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THE DEVELOPMENT OF A NEW AUTOMATED BREATHING METABOLIC SIMULATOR

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ABSTRACT

The development of a breathing metabolic simulator that is accurate and reliable enough to reduce emphasis placed on manned testing of respirators has been a goal of long standing in the respirator industry. This paper addresses the development history and performance capabilities of a fully automated breathing metabolic simulator developed for the U.S. Bureau of Mines by Reimer Consultants under BuMines Contract J0100098. The simulator is capable of simulating all normal human respiratory functions including oxygen uptake, CO₂ production, breathing waveform and thermal effects, and can shift quickly from one metabolic state to another. Also presented are the simulation parameters used to represent the metabolic state equivalents of the NIOSH man tests. The simulator is capable of all operating modes from manual to fully automatic. In the fully automatic mode, simulations of entire NIOSH man tests and all the required data collection can be performed without operator intervention. Significant data organization capabilities either in real time or post test are also available.

DEVELOPMENT HISTORY

The first Automated Breathing Metabolic Simulator (ABMS) was delivered to the Bureau of Mines by IBM in 1973 (IBM, 1973). That unit was basically an automated version of a manually controlled breathing metabolic simulator that IBM had developed previously (Bartlett, et al., 1972). The IBM version of the ABMS continued in service until early 1980 when increasing maintenance difficulties and apprehensions centered around the oxygen uptake process (the catalytic combustion of methane) prompted its retirement. In mid-1980, Reimers Consultants (RC) began work on two contracts for the Bureau of Mines. The first was a supply contract for a manually controlled Breathing Metabolic Simulator (BMS) based standard RC designs in use at the time (RC has been building and operating breathing simulators since 1973). The second was a development contract for a prototype automated unit which was originally intended to employ process designs as similar to the manual BMS as possible.

The basis criteria which guided the ABMS development were:

- o The simulations produced by the ABMS were to be as physiologically appropriate as possible.
- o The construction was to employ low cost methods using standard, commercially available items wherever possible.
- o Operation was to be simple and easily learned. Complex computer programs were to be avoided.
- o The ABMS was to be capable of manual as well as automatic operation. All data inputs into the computer were to be paralleled with analog outputs suitable for general purpose laboratory recorders.

The Reimers manual BMS went into service in mid-1981. Experience with it quickly indicated that some adjustments were required in the oxygen uptake process. An early version of the volume exchange process is described herein. It removed oxygen satisfactorily. However, it also had a tendency to alter the nitrogen constituent in the process gas. This effect, if not properly managed, can lead to abnormally low oxygen concentrations and breathing bags which run either too full or too flat. The later discussion regarding "nitrogen fidelity" is a direct result of the experience with that manual BMS. The nitrogen fidelity of the oxygen uptake system has been improved at least an order of magnitude, and is expected to function well. However, more operating experience is needed before that can be verified.

The ABMS is presently nearing completion at RC's Falls Church, VA facility. The development has taken nearly a year longer than expected. However, the simulator is performing well in its shakedown trials, and it is expected to go into service in early 1984.

Figure 1 shows the general arrangement of the ABMS. It has been designed in three modules: a Breathing Simulator Module (BSM), a Gas-Analysis Module (GAM), and a Supervisory Controller (SC). Each of the modules is capable of stand alone operation. The BSM can be run in a completely manual mode without the SC and with gas analysers of convenience. Similarly, both the SC and GAM are capable of being put to general purpose use apart from their designated applications as portions of the ABMS. The principal performance capabilities of the ABMS are given in Table 1. The following paragraphs provide brief explanations of how the various ABMS systems function.

BREATHING SIMULATOR MODULE

The BSM is the heart of the ABMS. It is designed to be operated either manually or by means of the SC. The principal elements which make up the BSM are described below.

Main Cylinder Assembly

The main Cylinder Assembly consists principally of a rolling seal position and cylinder assembly, a zero backlash ball screw drive and high response servomotor as shown in Figure 2. The rolling seal piston design provides excellent sealing reliability with very low friction. However, rolling seals behave in a reliable fashion only when in tension.

Consequently, two seals with a vacuum in between are used as shown. Furthermore, since the differential pressures normally existing in the process loop are small relative to the vacuum applied to the rolling seal, they have virtually no effect on system behavior. Measured compliance values for the rolling seal designs employed are on the order of 0.01 cm^3 increase in net cylinder volume per $\text{cm H}_2\text{O}$ increase in process loop pressure; e.g. the rolling seal is effectively non-stretching and therefore has no detrimental effects on the accuracy of the waveform. A pressure switch on the vacuum exists to ensure satisfactory seal performance.

The servometer drive is controlled by velocity signals sent to the amplifier by the Waveform Generator (WG). Signals sent back to the WG by the rotary shaft encoder keep it informed as to the exact location of the drive. Upper and lower travel-limit switches, wired to the signal locking circuits on the amplifier, are employed to prevent overtravel of the drive in the event of an erroneous control signal. The velocity transducer shown has no specific control function. However, the SC monitors its output to verify that it is getting the velocity-versus-position profiles it requests of the Waveform Generator.

Waveform Generator

The Waveform Generator is the real-time system that controls the velocity position-time characteristics of the piston drive. It consists of several components which together provide accurate, yet flexible and simple-to-use waveform control (see Figure 3). Each component is described briefly:

- o Microprocessor CPU. Interprets the permanent program and directs the operation of the other sub-systems.
- o Keyboard/Display. Provides local input-output for manual operation as well as status information (breathing rate and breath number) when the system is running.
- o Non-Volatile Memory. Stores 20 separate waveforms from which several test sequences can be developed.
- o Permanent Memory. Stores the program which defines Waveform Generator operation.

- o Volatile Memory. Stores detailed waveform parameters for the piston profile currently running.
- o Process Interface. Monitors piston position and produces the piston velocity control signal.
- o IEEE-488 Interface. Communicates with the SC.

When a sequence of individual waveforms is defined, each being specified as to duration and storage number, the WG automatically extracts them in the specified sequence from the non-volatile memory. As they are executed, the system controls piston motion to accurately reproduce the waveform profile. If the SC is used, the WG maintains synchronous communication with it to assist in the correct timing of data acquisition. A sequence of up to 20 waveforms can be included in an automatically controlled test. Each waveform can be used for up to 9,999 sequential breath cycles before the test sequence must move to the next waveform.

Waveforms in non-volatile storage can be replaced with new ones as desired, either by the SC or with more effort through the manual keyboard. Similarly, a sequence of waveforms can be defined either by the SC or manually. The WG may be used either in conjunction with the SC or as a stand-alone system without sacrificing performance. This permits almost normal use of the BMS module in the event that the SC is "down" or being used elsewhere. It also permits simple tests and process system diagnostic work to be performed without the need to activate the SC.

Display prompts are used to guide the operator through routine setup steps. Consequently, manual operation of the WG has proven to require very minimal operator training.

Temperature and Humidity Monitoring and Control Systems

The operation of this system can best be described by dividing it into three elements: the inhalation mixing box and associated instruments, the main piston assembly (discussed previously), and the exhalation temperature and humidity-control system. When the simulator inhales, gas is drawn through the test mannikin head and into the inhalation mixing box. The inhalation mixing box has an internal volume of approximately 2 liters, and causes the gas to be pneumatically homogenized, thus enabling accurate readings of volume-average gas properties to be made with common laboratory-grade instrumentation. The mixing box also provides a convenient location for mounting the necessary sensors. This method is especially useful for obtaining accurate measurements of inspired gas temperature. The pneumatic homogenizing slows down to rates of temperature change so that a good laboratory-grade thermistor can follow

them accurately and generally eliminates any measurement problems due to condensate formation on the thermistor bead.

The expired temperature and humidity control system is a slightly modified version of a standard design that Reimer Consultants has used with good success for several years (Reimers, 1974). As the process leaves the Main Cylinder Assembly, it passes first through the bubble chamber where it passes from a bubble tube through a heated water bath. The water bath temperature is controlled by an temperature indicating controller which is set for the desired exhalation dewpoint and senses the temperature of the gas leaving the bubble chamber. A separate temperature sensor in the water is used in conjunction with a limit switch in the heater line to prevent overheating of the water when the simulator is idle or in the event of a heater controller malfunction. From the bubble chamber, the process gas travels to the exhalation mixing box via the afterheater assembly where dry heat is added. The power to the afterheater assembly is also controlled by an temperature indicating controller which senses the dry bulb temperature in the exhalation mixing box. As is the case with the inhalation mixing box, the exhalation mixing box, also approximately 2 liters internal volume, serves to pneumatically homogenize the gas and to provide a convenient mounting place for the temperature and humidity sensors. The afterheater assembly and exhalation mixing box are mounted inside an insulated box which is heated by the waste heat from the afterheater assembly. A small fan is used to circulate the air inside the box. This arrangement keeps the outside surfaces of the afterheater assembly and exhalation mixing box as warm as the inside surfaces. This has been found to help prevent heat loss from the exhalation gas and also to help prevent condensation due to cold spots in the flow path.

The temperature controllers which control the temperatures of the bubble chamber and afterheater assembly are both capable of either local or remote setpoint control. When in the local control mode, the controllers accept their setpoint commands from a knob on the panel face. In the remote mode, they take their setpoint command from the SC.

The circuit shown in Figure 4 was developed to permit accurate measurement of true volume-average parameters with common laboratory grade instrumentation. However, the penalty is a circuit with about 7 liters internal volume. If studies are to be performed where the variable of interest is sensitive to the circuit volume, such as a study of nitrogen wash-out in an oxygen self-rescuer, then the circuit volume must be reduced to about 1.5 liters or roughly the equivalent of human FRC at moderate work (Sparks, et al., 1980). This can be accomplished by eliminating the mixing boxes and reducing system volumes elsewhere. However, the instrumentation necessary in that case to achieve the desired

accuracies becomes significantly more sophisticated.

C02 Addition System

Figure 5 shows principal elements in the C02 addition system which is basically a constant flow addition process controlled by an indicating mass-flow controller. The set-point signal to the system may be generated from either a manual control on the front of the BMS module in by the SC. The 4-way selector valve allows C02 flow to be blocked, directed to a vent (useful for calibration checks), or directed to the appropriate point in the process loop depending on whether or not the oxygen uptake is in use. The C02 add rate process shown is simple and has been found to work very well.

Oxygen Uptake System

The oxygen uptake process employed involves removing gas from the process gas at a rate calculated to give the desired removal rate of oxygen and the simultaneous replacement with an equivalent volume of oxygen-free gas (Figure 6). In the circuit shown this is accomplished by a set of three pistons which are driven from the main piston drive via a moveable fulcrum lever. The removal cylinder pumps gas out of the circuit at a rate calculated to give the desired oxygen removal rate (Equation 1). The supply cylinder pumps an equivalent volume of C02 and diluent (normally nitrogen) back in. The balance chamber mirrors the flow effect that the supply and removal cylinders have on the process gas flow so that the oxygen uptake rate can be adjusted without disturbing the flow rate of the process gas.

The rate at which oxygen is removed is

(1)

$$V_{O_2} = V_{O_2} \times RMV \times ER,$$

where V_{O_2} = oxygen removal rate at ambient conditions,
 V_{O_2} = oxygen concentration in the process loop,
 RMV = ABMS respiratory minute volume, and
 ER = exchange ratio, the ratio of removal flow to RMV.

In most test situations, V_{O_2} is linearly related with RMV. In the design shown, V_{O_2} is nearly linear with RMV. Thus, the appropriate ER setting is determined principally by the oxygen concentration in the process loop, with a slight secondary effect due to ABMS tidal volume. This basically single variable relationship between process variables and the appropriate ER setting plus the automatic nature of the diluent gas replacement process make it possible for a good operator to achieve adequate oxygen uptake control manually. Oxygen uptake control can also be effected by the SC via the SC input to the ER controls.

The volume exchange process described above appears simple at first glance. Indeed, it is a very straightforward

process if the types of breathing apparatus to be tested all have some type of volume generation/regulation system, as for instance do all types of underwater breathing apparatus. However, if apparatus are to be tested which possess no significant volume generation capacity, such as potassium superoxide oxygen self-rescue apparatus, then the fidelity requirements on the nitrogen constituent in the process gas become quite stringent if normal counterlung (breathing bag) behavior is to be achieved. For these apparatus the difference between the amount of nitrogen removed and the amount of nitrogen returned to the circuit must be less than about 0.1% of tidal volume (2cc in a 2 liter tidal volume). Assuming an average RMV over a one hour test of 30 liters per minutes (1 ppm), that accuracy gives a potential net gain or loss of the nitrogen constituent in the circuit of 1.8 liters. That is quite enough to create some confusion on the part of the test director, especially if he is unaware of what is going on.

The circuit shown is capable of "nitrogen fidelity" within the 0.1% of tidal volume target given as long as the simulation respiratory quotient, R , (ratio of CO_2 added to oxygen removed) remains at one pre-selected value. Experimental data now available at $R = 1$ indicates that the nitrogen fidelity of the ABMS varies no more than 0.11% of tidal volume over a wide range of RMV and ER with variations much less than that over the most frequently used values of RMV and ER. However, for the circuit shown, a 10% variation in R ; for example, from 1.0 to 0.9, will cause the nitrogen fidelity to change by 1% of tidal volume. Fixing R at a specific value for test situations where very accurate nitrogen fidelity is required is a testing limitation that can be readily tolerated. Indeed test protocols for underwater breathing apparatus have fixed R at 1.00 for years, (4.6) without any hardware necessary for doing so. However, as simulation procedures and the expectations of those procedures advance it may become desirable to achieve both very accurate nitrogen fidelity and wide variability in R . In that case the circuit shown would require some modification to accomodate the variability in R or a different update process would have to be used. One presently available such process is to use sample pumps and mass flow meters for the removal and supply functions instead of the cylinders shown. However, such an approach is not manageable except under computer control, and it requires the flowmeters to operate at the very best possible accuracies. The optimum method in terms of nitrogen fidelity involves chemically scrubbing the oxygen in a manner that does not upset the nitrogen content of the circuit. The old Bureau ABMS employed such a method. However, it involved the catalytic combustion of methane, an intrinsically hazardous process with all of the hazard attendant thereto (IBM, 1973). What is needed is a chemical scrubbing process that operates without requiring high temperatures, combustible gas or expensive non-reusable chemicals. Such an optimum scrubbing system is not yet available, to the author's

knowledge.

Differential Pressure Measurement System

A Differential Pressure Measurement System complete with a primary calibration source (water manometer) is self-contained within the ABMS (Figure 7).

Test Mannikin

The ABMS is provided with 5th, 50th and 95th percentile anthropomorphic male heads plumbed as shown in Figure 4. As a matter of design philosophy, all RC breathing simulators are configured so that the conditions existing at the plane of the mouth opening of the test mannikin can be controlled (exhalation half cycle) and monitored (inhalation half cycle) as accurately as possible. That is the reason for the dual uni-directional tracheas shown in Figure 4. Dead space can easily be added to the mannikin head by teeing the tracheas together at some point appropriately distant from the mouth opening. However, it has been the author's experience that in a testing situation, dead space serves little purpose and complicates the establishment of well-defined and easily reproducible test criteria.

GAS-ANALYSIS MODULE

The Gas Analysis Module (GAM) is designed to continuously draw gas samples from the inhale and exhale mixing boxes; analyze the samples' carbon dioxide and oxygen concentrations; and then return the gas samples to their respective locations (Figure 8). Both sample streams have individual sample pumps and flow controls. Both analyzers employ 100 ms response time medical cells. In the present system, the analyses read-outs lag real time by about 15 seconds. However, faster response capabilities can readily be achieved with different plumbing arrangements. The GAM contains a calibration gas panel that allows up to 4 calibration gases to be supplied to the analysers. Since the analysers measure partial pressures rather than concentrations per se, a pressure gauge is provided for each sample cell so that sample cell pressures during calibration evaluations can be controlled at the same pressure as they are during normal operation.

SUPERVISORY CONTROLLER

Figure 9 shows the general arrangement of the Supervisory Controller (SC). The SC programs are organized into several major and minor functional areas as described below and presented in the block diagrams contained in Figures 10, 11, and 12. All the SC programs are menu driven with liberal prompts. Consequently, user training is expected to be easily accomplished.

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- a. Waveform Definition. Assists in developing waveforms, e.g., the parameters which describe the time-position-velocity profile of motion.
 - o Define Waveform - Build a profile from sinusoidal waveshapes, waveshapes made up of linear segments, or those described by a Fourier series.
 - o Store or Replace Waveforms - Provide permanent storage of the profile information on the magnetic disc.
 - o Plot Profile - Generate a plot of a profile for permanent record or for purposes of checking.
- b. Test Definition. Generates a series of metabolic states, e.g., the parameters which describe all of the ABMS functions. Once generated, the test series can be automatically run on the ABMS in sequence with all control and data acquisition operations completed with minimal operator intervention.
 - o Define Metabolic State - Build a set of parameters including waveform profile, O₂ uptake, CO₂ generation, temperatures and humidities which specify all ABMS functions for a single test condition; for example, running at 3 mph. Table 2 is a sample list of metabolic states.
 - o Define Test Sequence - Set up a series of metabolic states, each to be run for a defined number of breath cycles. This sequence is then stored on magnetic disc for later transmission to the ABMS where it is used to control a full test series. A tabulation of test sequences is shown in Table 3.
 - o Define System Monitor - Generate a table of alarm and shutdown limits which is used by the SC to alert the operator to abnormal conditions and to shut down the system in the event of conditions hazardous to the ABMS.
 - o Transmit Waveform - Send data to the Waveform Generator through the IEEE-488 bus for storage in non-volatile memory. The Supervisory Controller maintains a record of which waveforms are currently in the Waveform Generator.

- c. Run Test. Initiates and controls the operation of the ABMS, as well as the acquisition of data during the running of each test.
 - o Transmit Test Sequence - Sends the test sequence (waveforms and number of breath cycles for each) to the Waveform Generator via the IEEE-488 bus.
 - o Start Test - Parallels the START function on the Waveform Generator to initiate ABMS operation.
 - o Stop Test - Similarly parallels the STOP function.
 - o Define Plots - For each segment of the test sequence, defines which test parameters are to be plotted to provide a permanent record of test results.
- d. Utility Programs. Provides various housekeeping functions for the ABMS system.
 - o Disc Utilities - Enables simple disc initialization for data storage and duplication of program discs for safe program storage.
 - o Lists - Provides hard-copy lists of the stored system information, including waveforms stored on disc and in the Waveform Generator, metabolic states and test sequences available, and an alarm/shutdown condition tabulation.
 - o Calibration - Provides for calibration of the data acquisition system and produces an archival record of the calibration data.

SIMULATION PARAMETERS

Work in the area of establishing optimum simulation parameters is continuing. However, the following comments can be made.

1. The metabolic states shown in Table 3 are based on the work of Kamon, et al (1975). RC's experience with testing of prototype breathing apparatus (two one-hour oxygen self-rescuers and one-hour entry and escape device) has been that they produce apparatus performance on a simulator (RC's own simulator) which closely resembles the apparatus

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performance in actual man-tests (unpublished data, 1983).

2. Bernard et al have published the equations for use with simulation tests of breathing apparatus for use by coal miners (1977).

(2)

$$V_E = 8.35 + 15.7 V_{O_2}^{1.35} \text{ and}$$

$$V_{CO_2} = 0.094 + 0.846 V_{O_2}^{1.18},$$

Where:

V_E = minute ventilation, lpm, STPD,

V_{O_2} = oxygen uptake, lpm, STPD, and

V_{CO_2} = carbondioxide production, lpm, STPD.

3. In the area of underwater breathing apparatus, well-defined sets of simulation criteria have been published by Reimers (U.S. Navy Report, 1974), Morrison and Reimers (1983), and Middleton and Thalman (1981).
4. Myhre has published results of the ventilation responses of Air Force firefighters to exercise that are useful when performing tests on breathing apparatus for firefighting use (1979).

CONCLUSIONS

The ABMS described herein is a versatile machine capable of performing almost any physiologically appropriate respiratory simulation. Several sets of useful simulation criteria are also available for use (e.g., Webb, 1964). However, the establishment of widely accepted simulation criteria has not yet occurred and each investigator must satisfy himself that the simulations he is using are appropriate.

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Table 1. Principal Process Performance Capabilities of the ABMS,

<u>Function</u>	<u>ABMS Process Performance Capabilities</u>
<u>Waveform Control</u>	
Tidal Volume	0.5 to 4.0 liters
Breathing Rate	5 to 60 breaths/minute
Peak Instantaneous Flow Rate	678 lpm
Shape Control	Any mathematically well-behaved waveform that meets the above three constraints and which can be represented by a series of 1014 velocity segments per liter tidal volume.
Oxygen Uptake	0.0 to 0.2 times the product of RMV and inspired oxygen concentration
CO ₂ Addition	0.5 to 4.5 slpm
Expired Temperature	Room Temperature plus 10°F to 100°F
Expired Relative Humidity	Inspired dewpoint or 90°F dewpoint (whichever is lower) to 100% R.H.
Dead Space	Simulator dead space is effectively zero. Dead space can be added at any time by inserting a volume (cavity, tube, etc.) plumbed for bi-directional flow into the breathing gas loop adjacent to the mouth opening of the test mannikin.
Functional Residual Volume	Approximately 7 liters with all gas processing functions operating. Lower volumes are possible with modifications to the process gas circuit.

Table 2. 8 sample Listing of Metabolite States
(50th percentile male)

Metabolic		Test Parameters									
State	Title	Tidal Res.		L/X	O2	CO2	Exp.	Oswp Wform			
No.		BPM	Vol	Vol	Ratio	OPTK	OIN	Temp	Taop	O#	O#
1	Stand & 8 sample	12.0	1.00	0.000	0.70	0.440	0.850	86.0	84.7	1	1
2	Walk-8 MPH	18.0	2.01	0.000	0.80	1.520	1.290	87.0	86.4	2	2
3	Climb	31.0	8.88	0.000	1.00	8.600	8.600	87.0	86.7	8	8
4	Pull-48 lbs.	26.0	2.04	0.000	0.90	1.810	1.720	87.0	86.4	4	4
5	Overcast-50 lbs. x 4	14.5	2.00	0.000	0.70	1.100	1.010	87.0	86.4	5	5
6	Run-6 MP#	32.0	8.01	0.000	1.00	8.060	2.910	87.0	86.5	2	2
7	Overcast-50 lbs. x 6	18.0	2.01	0.000	0.80	1.620	1.460	87.0	86.4	7	7
8	Carry-44 lbs. @ 8 MP#	28.0	1.98	0.000	0.90	1.920	1.820	37.0	86.4	7	7

Table 3. Sample Tabulation of Test Sequences

Sequence # 1 Man test IV-50%ILE consists of 18 metabolic states totalling 1447 breaths

Metabolic State #'s:

1 2 3 2 4 2 5 1 2 6 7 4 1 2 4 8 1 2

of breaths

36 36 31 36 130 54 116 24 72 32 162 78 24 108 130 84 24 270

Sequence # 2 ABMS test 1 consists of 5 metabolic states totalling 145 breaths

Metabolic State #'s:

1 2 3 4 6

of breaths

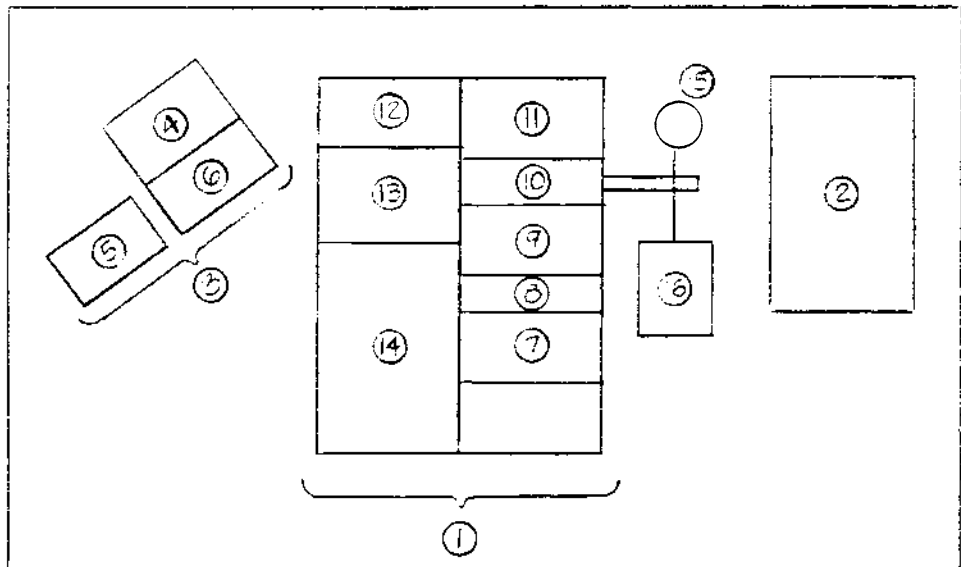
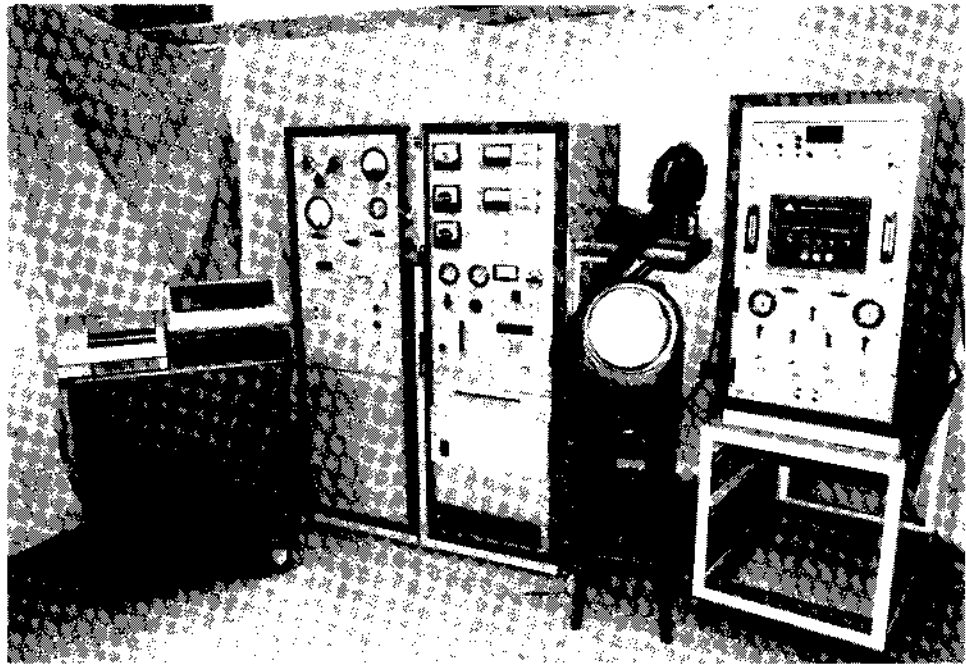
20 20 30 25 50

Sequence # 3 Test of system consists of 3 metabolic states totalling 36 breaths

Metabolic State #'s:

1 3 5

12 12 12



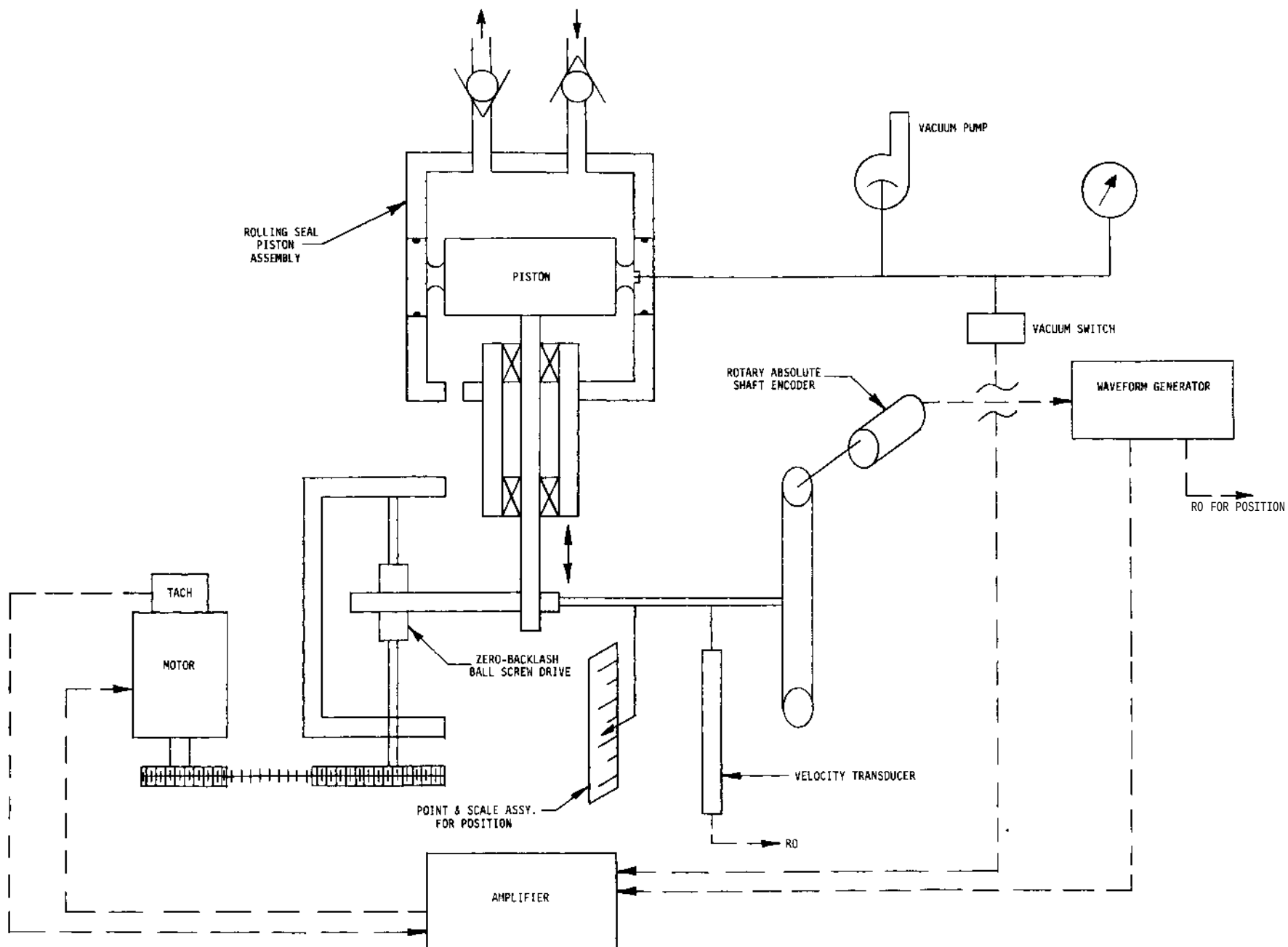
1. Breathing Simulator Module

- 7. HP-2240A Data Acquisition and Control System
- 8. Pull-out Shelf
- 9. Waveform Generator Module
- 10. CO₂ Add Module
- 11. Temperature and Humidity Monitoring and Control Module
- 12. Differential Pressure Measurement Module
- 13. Oxygen Uptake Module
- 14. Piston and Cylinder Assembly
- 15. Mannikin Head (with mask)
- 16. Bio-Pak 60 Closed Circuit Rebreather (for illustration purposes only)

2. Gas-Analysis Module

- 3. Supervisory Controller
- 4. HP-85 Scientific Calculator
- 5. HP-9876A Thermal Printer/Plotter
- 6. HP-82901M Dual Floppy disk Drive

Figure 1: ABMS General Arrangement



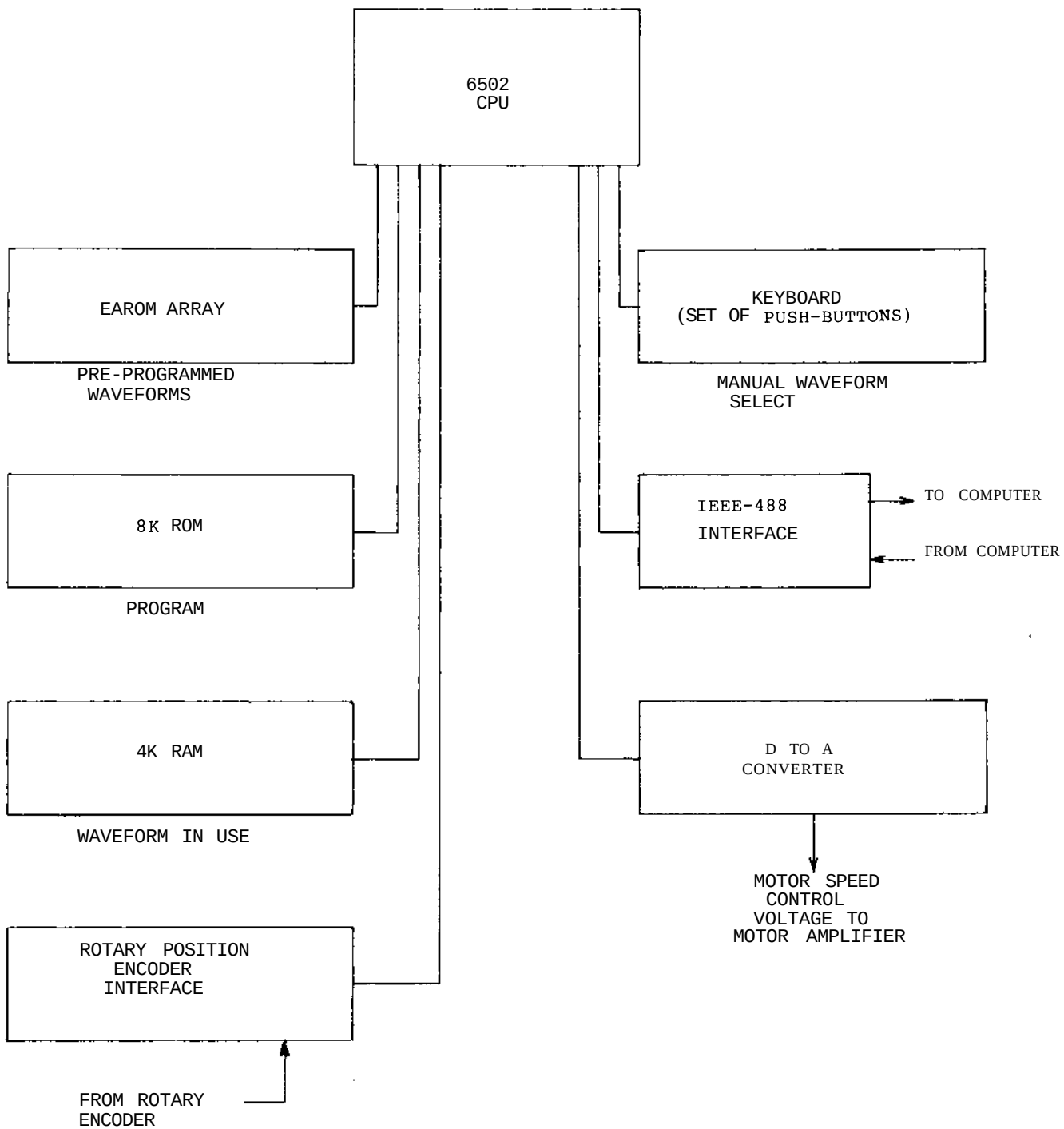
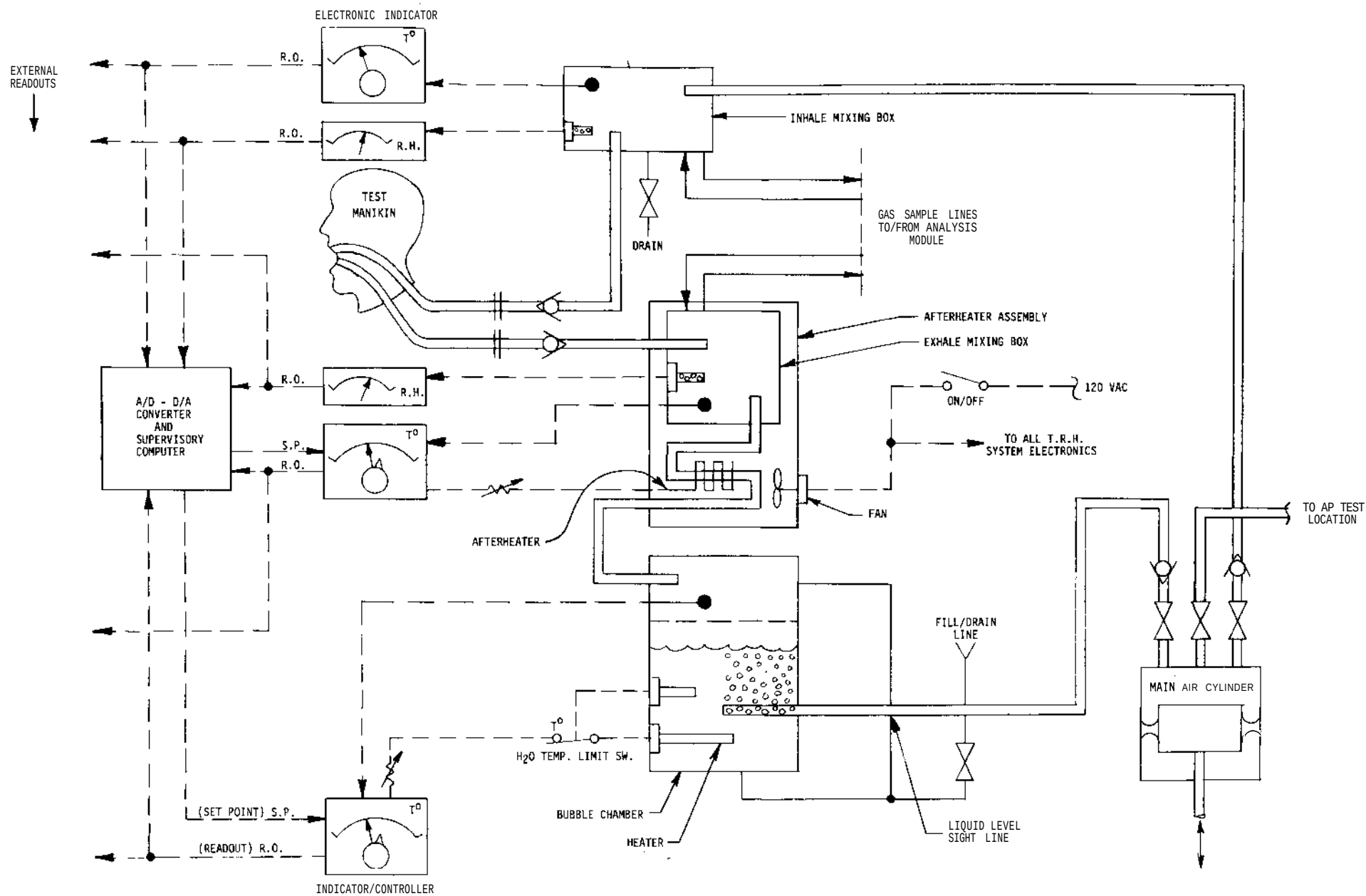
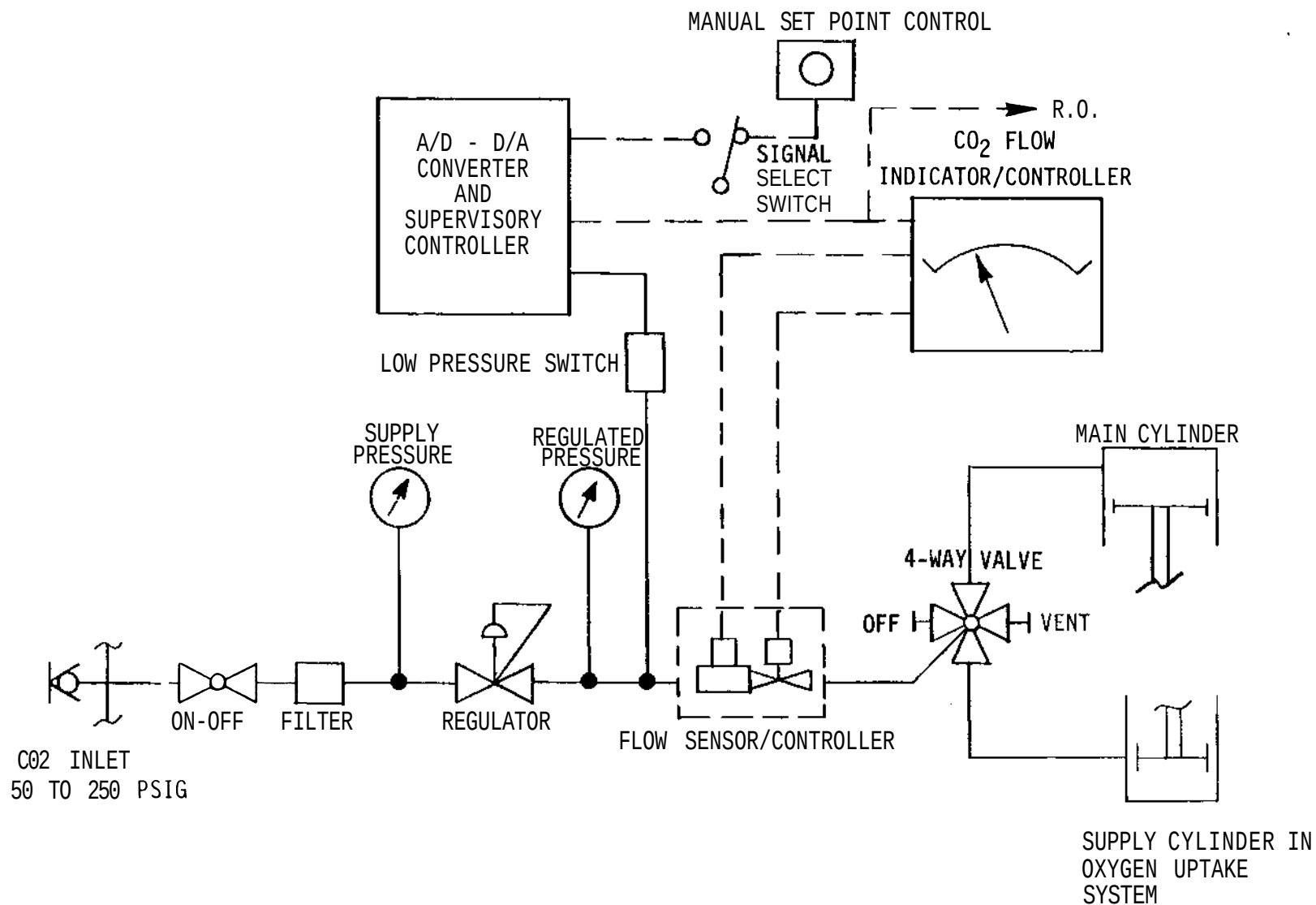
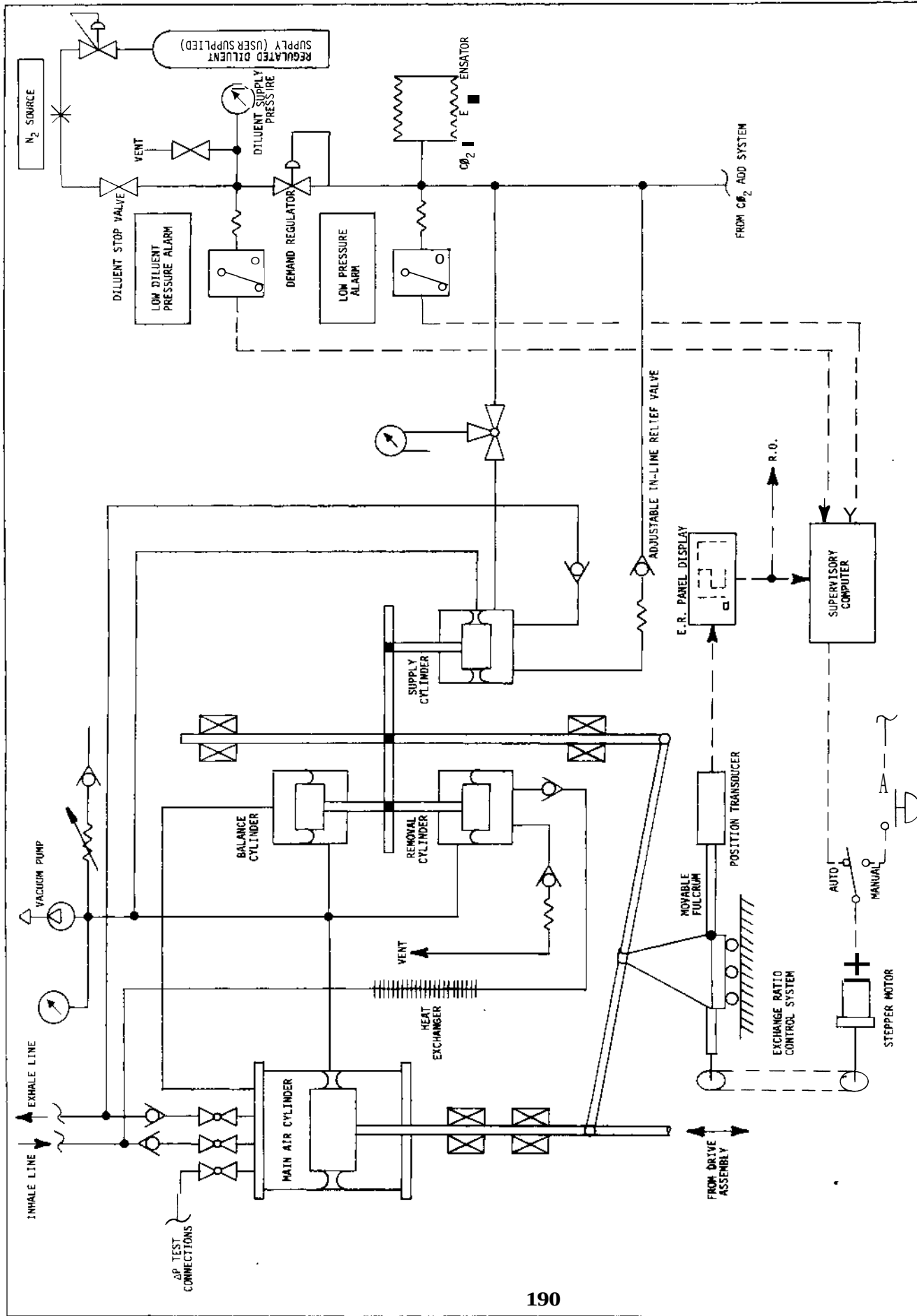


FIGURE 3. Waveform Generator, principal components.



FIGURE 5 CO₂ ADDITION MODULE SCHEMATIC



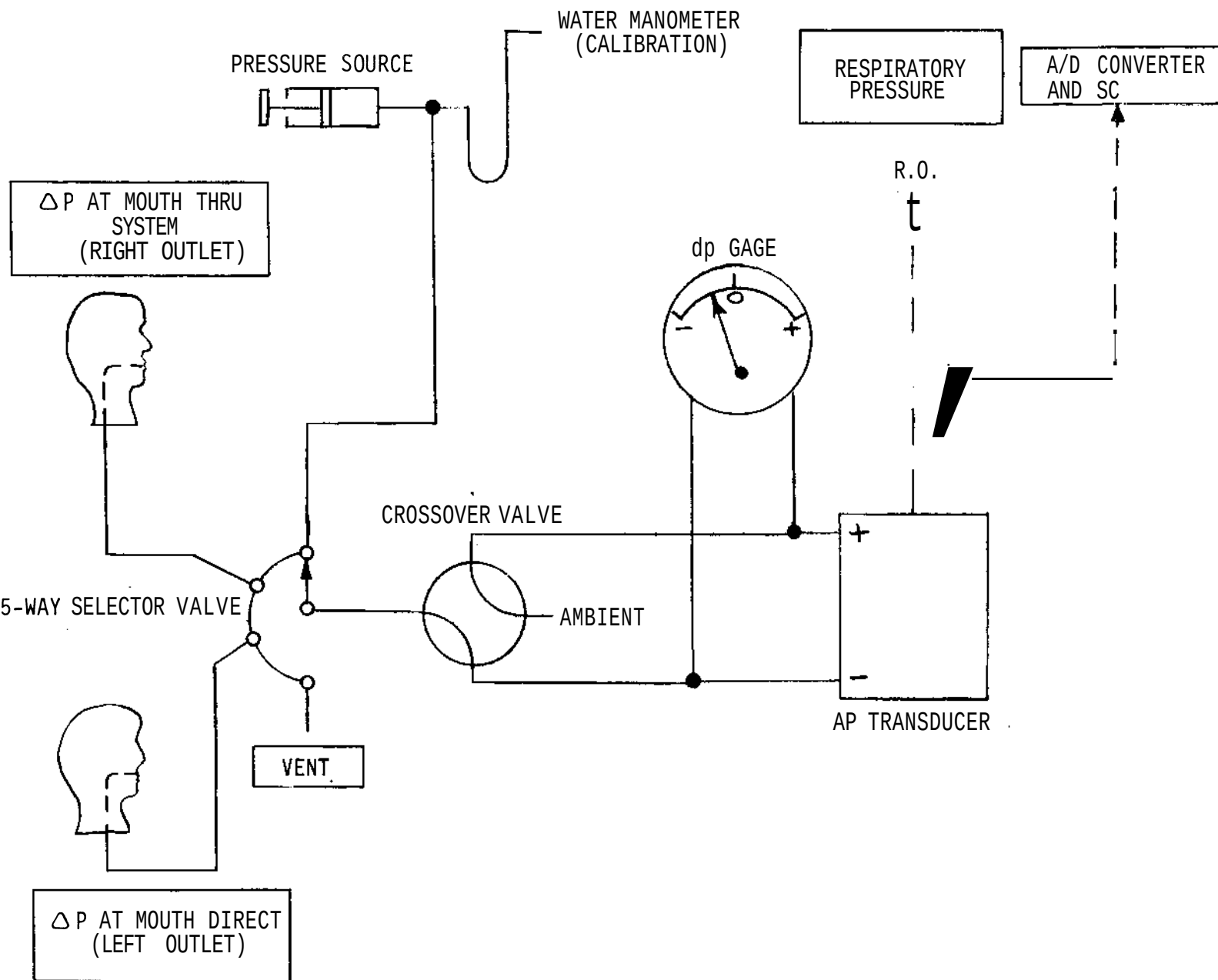
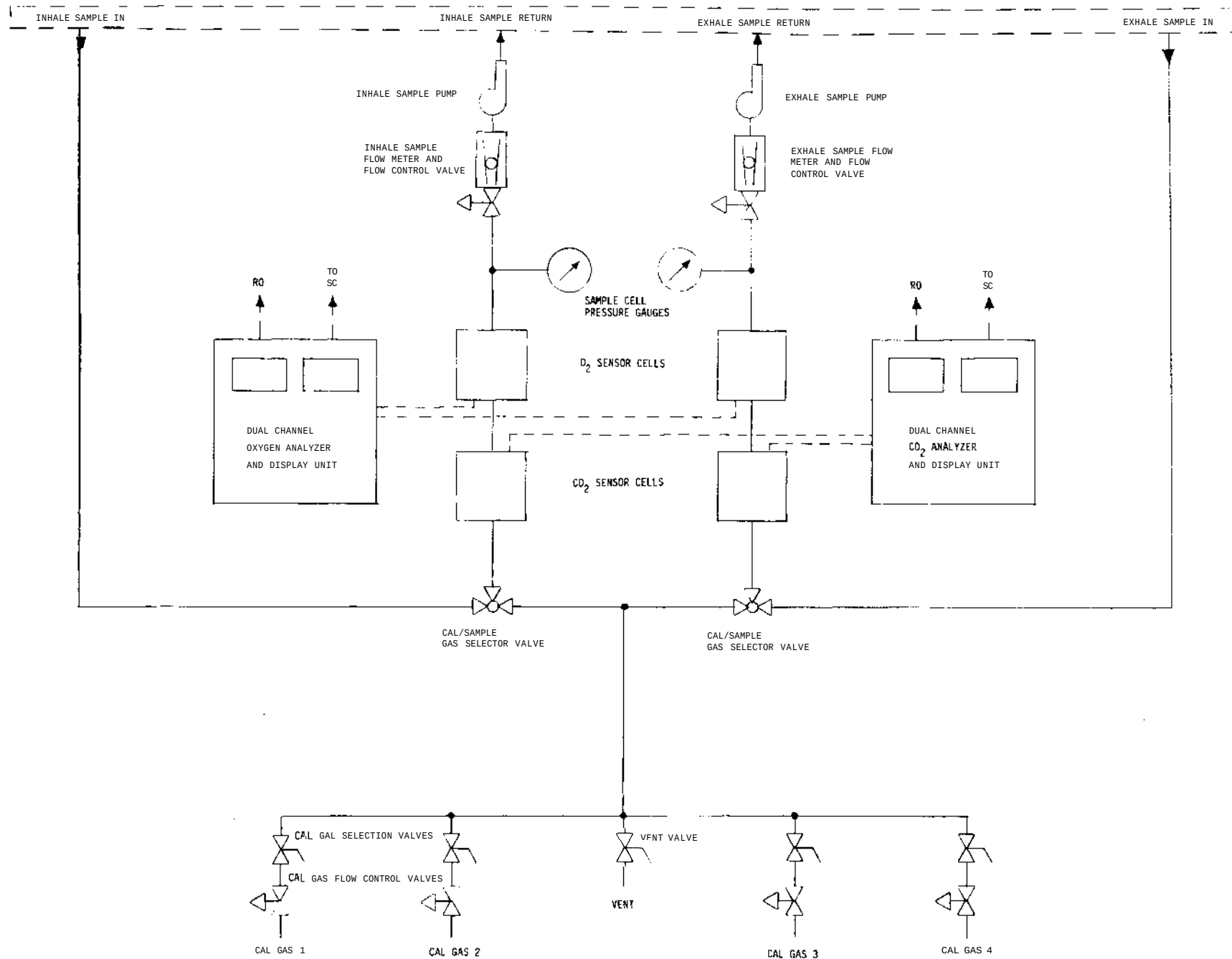


FIGURE 7, ABMS DIFFERENTIAL PRESSURE MEASUREMENT SYSTEM



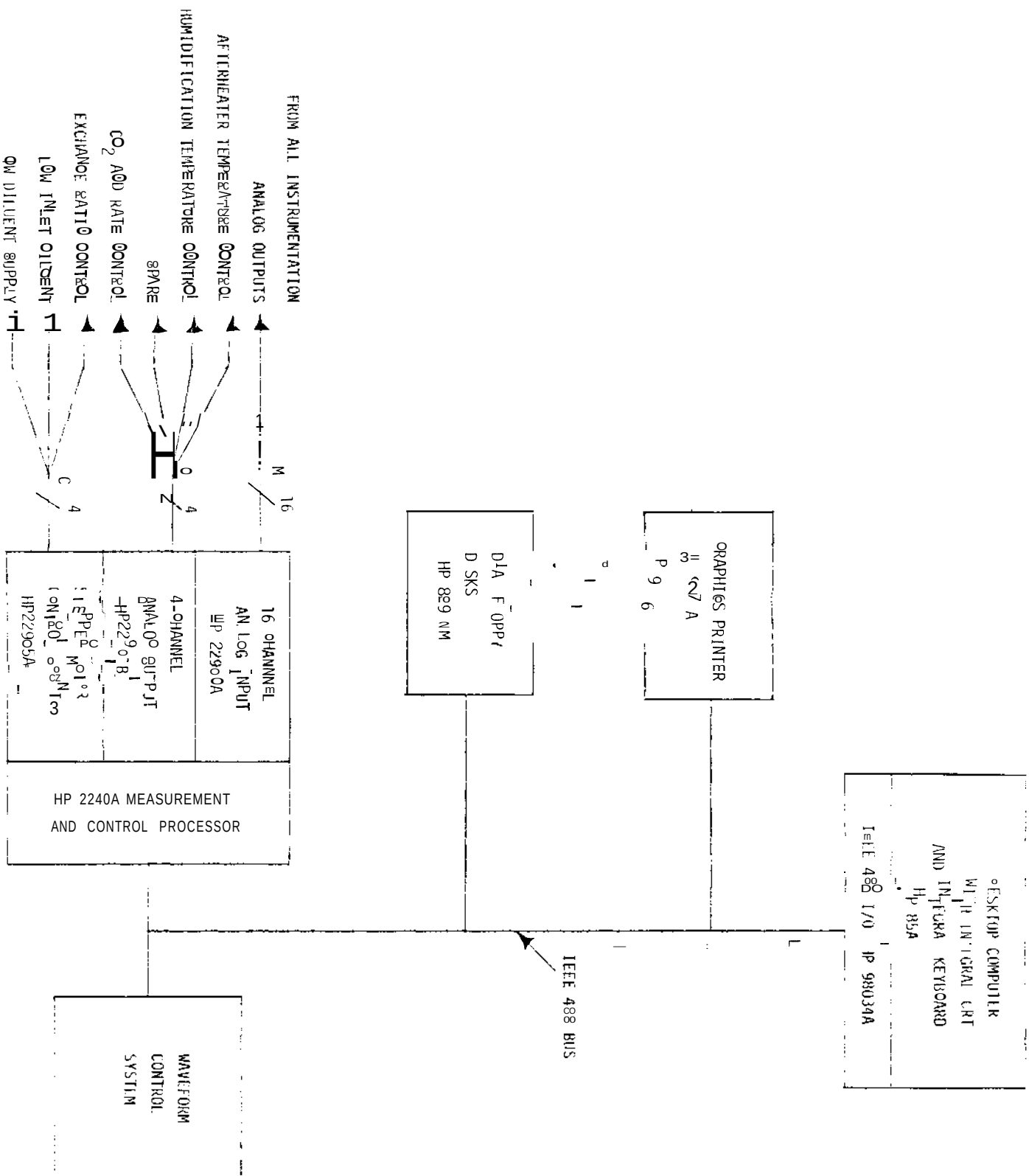


Figure 9. SUPERVISORY CONTROLLER GENERAL ARRANGEMENT

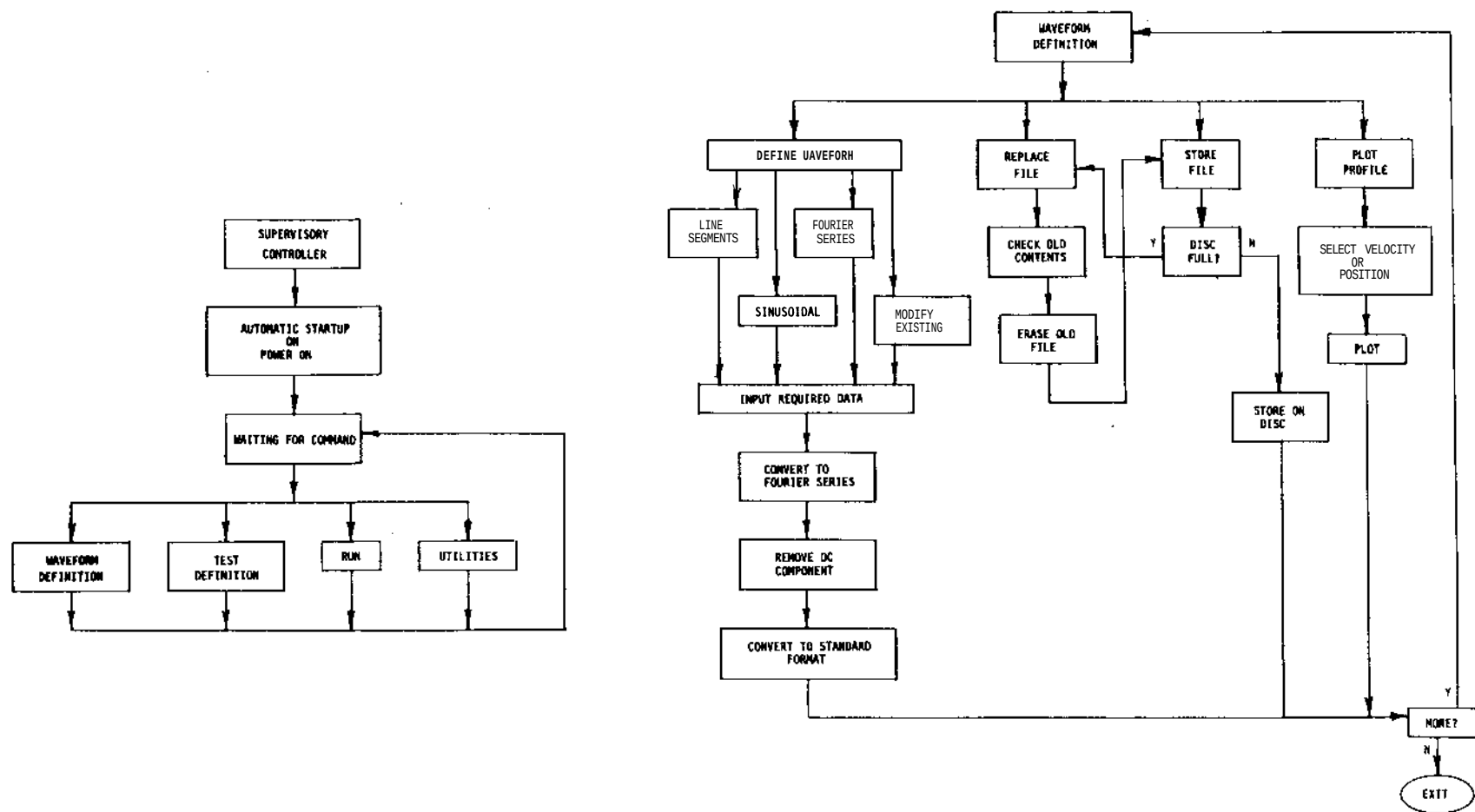


FIGURE 10. Overall system operation and waveform definition block diagrams.

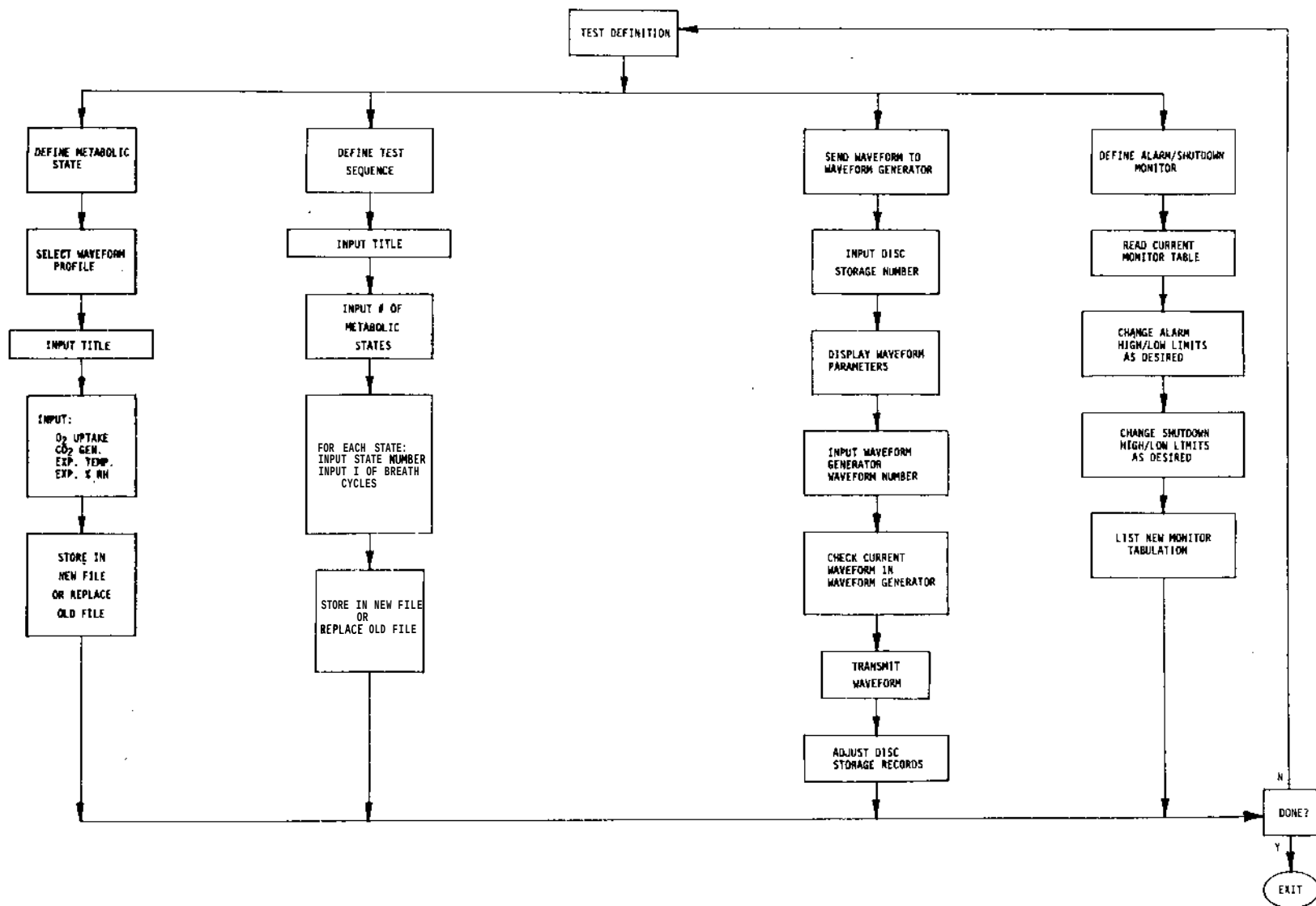


FIGURE 11. Test definition block diagram.

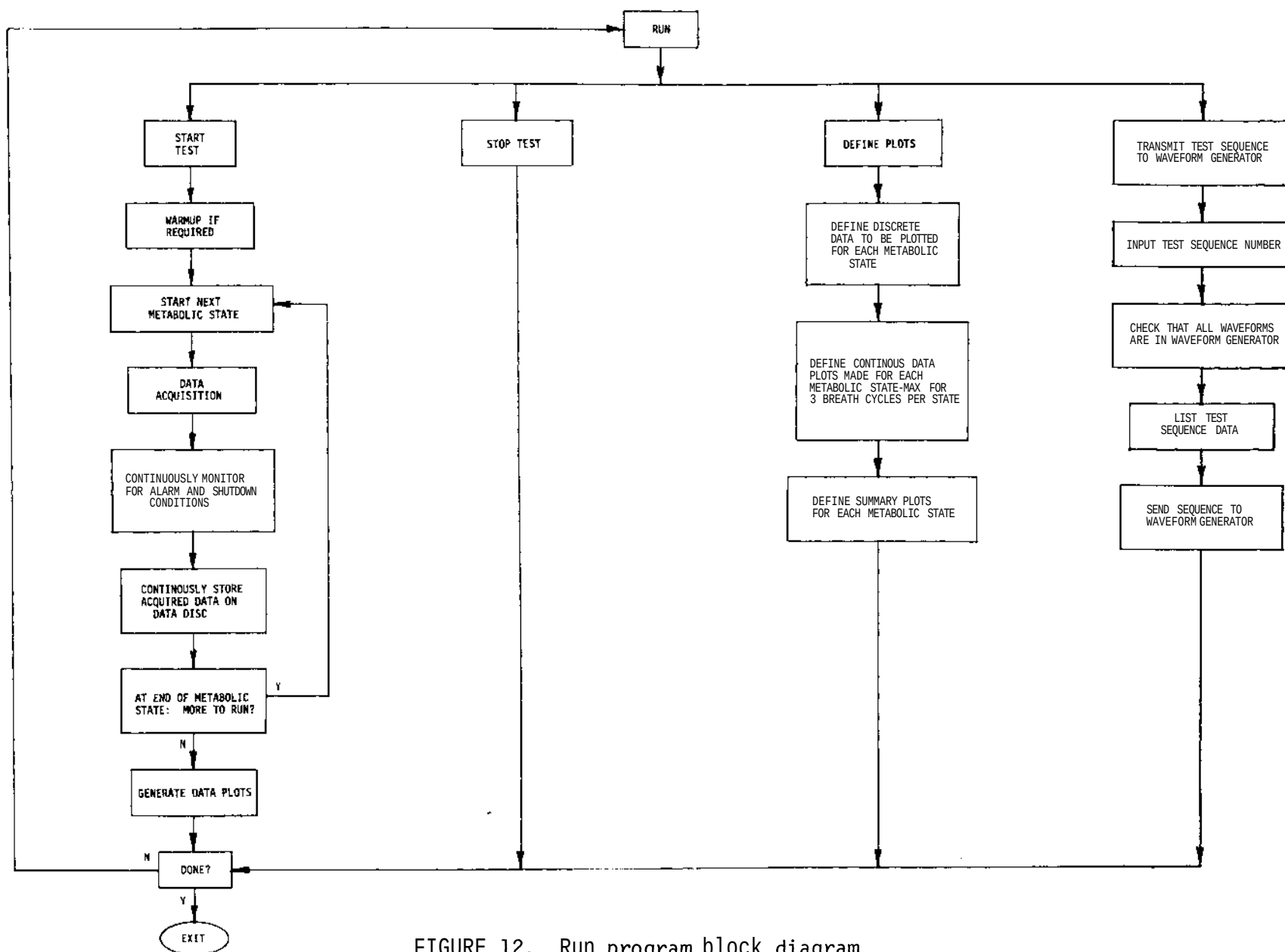


FIGURE 12. Run program block diagram.