Fig 4).

The neurological data acquisition unit will transmit data obtained from implantation of surface and deep brain electrodes in accordance with the stereotaxic technique established in this laboratory. Typical electrode placements are shown in Figure 5. From a physiological standpoint, the unit must weigh no more than 350 grams and occupy a volume of less than 150 cm^3. The cardiovascular telemetry unit, if implanted in the pleural cavity must weigh no more than 100 gms, occupy a volume of no greater than 100 cm^3, be of specific gravity 1.0 to 1.1 and be shaped as shown in Fig. 6. This area of implantation was selected primarily for its low rejection characteristics, ease of surgical implantation, and dynamic damping characteristics.

B. TELEMETRY SYSTEM ACHIEVEMENTS

A large segment of the total program effort was devoted to telemetry system advancements, resulting in the total development of two distinct data processing concepts; the former utilizing frequency multiplexing techniques and the more recent utilizing time division methods. Early in the program, a seven channel FM/AM telemetry system was completed and has been used extensively with outstanding results for data acquisition during behavioral training, primate inserted system tests, and in the daily recording periods. More recently, a PAM/FM system has been developed that features considerably lower power consumption and is more efficiently packaged to meet the objectives of the mission requirements.

1. PAM/FM SYSTEM

Time division multiplexing was selected in preference to frequency division multiplexing after analysis of the size and power requirements of each. The advantages of the former have increased greatly with the recent development and commercial availability of Complementary Symmetry Metal Oxide Semiconductor (CMOS) integrated circuits. Moreover, after considering the trade-off between signal-to-noise ratio and circuit complexity, PAM was chosen over PCM and other time division methods.

a. PAM/FM SYSTEM DESCRIPTION

Design, Development, Fabrication, and Test of an eight channel PAM/FM telemetry system was accomplished. To our knowledge, the system represents a major breakthrough in the area of remote sensing and transmission of physiological data and is indeed state of the art. Furthermore, the design concept when extended to a twenty-one channel system is capable of satisfying the mission requirements as set forth.

A multichannel biotelemeter consists of signal conditions, multiplexer, and transmitter. A description of each is offered below:

a.1 AMPLIFIERS

Each differential amplifier is comprised of three Fairchild µA 735 integrated circuit operational amplifiers per data chennel, two of which are connected as direct input voltage follower stages (unit gain). The output of each pair of amplifiers represents the differential physiological signal and is capacitively coupled to the third integrated circuit which is configured as a differential gain stage. The AC coupling between stages sets the lower 3 dB cutoff frequency to 0.5 Hz and is required to block the often large DC offset potential on the monitoring electrodes and to minimize the 1/f noise contribution between DC and 0.5 Hz. This design provides three important performance characteristics. First, the voltage follower stage has extremely high input impedance (<50 MΩ). Second, the low, reasonably matched source inpedances of the voltage follower results in increased rejection of signals common to both inputs. Third, through the use of integrated circuits, the number of components is minimized, and optimal efficiency may be realized utilizing hybrid packaging techniques. The amplifier circuit design is shown in Fig 7.

a.2 MULTIPLEXER

Time-division multiplexing was selected in preference to frequency-division multiplexing after analysis of the size and power requirements of each. Moreover, after considering the trade-off between signal-to-noise ratio and circuit complexity, PAM was selected over PCM and other time-division methods. The resultant multiplexer design, shown in Fig 8 for an eight channel system is noteworthy for its simplicity and for its extremely low power consumption (<7 μA @ $\pm$2.7 VDC). The eight channel multiplexer is comprised of two RCA CD4016 four channel analog switch integrated circuits, one RCA CD4001D, an integrated circuit device containing four dual imput digital gates, two of which are interconnected as a free running multivibrator to provide the timing signal, and one RCA CD4017 decade counter integrated circuit. The multivibrator timing is set to provide a 2.56 kHz square wave to the decade counter which in response generates an output level sequentially from each of the ten gates. Two of the decade counter outputs are connected to resistive voltage dividers which generate appropriate voltage levels to form two synchronization pulses. The remaining decade counter outputs are used to control the eight analog gates. The sync pulses and sampled analog levels are connected in common (summed) to form a single PAM pulse train. Each gate is sampled 256 times per sec. The voltage divider networks at the input of the analog switches are designed to deliberately offset the amplifier output signals such that they always remain positive. This is done to avoid the dead zone characteristics of the bipolar analog switches. In addition, the DC offset between adjacent channels are deliberately set to differ by 50 mV to reduce the possibility of losing channel synchronization.

a.3 TRANSMITTER

A 90 MHz variation of the Vackar oscillator is shown in Fig 9. The resultant design has excellent stability for a single transistor oscillator over a wide range of both temperature and supply voltage. The oscillator frequency is modulated by replacing one of the oscillator's tank circuit capacitors with a varactor diode fed by a voltage follower integrated circuit amplifier. The transmitter is operated at 330 μA @ ±2.7 VDC and, for the near field application, generates adequate RF power.

a.4 PACKAGING DESIGN

An eight channel prototype unit was constructed using standard printed circuit board techniques in an 8.573 cm x 8.573 cm x 3.175 cm package (see Fig 10). This unit was subjected to extensive functional and environmental testing. Successful test results provided the go ahead for fabrication of an eight channel implantable telemetry system using thick film hybrid packaging techniques.

The assembly consists of eight hybrid thick film amplifiers fabricated on individual ceramic substrates. The substrate is processed using various conductive and resistive inks to form a passive network of resistors and conductors to which active devices are attached with conductor epoxy. The units are mounted on a circular ceramic mother board containing the multiplexer circuitry. Internal interconnections are made using conventional fired thick film conductor patterns and thermocompression wirebonding techniques. Future assemblies will use beam lead techniques to maximize yield and minimize cost. After functional testing, the units will be sealed with glass. The amplifiers and multiplexer were combined on a circular alumina substrate, 7.35 cm in diameter by 0.97 cm thick (Fig 11).

b. SPECIFICATIONS

The subsystem specifications as measured from the prototype unit are shown below:

BIOTELEMETRY AMPLIFIER

1.	Gain:	1000±25 (Selectable)
2.	Frequency Response:	0.5 Hz to 100 Hz (3 dB pt.)
3.	Noise:	<2 μV P-P referred to input (Z_S = 50 K)
4.	Common Mode Rejection Ratio:	>90 dB
5.	Input Impedance:	>50 MΩ
6.	Power Concumption:	<60 μAC±2.7 VDC
7.	Maximum Voltage Swing:	±2.5 VDC
8.	Supply Voltage:	±2.7 VDC

FM TRANSMITTER

1.	Frequency of Oscillation:	90 MHz
2.	Power Consumption:	330 μAC @ ±2.7 VDC
3.	Noise:	<1 μV rms (Z_S = 100 K)
4.	Size (printed circuit board):	5.08 cm x 2.16 cm x .635 cm
5.	Weight:	5 grams
6.	Deviation Sensitivity:	1 kHz/mV P-P
7.	Frequency Response:	DC to 10 kHz

c. POWER CONSIDERATIONS

The power budget of an eight channel system for near field applications is shown in Table 13.

TABLE 13
8 CHANNEL SYSTEM
POWER BUDGET

	VDC Voltage	μ amps Current	μ watts Power
Amplifier (each)	±2.7	54	292
Multiplexer	±2.7	7	38
Transmitter	±2.7	330	1782

The current drain of an eight channel system would be $8\,(I_{amp}) + I_{mult} + I_{xmtr} = 8(54) + 7 + 330 = 769\ \mu A$. The 180 days mission therefore requires a power source delivery of 3.32 amp. hrs.

Extension to a larger number of channels merely requires the addition of supplementary analog switches and an extension of the sequential digital output from ten to the required number of channels. The clocking rate would necessarily be increased in order to maintain an equivalent bandwidth response. Higher sampling rates require additional power consumption by CMOS elements. A power budget is shown in Table 14 for a twenty-one channel system.

TABLE 14
21 CHANNEL SYSTEM POWER BUDGET

	VDC Voltage	μ amps Current	μ watts Power
Amplifier	±2.7	54	292
Multiplexer	±2.7	26*	140
Transmitter	±2.7	330	1782

*Estimated

Eminent power sources, including nuclear sources, biological fuel cells, and piezoelectric devices have been received and were found not compatible with the voltage requirement of our system. To date, we have used commercially available mercury cells exclusively. Approximately 80% of the rated capacity of certified cells can be expected. The specifications of one such cell, the Mallory RMICC is presented below:

Maximum suggested current drain	20 ma mA
Service Capacity	1000 mah
Service Rated at	5 ma
Diameter	1.59 cm
Length	1.65 cm
Weight	12.2 g
Volume	3.29 cm^3

d. DATA ACQUISITION

The transmitted signal may be detected by any high quality receiver that has been modified by removing the AFC network. The removal of AC coupling within the receiver eliminates cross talk between adjacent channels. In our receiving station the wavetrain is then routed to an EMR model 515 PAM Synchronizer which is used to decode frame and channel sync timing pulses, and to recalibrate the signal level as a function of the maximum to minimum sync pulse voltage difference. The synchronizer also reformats the amplitude variant PAM signal into a binary ten bit parallel output which, along with the frame and channel sync pulses, is routed to an EMR model 516 Demultiplexer where it is reconverted into the eight analog channel outputs. The digital output from the PAM is also connected to a PDP-8I computer that formats the digitized data for recording on digital magnetic tape. The eight analog outputs from the demultiplexer are routed in parallel to a Beckman type R oscillograph and a Sanborn model 769 eight channel high persistance oscilloscope for display. The total system block diagram is shown in Figure 12. We are presently evaluating several receiving antenna systems in an attempt to obtain omnidirectional reception with minimum physical size. A modification of the three orthogonal antenna system reported by Mackay appears to be the best system for minimizing dropouts resulting from nonalignment of transmitter and receiving antenna.

The data acquisition and processing equipment described above were combined with associated test apparatus as shown in block diagram form in Figure 13, to form a test console containing all the equipment necessary for complete functional testing of PAM/FM telemetry systems. A photograph of the console is shown in Figure 14.

B.2 FM/AM SYSTEM

a. DESCRIPTION

Design, development, fabrication, and test of a seven channel FM/AM telemetry system was accomplished. The system employs seven voltage controlled oscillatiors to generate IRIG standard frequency modulated subcarriers which are linearly summed and used to amplitude modulate a crystal controlled transmitter. The subcarriers carry the physiological data signals and thus, the calibration of the data channel is independent of signal strength. The system is shown in block diagram form in Figure 15. The system has been well documented[1] therefore, the circuits operation will not be discussed. The schematics of the amplifier, voltage controlled oscillator and AM crystal controlled transmitter are shown in Figures 16, 17, and 18 respectively.

b. SPECIFICATIONS

The specifications of the individual components are set forth below:

AMPLIFIER

1. Frequency response: 0.5 to 50 K Hz (bandwidth may be restricted to 100 Hz by utilizing 220 pf capacitors across feedback resistors.
2. Supply voltage: ± 3 volts D.C. nominal: Circuit operates from ± 2.8 to ± 4.2 volts.
3. Gain: 1500 nominal (may be increased to 10,000): From 1200 to 3000 over supply voltage range.
4. Input impedance: 500 K to 250 K (differential) over supply voltage range; 260 K at ± 3 volts supply.

5. Common mode input impedance: 500 K

6. Dimensions: Height: 1.5 cm

   Depth: 1.5 cm

   Length: 1.2 cm

7. Weight: 7 gms

8. Power dissipation: 300 μ watts (50 μ amp at ± VDC.)

9. DC offset: 250 mv

10. CMMR: 80 db

11. Output impedance: < 300 Ω

12. Noise: 1μv rms, 10 K ohm source impedance

    20μv rms, 250 K ohm source impedance

c. POWER CONSIDERATIONS

The power budget for the FM/AM telemetry system for near field applications is shown in Table 15.

TABLE 15

FM/AM POWER BUDGET

	VDC Voltage	(μ amps) Current	(μ watts) Power
Amplifier (each	±3	50	300
VCO (each)	±3	107	640
Transmitter	±3	1000	6000

d. DATA ACQUISITION

In our laboratory, the transmitted signal was received by a Defence Electronics Inc. model TMR-5A receiver with a model TMH-B5 tuning unit. The receiver provides a demodulated output connected in parallel to Electro-Mechanical Research Inc.

model 189 standard IRIG discriminators. The subcarrier discriminator outputs reformat the signal to analog and are routed in parallel for recording.