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A CLOSED LOOP LIFE SUPPORT SYSTEM FOR DETERMINING METABOLIC GASES PRODUCED BY SMALL ANIMALS

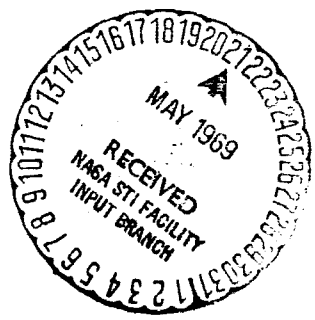
Authors

A. E. Binks N.L. Bonatucci R.M.Ross



GENERAL ELECTRIC COMPANY

Missile & Space Division
Re-Entry Systems Department
Valley Forge, Pennsylvania



(This work performed under contract NAS2-1900 with NASA Ames Research Center)

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A CLOSED LOOP LIFE SUPPORT SYSTEM

FOR DETERMINING METABOLIC GASES PRODUCED BY SMALL ANIMALS

A.E. Binks N.L. Bonatucci R.M. Ross

Spacecraft life support systems have to conform to increasingly restrictive design requirements as the length of space missions increase. Limitations on size, weight and power consumption require that a careful evaluation of all aspects of the system be made. A major component of the life support system is the gas management assembly (GMA). The GMA uses chemical adsorbents to reduce the gas and vapor concentrations within a space capsule to acceptable levels and it is very desirable that the amounts of these adsorbents carried on the flight is at the minimum level possible.

During the course of the Biosatellite program a need arose to design a GMA capable of supporting small animals for a period of 21 days. The experiments described here were undertaken to measure the trace contaminant gases and vapors emitted by rats, their liquid diet and their waste products in order to effectively design a trace contaminant control canister for the GMA.

The hazards associated with trace contaminants in the atmospheres of spacecraft, space simulators and submarines have been illustrated several times. A well documented study[1] by the Boeing Company in the MESA program illustrates this: MESA 1 had to be aborted after five days because of the crew's nausea. The symptoms of the crew's illness indicated poisoning by dichloracetylene[2], which was subsequently identified in the gases desorbed from the

charcoal adsorbent used in the capsule. Dichloracetylene is produced by the decomposition of chlorinated hydrocarbons such as trichloroethylene. This solvent had been used during preparation of the MESA I capsule.

Although there is considerable information available on contamination of closed atmospheres by humans and by system components, no data is available on trace contaminant emission from rats.

Experimental Approach

The stated goal of quantitatively measuring the contaminant gas and vapor generation rates could only be achieved if the rats were enclosed in a leak tight closed system. The rats consume oxygen, which must be replaced, and produce carbon dioxide, which must be removed. An automatic method of oxygen replacement and carbon dioxide removal was to be preferred since this minimized the necessity for constant supervision of the equipment. A method for feeding the rats without breaking into the system was also necessary. The trace gases and vapors presented us with a complex mixture for analysis. It was necessary to determine the components of this mixture and the most effective method for doing this is by infrared spectrophotometry. The spectra obtained by this method show the molecules in terms of the fundamental vibrations and rotations of their chemical bonds. The use of standard spectra, obtainable from the literature, allow one to determine the molecules present.

It was decided to put the spectrophotometer directly in the circulating air of the closed system rather than to take air samples at intervals and then inject them into the spectrophotometer. In-line operation allowed us to easily measure a large volume of the system atmosphere and this resulted in greater sensitivity to gases and vapors present in low concentrations.

The removal of a large volume of the atmosphere is impractical. Therefore, a sampling method would have much lower sensitivity.

Description of Apparatus (For full description see Appendix)

The experimental arrangement is shown in Plate 1. The test chamber is in a closed system with a pump and infrared spectrophotometer with gas-cell attachment. The manifold which connects these components is of glass. Glass stopcocks sealed into the manifold systems can be closed as desired to allow the circulating air through canisters which are situated on by-pass lines.

The oxygen content of the system atmosphere is indirectly monitored by a pressure drop detector since the carbon dioxide produced by the rats is adsorbed in a lithium hydroxide canister and the removal of this gas causes a pressure drop in the system. The limb of a manometer which is in contact with the system atmosphere, is situated directly in the light path between a light source and a photocell-relay. The position of the manometer column is adjusted so that as the pressure in the system drops, the mercury column interrupts the light beam. The circuit is arranged so that a solenoid valve now opens and allows oxygen to enter the system until the pressure is sufficient to return the mercury column to a position below the light beam. The solenoid valve is then closed by the photocell-relay circuit. The operation is fully automatic and this arrangement adequately controlled the oxygen content of the system atmosphere during the whole of the 21 day test.

The infrared spectrophotometer and gas cell attachment directly in line made it possible to continuously detect and analyze the contaminants produced by the rats. As the contaminant gas concentrations increased it became possible to more accurately analyze the amounts present (by gas chromatographic and detection tube methods). Small samples of system atmosphere were withdrawn to carry out these analyses. These samples were also analyzed for oxygen and nitrogen content.

The rats could obtain nutrition (a liquid Schwarz diet) by biting a lever in the feeder bowl in their cages, a feeder programmer ensured that the rats could not overfeed themselves.

Trace Contaminants Identified

The gas cell of the infrared spectrophotometer was adjusted so that an absorption path length of 1375 cms was obtained. The lowest absorbance easily detectable on the infrared spectrum trace is approximately 0.005, consequently the minimum concentration of trace contaminant observable,

$$C_{min} = 0.00000364 \times k^{-1}$$

The bsorption coefficient (k) for the contaminant can be obtained from published data or by calibration of the instrument using standards.

Major trace contaminants observed in the system after 21 days were methane, ammonia, carbon monoxide, methanol, ethanol, hydrogen sulfide, acetone and amines. Generation rates (units: ccs of trace contaminant/gm of rat/hour) were measured for methane (560×10^{-6}): ammonia (430×10^{-6}): carbon monoxide (4.1×10^{-6}) and hydrogen sulfide (measured indirectly as less than 800×10^{-6}). Other contaminant generation rates were less than 1×10^{-6} cc's/GM/hour.

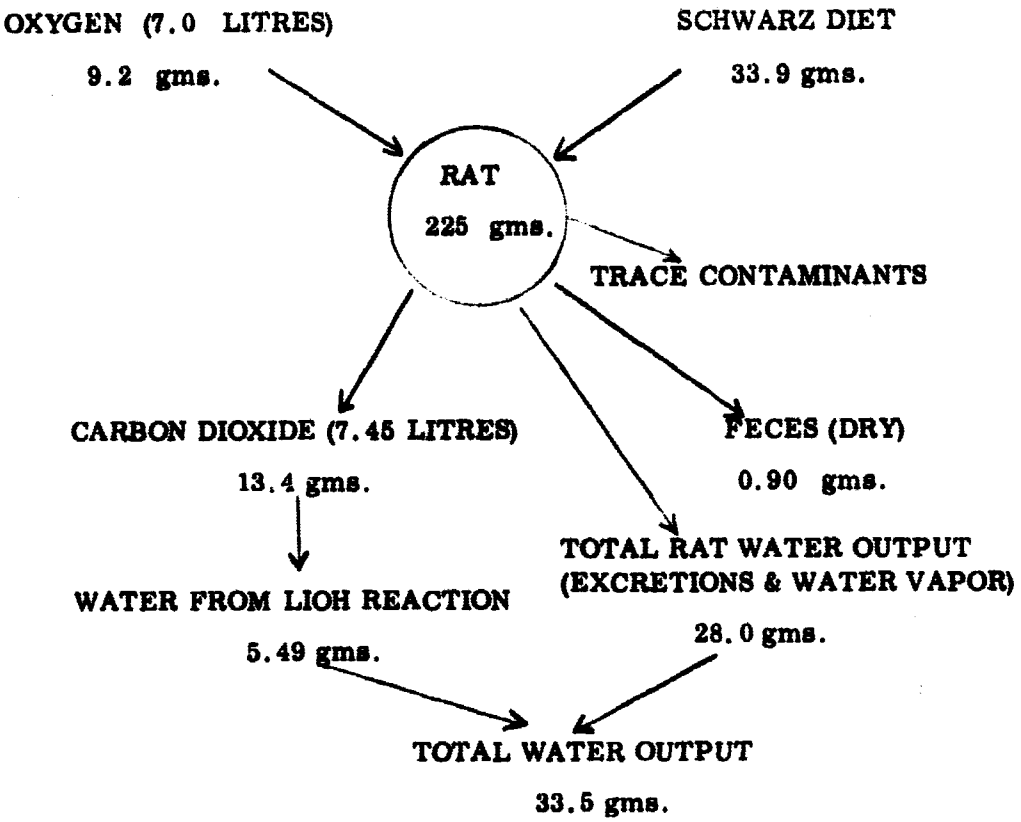


FIGURE 1 SUMMARY OF EXPERIMENT IN TERMS OF WEIGHT BALANCE PER DAY FOR AN AVERAGE RAT

The rats used in these experiments were Sprague Dawley female virgins and they weighed around 225 grams each. Their average weight gain (0.66 gms) during the 21 day test was less than the average gain (17 gms) of three control rats which fed on the liquid diet in the laboratory atmosphere for 21 days. However, the test rats completed the test in good condition with normal temperatures, firm feces, clear eyes and no excessive chisel tooth growth.

A study of the weight balance for the system during the test is summarized in Figure 1.

Using the results of this study and previously known data on atmospheric contamination by space capsule system components, a trace contaminant control assembly was designed which was capable of maintaining eight rats for 21 days.

The system described is suitable for all small animals. It requires little supervision. It has applications in the Advanced Biosatellite Program and is more generally applicable to studies of long term effects of toxic gases on small animals.

References

1. Space Cabin Contaminant Study Spurred by Environment Tests, Technology Week, 18 20 (July 4, 1966)
2. A New Hazard in Closed Environmental Atmospheres, R. A. Saunders, Arch. Environ. Health, 14 380 (1967).

APPENDIX I

DESCRIPTION OF APPARATUS

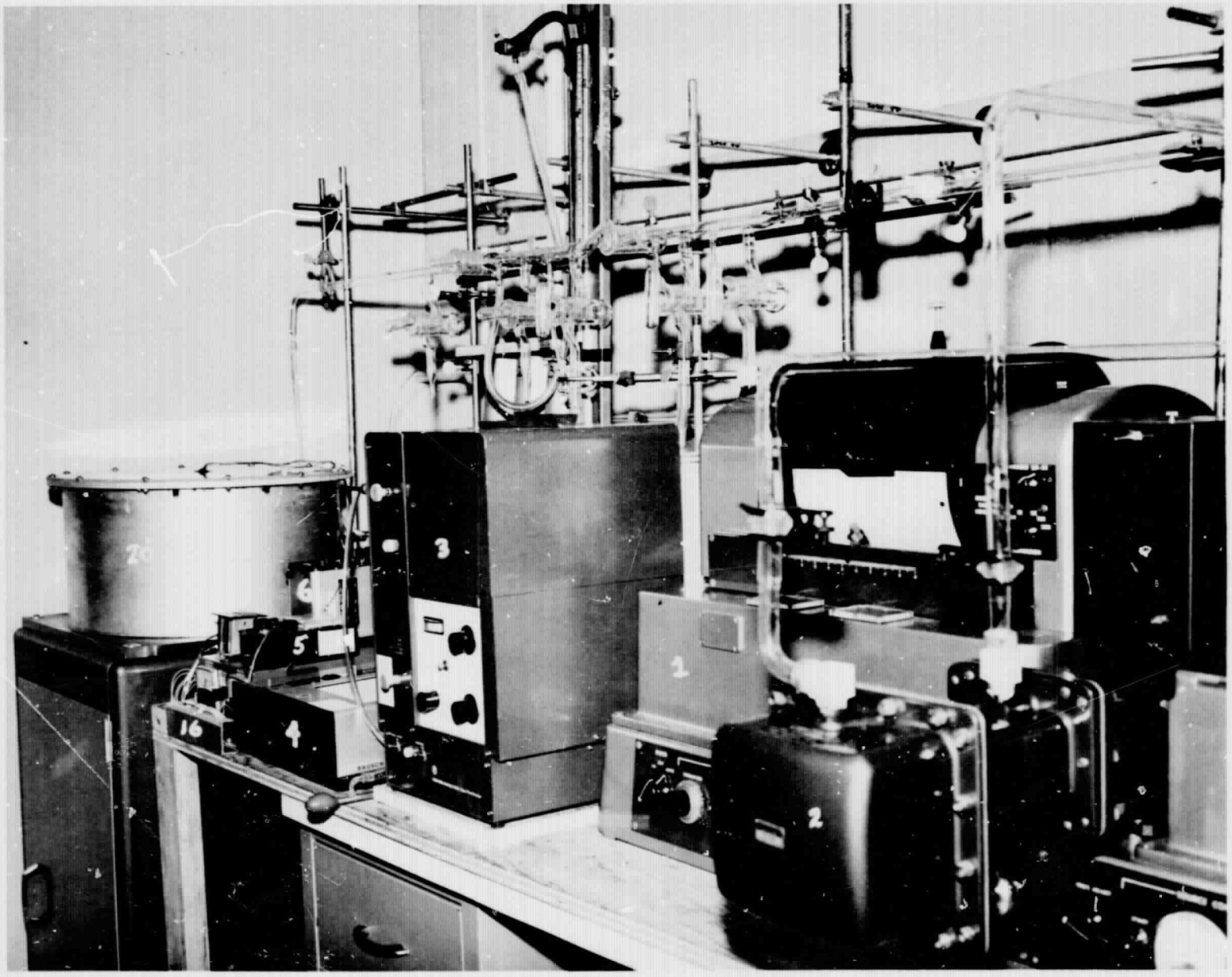


PLATE 1

GENERAL VIEW OF APPARATUS

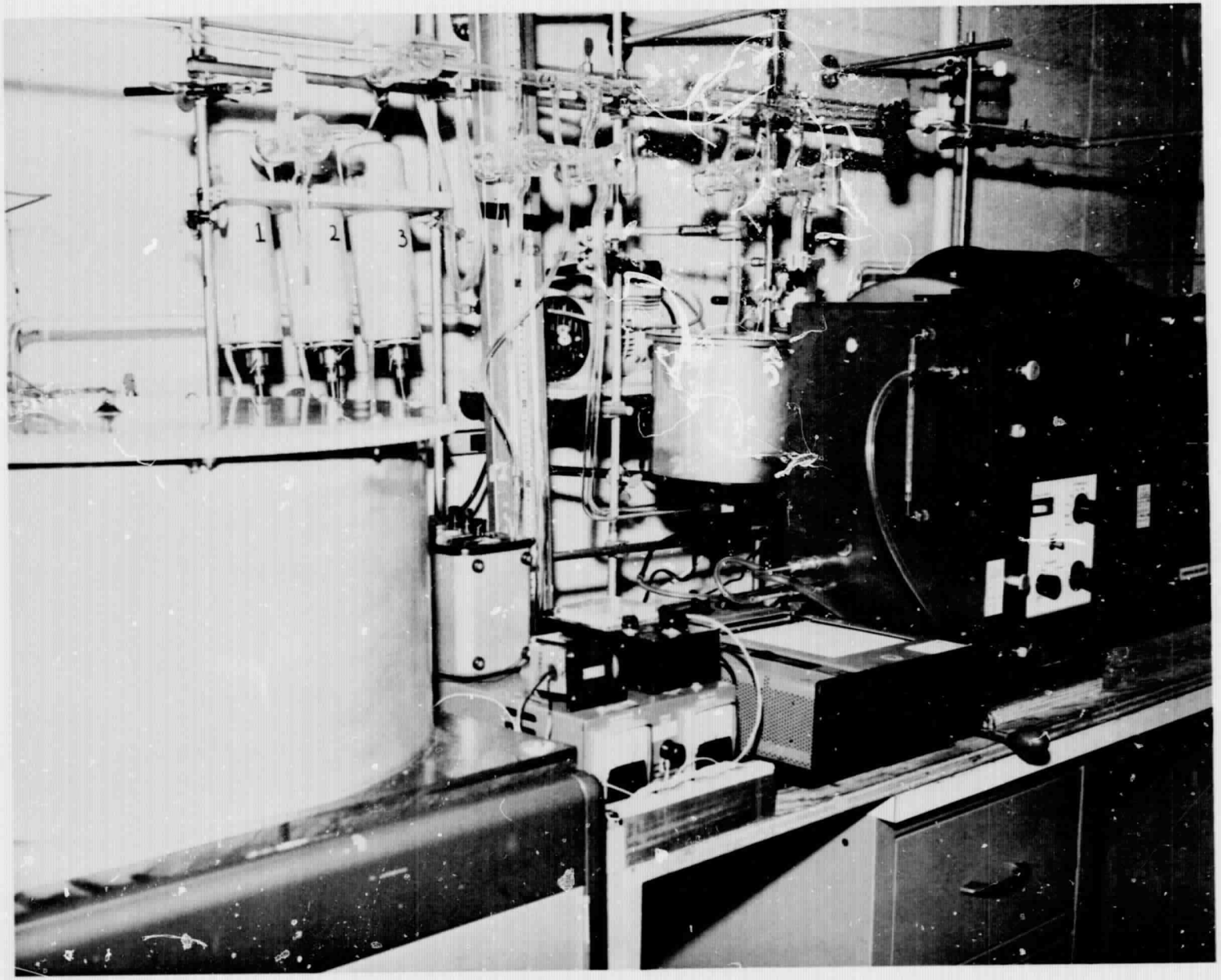


PLATE 2

GENERAL VIEW OF APPARATUS

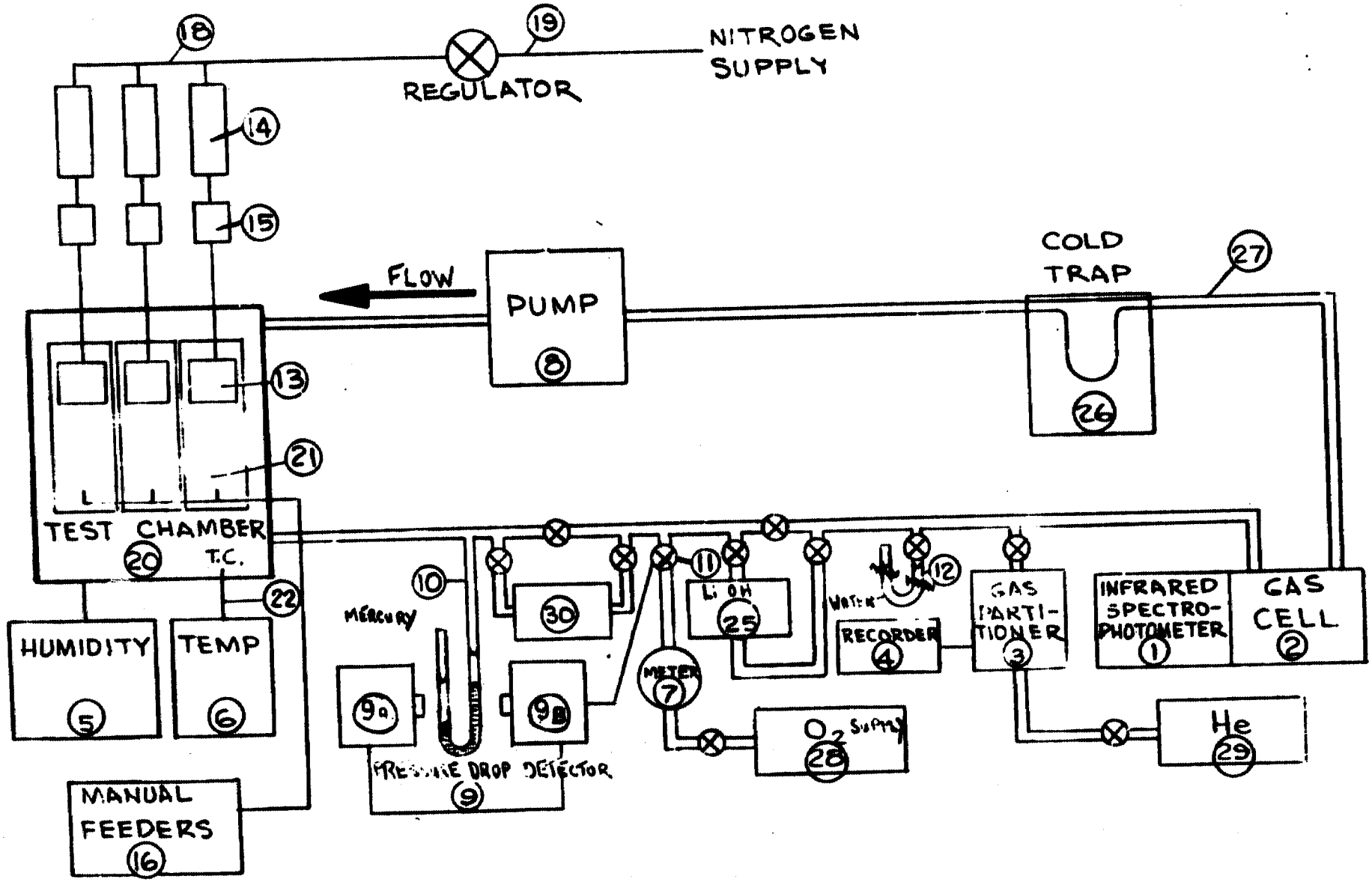


FIGURE 2: BLOCK DIAGRAM OF SYSTEM (COMPONENTS ARE DEFINED IN APPENDIX)

APPENDIX 1

DESCRIPTION OF APPARATUS

A.1. General Description of the Apparatus

The apparatus used in these experiments is shown in Figure 2. General views of it are shown in Plates 1 and 2.

The test chamber (20) is in a closed system with the pump (8), cold trap (26) and infrared spectrophotometer with gas-cell attachment (1 and 2). The manifold (27), which connects these components, is of glass, glass stopcocks sealed into the manifold systems can be closed as desired to allow the circulating air through the canisters (25 and 30) which are situated on by-pass lines.

The oxygen content of the system atmosphere is indirectly monitored by the pressure drop detector (9). The carbon dioxide produced by the rats is absorbed in the lithium hydroxide canister (25) and the removal of this gas causes a pressure drop in the system. The limb of the mercury manometer (10) which is in contact with the system atmosphere, is situated directly in the light path between the light source (9A) and the photocell-relay (9B). The position of the mercury column is adjusted so that as the pressure in the system drops, the mercury column interrupts the light beam. The circuit is arranged so that the solenoid valve (11) now opens and allows oxygen to enter the system until the pressure is sufficient to return the mercury column to a position below the light beam. The solenoid valve is then closed by the photocell-relay circuit. The operation is fully automatic and this arrangement adequately controlled the oxygen content of the system atmosphere during the whole of the 21 day test.

The infrared spectrophotometer and gas cell attachment directly in line made it possible to continuously detect and analyze the contaminants produced by the rats. As the contaminant gas concentrations increased it became possible to analyze the amounts by gas chromatographic and detection tube methods and small samples of system atmosphere were withdrawn to carry out these analyses. These samples were also analyzed for oxygen and nitrogen content. Humidity and temperature were monitored by an electric hygrometer (5) and a thermocouple (22). The trap (26) was incorporated in the manifold to assist in humidity control. The use of anhydrous lithium hydroxide in these experiments was found to control humidity adequately, however, and the cold trap was not used.

The feeder system is described in Section A.4.

A.2. Test Chamber

The test chamber is shown in Figure 3 (SK-D-9145-X-015). It is constructed of aluminum except for the base plate which is of stainless steel and the top plate which was of clear plexiglass to allow illumination of the rats on the lighting cycle.

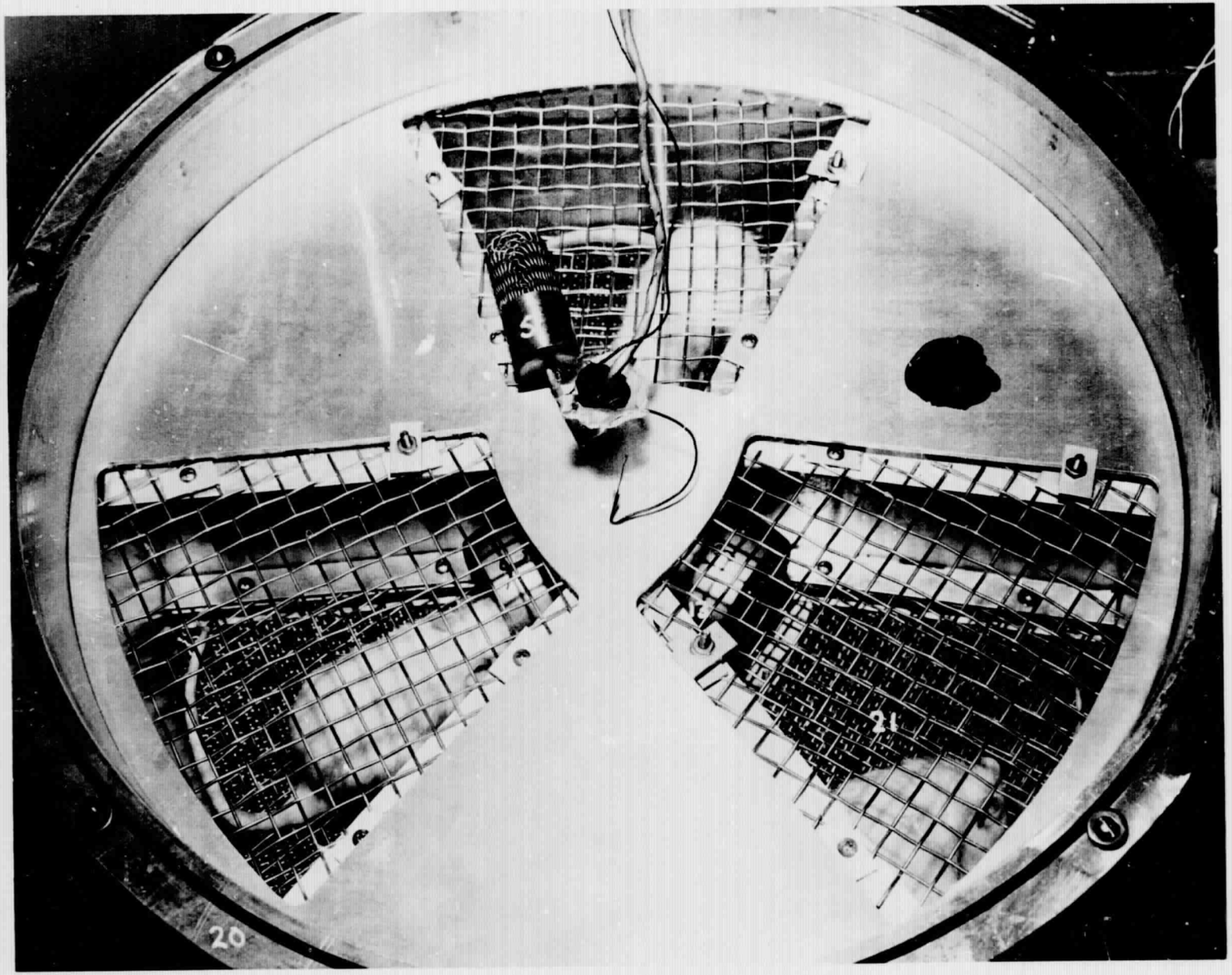
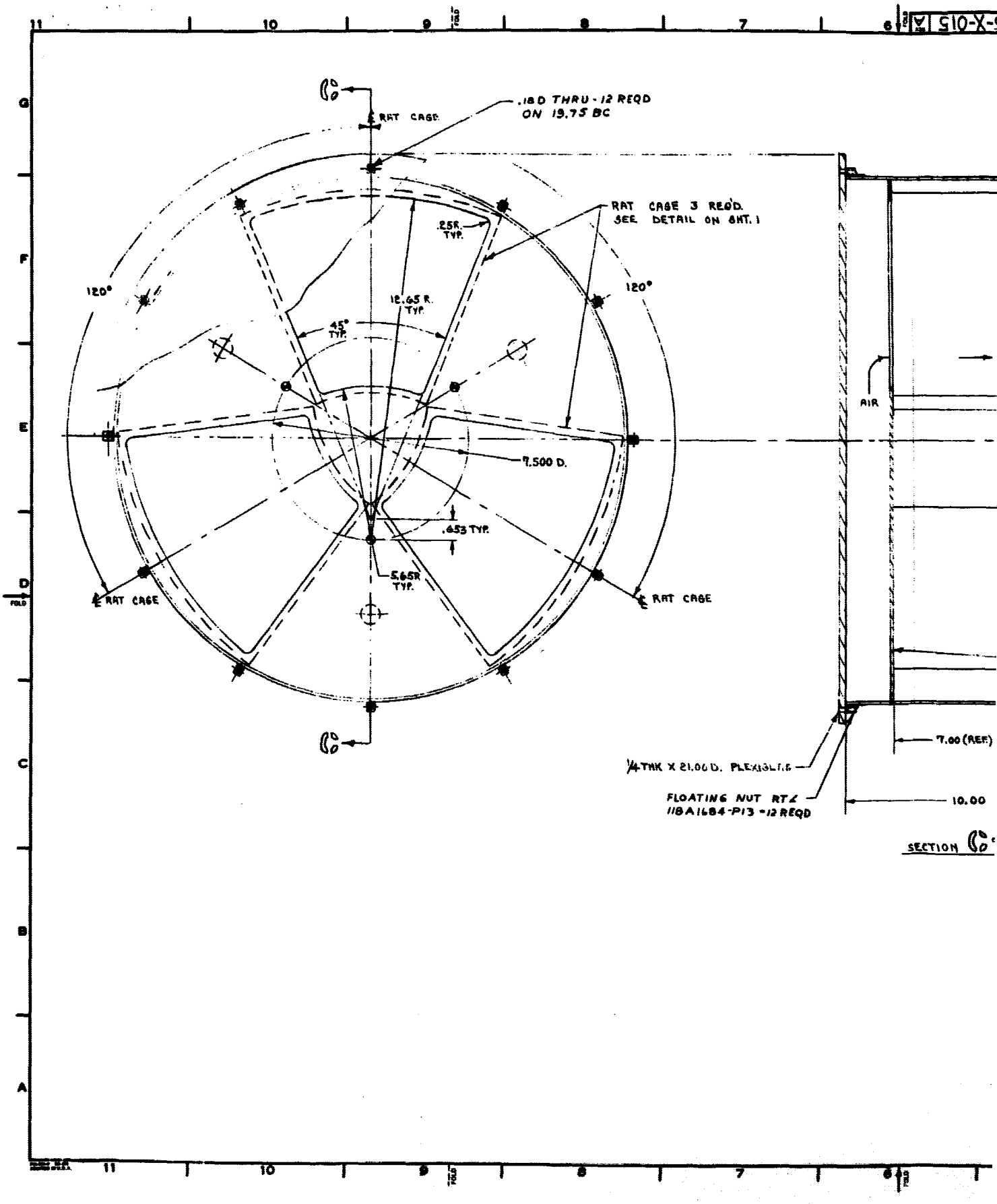


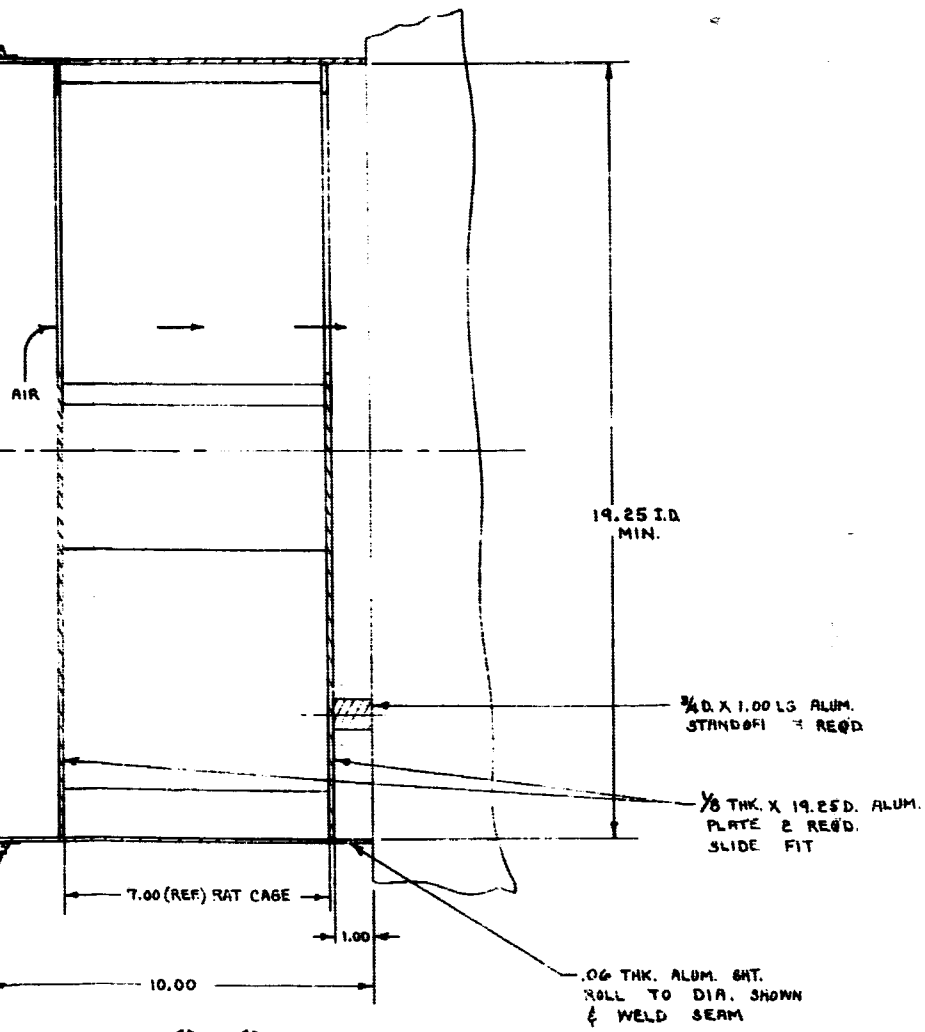
PLATE 3

TEST CHAMBER DURING 21 day TEST

14-A


.18D THRU - 12 REQD
ON 19.75 BC
RAT CAGE
RAT CAGE 3 REQ'D.
SEE DETAIL ON SHT. 1
.25R.
TYP.
120°
120°
12.65 R.
TYP.
45°
TYP.
7.500 D.
.653 TYP.
5.65R
TYP.
RAT CAGE
RAT CAGE
AIR
7.00 (REF)
¼ THK X 21.00 D. PLEXIGLAS
FLOATING NUT RTZ
11BA1684-P13 - 12 REQD
10.00
SECTION

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	ADD 12 -.18 D HOLES ADD 12-RT ∠ FLOATING NUTS	7/11/68	RD



SECTION C₀ – C₀

Figure 3

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES – TOLERANCES ON: 2-PLACE DECIMALS ± .03 ALL SURF. 3-PLACE DECIMALS ± .010 ANGLES ± ½° FRACTIONS ± ✓	SIGNATURES	DAY	MO	YR
MATERIAL – NOTED	L. D. DANSBURY	4	4	68
	9130-44-H3EC-01			

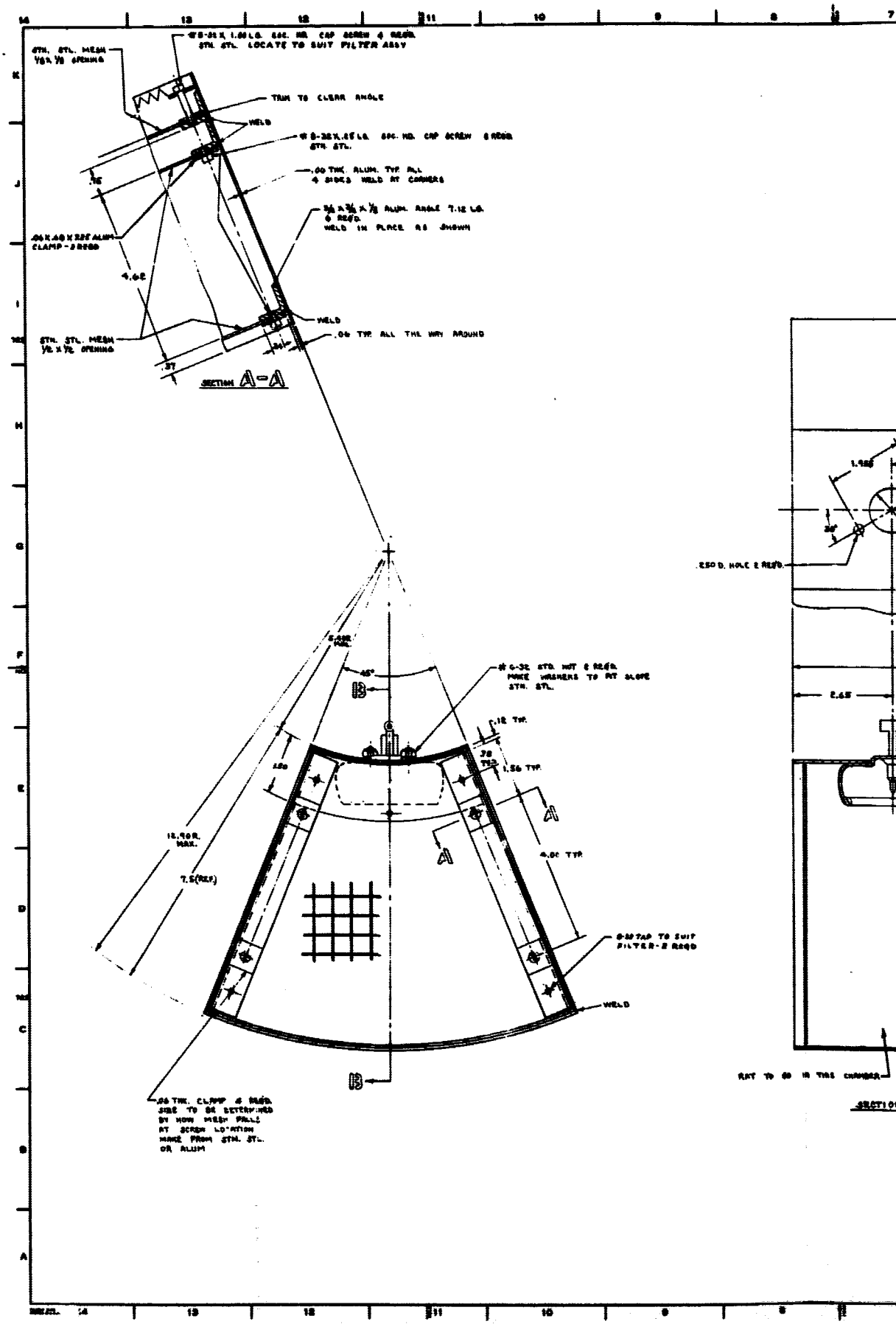
GENERAL ELECTRIC

Test Chamber
Bios.

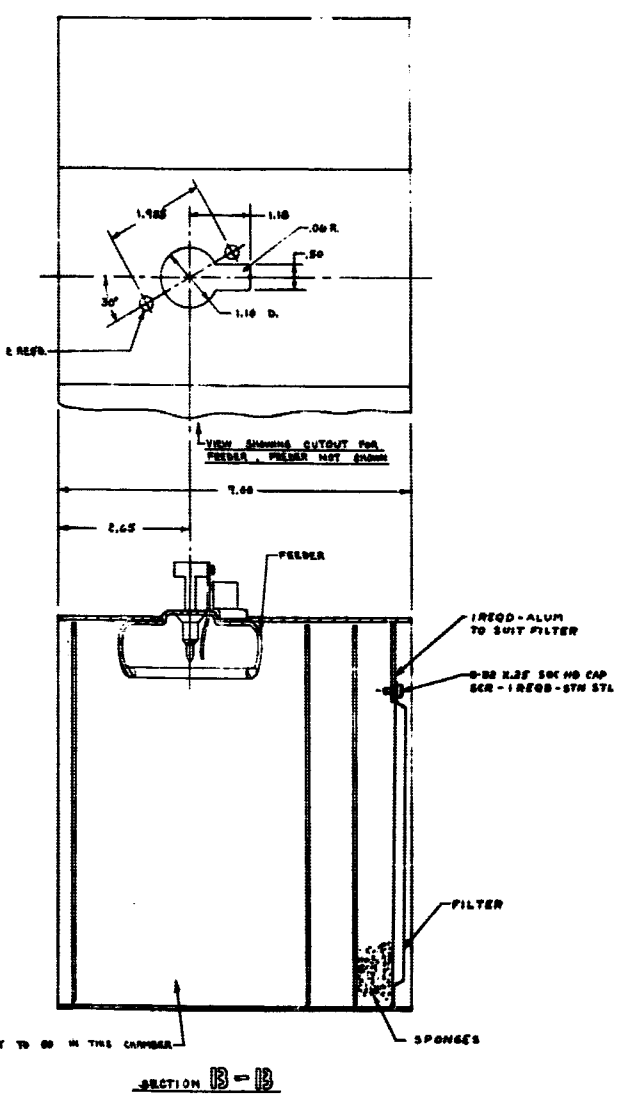
SIZE	CODE IDENT NO.	SK9145-X-015	REV.
D			A

SCALE HALF SHEET 2 OF 4

15-A


#8-32 X 1.00 LG. SOC. HD. CAP SCREW 4 REQD. STN. STL. LOCATE TO SUIT FILTER ASSY
STN. STL. MESH 1/8 X 1/8 OPENING
TRIM TO CLEAR ANGLE
WELD
#8-32 X .65 LG. SOC. HD. CAP SCREW 8 REQD. STN. STL.
.06 THK. ALUM. TYP ALL 4 SIDES WELD AT CORNERS
.06 X .68 X 2.25 ALUM. CLAMP - 3 REQD.
4.62
WELD
.06 TYP. ALL THE WAY AROUND
STN. STL. MESH 1/8 X 1/8 OPENING
.37
SECTION A-A
.250 D. HOLE 2 REQ'D.
1.938
2.65
#6-32 STD. HOT 8 REQ'D. MAKE WASHERS TO FIT SLOPE STN. STL.
45°
B
.12 TYP.
.78 TYP.
1.56 TYP.
A
4.01 TYP
12.90 R. MAX.
7.5 (REF.)
#8-32 TAP TO SUIT FILTER - 2 REQD
WELD
.06 THK. CLAMP 4 REQ'D. SIZE TO BE DETERMINED BY HOW MESH FALLS AT SCREW LOCATION MAKE FROM STN. STL. OR ALUM

15-B



SECTION B-B

Figure 4

Rat Cage Bios.	
E	SK9145-X-015 A

15

The base plate carried two ½" holes allowing inlet and outlet tubes of the glass system to be sealed in and a 1" diameter hole carrying both inlet feeder tubes and electrical leads for operation of feeder microswitches.

The electrical leads for the thermocouple and hygrometer passed through the plexiglass top.

An "O" ring seal was used to ensure that the plexiglass top was leak tight.

An upper view of the test chamber during an experiment is shown in Plate 3.

A.3 Rat Cages

Figure 4 is a reproduction of the rat cage drawing (SK-E-9145-X-015).

The cages were constructed of aluminum with the exception of the meshes which were all of stainless steel.

The sponges and bacterial filters were supplied by NASA as flight approved equipment. They were of the same type used in the Thermal Interface Test.

Part of the cages may be seen in Plate 3.

A.4 Feeder System

Figure 5 shows a schematic wiring diagram of the feeder system. The feeder bottles 1, 2, and 3 contain bladders which hold the liquid diet. Immediately below the bottles are the feeder demand valves which are opened when the microswitches in the rat cages are closed by the rat biting a feeder lever immediately below the feeder nipple in the feeder bowls, The bottles are pressurized (by the nitrogen supply in this case but by FREON C.318 in flight) and opening the demand valve forces a small known volume of diet through the nipple into the bowl.

A feeder programmer is incorporated which prevents the demand valve from opening for 90 seconds no matter how often the microswitch is actuated. This system is shown in Appendix 2.

A.5 Oxygen Supply

Figure 6 shows the oxygen control system in detail. The general operational details of this system were described in Section A.1. It was found necessary to protect the circuit from lamp failure since the oxygen inlet solenoid valve remains open in these circumstances and pressure build-up in the system could be catastrophic. The system adopted was to place a wire in the laboratory atmosphere side of the mercury manometer and use the mercury column to close a circuit with another wire, placed just above the mercury level, on the "laboratory side" of the manometer if pressure were to build-up due to lamp failure. Closing of this circuit resulted in closing of the solenoid valve as shown in Figure 6.

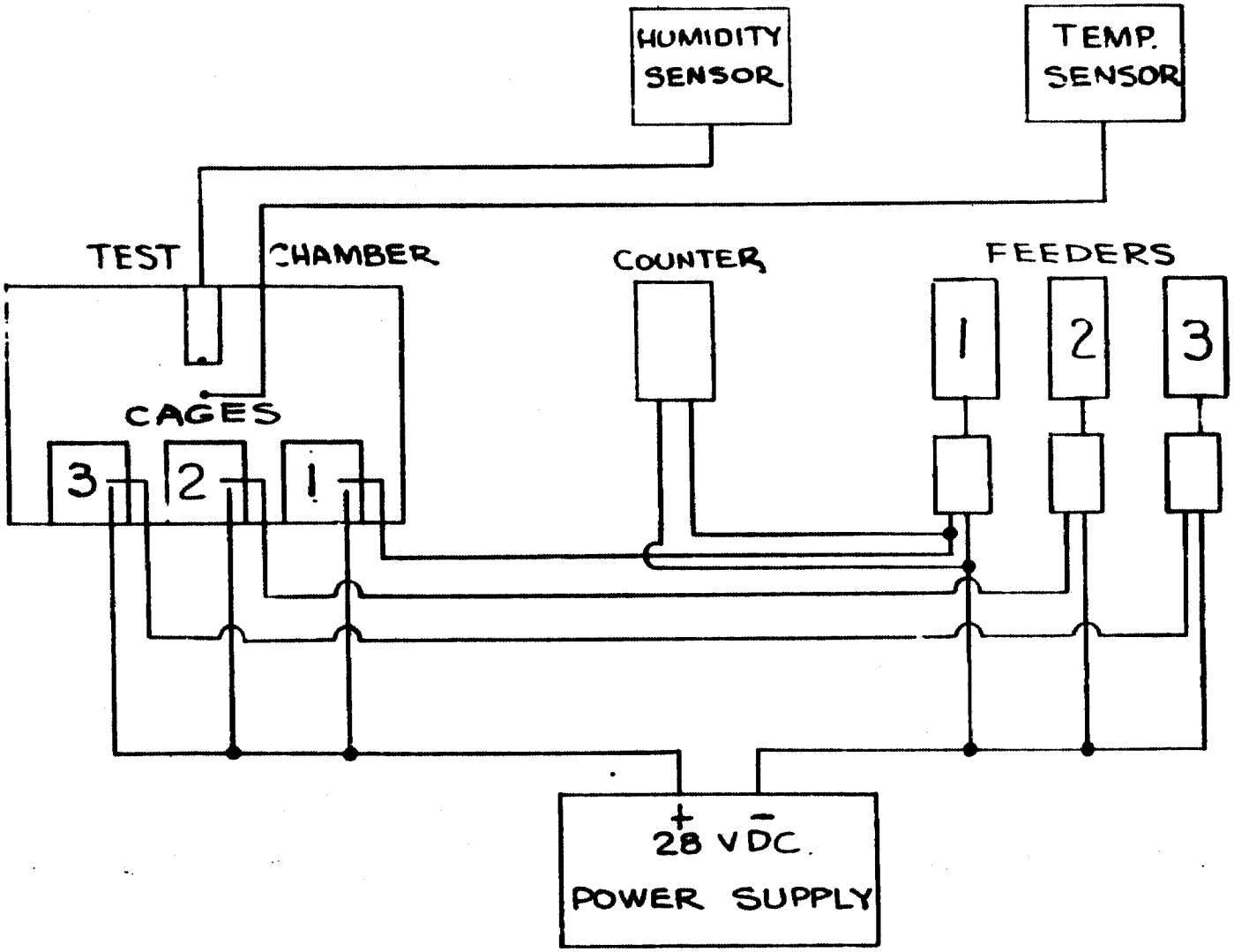


FIGURE 5: SCHEMATIC WIRING DIAGRAM OF FEEDER SYSTEM

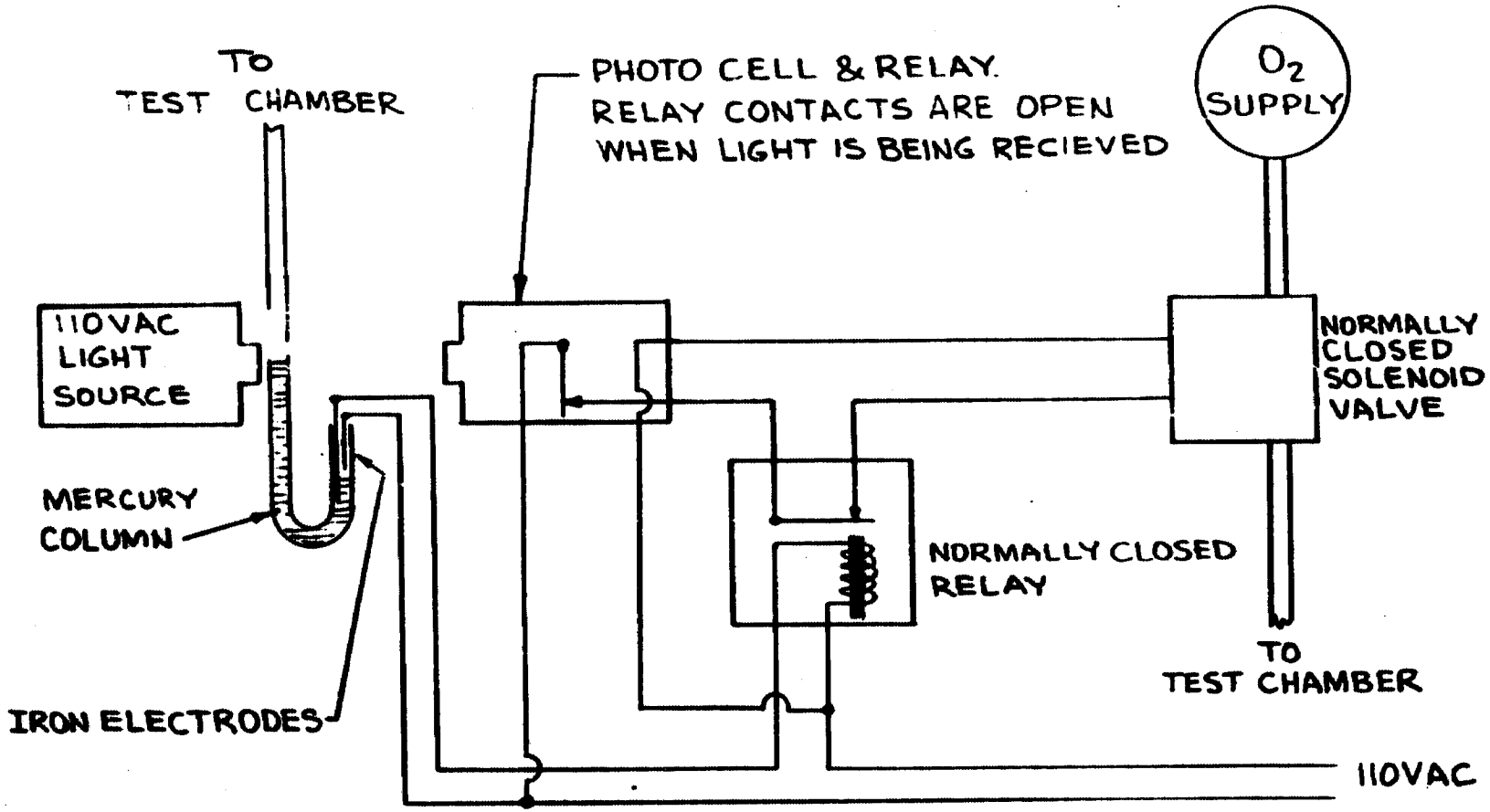


FIGURE 6: OXYGEN SUPPLY WIRING DIAGRAM

A.6 Detection and Measurement of Contaminant Gases

A.6.1 Infrared Spectrophotometry

Contaminant gases were identified and measured where possible by use of a Perkin Elmer Infrared Spectrophotometer (Model 21) with gas cell attachment (186-0214).

The gas cell was adjusted to give an analytical path length of 13.75 meters and hence it gave very much higher sensitivity to low gas concentrations than would be possible with the usual infrared gas cells.

The detection limit for a particular molecule at a certain wavelength depends on the concentration, c, the path length l and the extinction coefficient K. The spectrophotometer measures the absorbance A which, from Beers Law, is equal ti Kcl at low gas concentrations. In these experiments the lowest absorbance detectable is about 0.005 and consequently the minimum concentration of a gas detectable (c') is:

$$c' = \frac{0.005}{13.75\ K} = 0.000364 \times K^{-1}$$

K can be obtained from published data or by calibration using known concentration of the identified contaminant gas.

The use of this spectrophotometer - gas cell system allowed us to detect the major gases of interest around the 1 p.p.m. level.

A.6.2. Gas Chromatography

Methane was detected and analyzed in these experiments. The gas was initially identified by infrared and it was possible to determine accurately the amounts present in the system air using a #5A Mole Sieve column in a Fisher- Hamilton Gas Partitioner (Model 29). Standard methane - air mixtures were used to calibrate the gas partitioner.

The gas partitioner was used to analyze the system air for oxygen, nitrogen and carbon monoxide contents. Carbon monoxide was not detected by the mole sieve column.

An air pollution gas chromatograph with a 20 Ft. Poropak Q column was used to analyze the gases evolved on heating samples of the lithium hydroxide and activated charcoal following the 21 day test.

A.6.3 Detection Tubes

Standard detection tubes for carbon monoxide and hydrogen sulfide were used on occasions. These tubes were supplied by Mine Safety Appliances Company, Pittsburgh.

A.6.4 Standard Chemical Analysis Techniques

Following the experiments the lithium hydroxide and activated charcoal absorbants were analyzed by the Schwartzkopf Laboratories for carbon, nitrogen and sulfur by standard chemical methods.

A.7 Leak Testing of System

Before the start of the experiments the system was thoroughly checked out for leaks using, initially, vacuum tests, i.e. tests for holding vacuum at 10^{-3} mms vacuum (N.B. The plexiglass top plate was replaced with a steel plate for these tests) and finally tests at just below (i.e. 5-10 cms of water) ambient pressure since the pressure differential at high vacuum seals up leaks at "O" rings which nevertheless prove troublesome under normal operating conditions.

A.8 Air Flow Rate In System

A.8.1 Flow Rate

The flow rate was measured using a venturi tube and inclined manometer under experimental conditions and found to be 10.2 litres per minute with no cannisters in the circulation path.

The rate dropped to 9.4 litres per minute when all the flow was through the lithium hydroxide canister. During the experiments the flow thourgh this cannister was varied using the stopcocks in order to control humidity and carbon dioxide content.

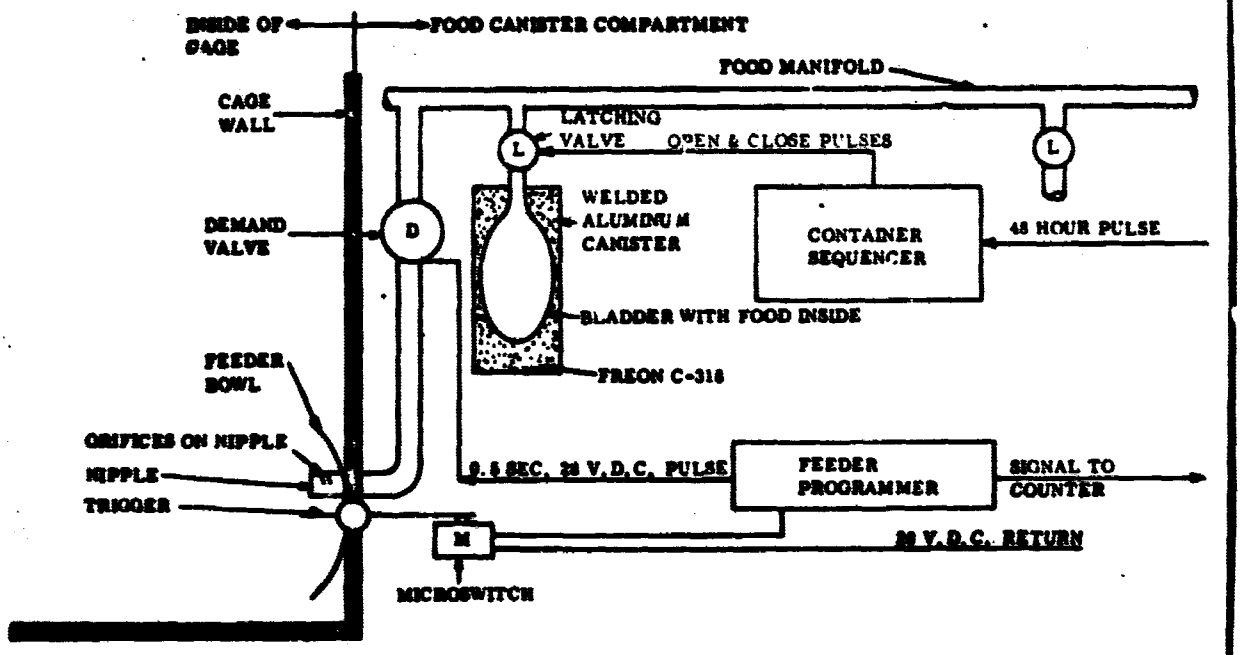
A.8.2 System Volume

The total volume of the system was measured by allowing a known volume of oxygen to enter the system and noting the pressure increase. Use of the ideal gas laws gave a total system volume of 36.0 litres (1.27 cubic feet).

Therefore, the air in the test chamber was changed every 3.5 minutes approximately. In the capsule, the air will be changed every minute (total volume of capsule is about six cubic feet for eight rats). We could not simulate this flow rate in our system because of the restrictions to the diameter of the glassware imposed by putting the gas cell directly in the circulation system, and obtaining accessibility to the canister assembly by placing it outside the test chamber.

The air volume per rat in our tests was 0.42 cubic feet, in the capsule it will be 0.75 cubic feet. Hence, the rats in our experiments encountered higher concentrations of contaminants than expected in the flight.

APPENDIX 2



DESCRIPTION OF FOOD CANISTER ASSEMBLY SEQUENCING AND OPERATION:

1) There are 11 food canisters each with a latching valve and all are connected to the food manifold.
2) Every 48 hours the container sequencer automatically receives a pulse which causes it to pulse the latching valve (L) which is open at that time. That valve then closes and the sequencer immediately pulses another latching valve causing it to open. This seals off the used canister from the manifold and opens an unused canister to the manifold
3) All 11 canisters are thus advanced (opened and closed) during 21 days, in sequence.
4) At any time a manual override signal can be transmitted to the sequencer causing it to advance one canister.
5) Once canister 11 (the last in the sequence) is opened it cannot be closed by means of pulses from the sequencer.
6) By means of a reset signal the sequencer can be reset so that canisters 1 through 10 can again be opened and closed if desired.
7) At the nominal 55°F temperature of the system the Freon in the canister develops 15 psig thereby squeezing the food through any open latching valve, to the manifold.

DESCRIPTION OF FEEDING PROCESS:

1) There are eight demand valves (D) connected to the manifold, and a feeder programmer for each demand valve. Each combination serves one rat.
2) When a rat bites the hinged trigger the N.O. microswitch (M) is closed, sending a signal to the feeder programmer. This device in turn sends a 0.5 second 28 vdc pulse to the N.C. demand solenoid valve (D), thereby opening it.
3) While the valve D is open the Freon pressure causes a food flow through the orifices on the nipple delivering food to the rat.
4) Since there is more than enough Freon in the canister to completely fill it in the gaseous state at the system operating temperature of 55°F, the Freon pressure is affected only by changes in temperature and not by changes in volume resulting from food depletion.
5) After 0.5 second the N.C. demand valve is de-energized and the food flow stops. The feeder programmer then prevents the valve D from opening for 90 seconds no matter how often the rat may actuate the trigger in this period. After 90 seconds she will obtain food if she bites.
6) When the valve is actuated the feeder programmer sends a signal to a counter. This information is eventually retrieved for assessment of food consumption by each rat.