EPA-600/1-77-048
October 1977

Environmental Health Effects Research Series

HUMAN EXPOSURE SYSTEM FOR CONTROLLED OZONE ATMOSPHERES

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FOR CONTROLLED OZONE ATMOSPHERES

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FOREWORD

The many benefits of our modern, developing, industrial society are accompanied by certain hazards. Careful assessment of the relative risk of existing and new man-made environmental hazards is necessary for the establishment of sound regulatory policy. These regulations serve to enhance the quality of our environment in order to promote the public health and welfare and the productive capacity of our Nation's population.

The Health Effects Research Laboratory, Research Triangle Park, conducts a coordinated environmental health research program in toxicology, epidemiology, and clinical studies using human volunteer subjects. These studies address problems in air pollution, non-ionizing radiation, environmental carcinogenesis and the toxicology of pesticides as well as other chemical pollutants. The Laboratory develops and revises air quality criteria documents on pollutants for which national ambient air quality standards exist or are proposed, provides the data for registration of new pesticides or proposed suspension of those already in use, conducts research on hazardous and toxic materials, and is preparing the health basis for non-ionizing radiation standards. Direct support to the regulatory function of the Agency is provided in the form of expert testimony and preparation of affidavits as well as expert advice to the Administrator to assure the adequacy of health care and surveillance of persons having suffered imminent and substantial endangerment of their health.

Research involving human subjects must be conducted under the most carefully controlled conditions. The human exposure system described in this publication assures a high degree of reliability with many safety features. The controlled laboratory environment produced by the system accurately simulates exposures occurring in urban areas, allowing the researcher to determine effects on a variety of health indicators. These research results, when compared to the information from animal studies and population surveys provide a sound basis for establishing environmental standards.

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ABSTRACT

An experimental exposure system for health effects research in environmental pollutants that permits the introduction and control of ozone (O_3) to an acrylic plastic chamber in which a human subject actively resides is described. Ozone is introduced into the chamber air intake and is controlled by an electro-mechanical feedback system operating from the electrical output of an O_3 gas analyzer.

A continuous record of O_3 concentration, temperature, and dew point is provided by an analog multipoint strip chart recorder. If the chamber O_3 levels exceed preset limits, an alarm system automatically stops the O_3 flow and switches the chamber exhaust to purge operation.

A complete air exchange occurs every 72 seconds. In an emergency, the chamber can be purged in 190 seconds. Chamber temperature and humidity are dependent upon conditioned laboratory air.

CONTENTS

SECTION 1

INTRODUCTION

Ideally experimental environmental exposure chambers for human subjects should be precisely monitored with automatic control of the pollutant levels and alarms that will stop the pollutant flow under adverse conditions. The intent here is to describe such a system where the pollutant level in the chamber is automatically controlled by the output signal of the pollutant analyzer monitoring the atmosphere of the exposure chamber. Presented as an example is the methodology used in establishing an experimental exposure system that continuously generates and maintains the desired ozone concentration by including the exposure chamber in the gas delivery feedback control loop. The exposure system consists of a spacious, transparent acrylic plastic chamber to contain the exposure atmosphere, an exhaust fan to maintain a fresh air supply, a method to inject known volumes of pollutant gases into the chamber air supply, a system of calibrated gas analyzers to determine the actual pollutant gas concentration in the chamber, and safety components to shut down the pollutant gas supply and sound alarms to protect the exposure subject. During exposure in the chamber, pollutant effects on human behavioral and physiological functions, such as visual motor coordination discrimination and cardiac, pulmonary, and peripheral circulatory response, can be evaluated.

In recent chamber studies, volunteers have been exposed to an ozone (O_3) atmosphere of 800 $\mu g/m^3$ [0.4 part per million (ppm)] ± 10 percent. Further exposure studies are planned for nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) atmospheres, both singly and combined with ozone.

The exposure chamber is located in EPA's Health Effects Research Laboratory facilities on the campus of the University of North Carolina at Chapel Hill and was developed as part of the Environmental Protection Agency's efforts to assess the adverse health effects of air pollution on humans. All human exposure experiments using the chamber are cooperative efforts between the University and EPA.

SECTION 2

MATERIALS AND METHODS

EXPOSURE CHAMBER DESIGN

Initial requirements for the exposure chamber, illustrated in Figure 1, involved keeping the design simple and the construction complexity minimal with the safety of the exposure subject uppermost in mind. Because a transparent chamber was desired, 1.2- x 2.4-meter (4- x 8-foot) transparent acrylic plastic sheets 1.3 centimeters (cm) (1/2 inch) were selected for the walls, floor, ceiling, and doors. To minimize cutting of the construction material, the chamber was made as close to an 8-foot cube as permitted by the space allocated in the laboratory facility. The corner and ceiling support members were made from 3.8-centimeter (1-2/3 inch) thick aluminum "U" channel stock. The closed backs and sides of the "U" shaped channels were bolted together so that adjoining sheets of plastic could be slipped into the open end of the "U" and sealed with silicone calking to form a rigid airtight seam. Seventeen 1.2- x 2.4-meter plastic sheets and 137.2 linear meters (450 feet) of "U" channel were required for the chamber.

The finished chamber interior provides a 2.44 x 2.44 meter (8 x 8 foot) floor area with a 2.23 meter (7 foot 4 inch) ceiling which represents a total enclosed volume of 13,282 liters (469 cubic feet). An 850-liter (30 cubic feet), stand-up, whole body plethysmograph was constructed inside and in one corner of the chamber with the entrance opening into the exposure chamber. Because the body plethysmograph door is normally closed, the instrument is sealed from the exposure gas. The gaseous pollutant is thus confined to a chamber volume of 12,432 liters (439 cubic feet). Dynamic pulmonary function measurements are made in a body plethysmograph as one test for subtle effects of pollutant gas exposure.

The doors to the body plethysmograph and exposure chamber were constructed from 76.2- x 208.3-cm sheets of 1.3-cm thick acrylic plastic. The door openings were made smaller than the doors to provide a surface around the periphery of the opening where gasket material could be sandwiched between the edges of the opening and the overlapping door. This provided a gas-leak-proof door without an elaborate door jamb and threshold. Door hinges of the type found on standard walk-in refrigerators were used with a cam door latch that was operable from either side of the doors.

CHAMBER AIR SUPPLY

The rear of the chamber was situated against an outside wall of the laboratory thus permitting the location of the exhaust fan outside the building. A low speed industrial radial wheel exhaust fan was selected to draw ambient laboratory air through the chamber. The noise produced by the exhauster is negligible because of the low operating speed of 920 revolutions per minute (rpm) and the remote location of the fan. A manufacturer-applied corrosion resistant coating (LENKOTE) on the fan wheel and weather proof housing protects the exhauster from the pollutant gases. A 22.9-cm (9-inch) diameter stainless steel vertical duct carries the output of the fan from its ground level location to 61 cm (2 feet) above the building roof line. Selection of the exhaust fan was based on the requirements for a standard, commercially available, low speed, weather proof fan that could produce a complete air exchange in the chamber within 2 minutes at an estimated differential air pressure of 5.1 centimeters (2 inches) of water across the chamber and air supply subsystem. A 2-speed, 0.5 horsepower, 115-volt, single phase motor was selected to drive the fan. Motor speeds of 1140 and 1725 rpm drive the fan at speeds of 920 and 1392 rpm. High speed operation of the fan is used only to purge the chamber, a process that can be accomplished in approximately 190 seconds under alarm conditions. Under normal low speed operation, the exhaust fan develops an actual pressure of 2.7 cm (1.06 inches) of water to move air at a rate of 10,393 liters per minute (367 cubic feet per minute (cfm)) through the air supply duct, the chamber, and the exhaust duct; therefore, one air exchange occurs in the chamber every 72 seconds.

The fan input is connected by a 22.9-cm (9-inch) diameter stainless steel duct to the center of the chamber back wall at the floor line. A 12.7- x 22.9-cm (5- x 9-inch) rectangular exhaust duct at the junction of the chamber floor and walls contain six registers; two on each side wall and two on the back wall. Each register has an adjustable 7.6- x 17.8-cm (3- x 7-inch) opening to provide a means of controlling the air flow within the chamber. Closing the register openings increases the resistance of the duct system and results in a reduced airflow. In the present study, the registers were placed in the maximum open position.

A perforated aluminum grill in the ceiling of the chamber covers a 71.1- x 71.1-cm (28- x 28-inch) square by 10.2-cm (4-inch) high dispersion box. The grill (available at most hardware stores) has a 3.2-millimeter (mm) diameter (1/8-inch) holes on 7.1-mm (9/32 cm) centers and 1.6-mm (1/16-inch) diameter holes on 2.4-mm (3/32-inch) centers between the larger holes.

An air supply duct with inside dimensions of 10.2 x 71.1 centimeters (4 x 28 inches) extends from the dispersion box 2.4 meters (8 feet) into the laboratory where the exposure chamber is located. The supply air is drawn through the duct and through the dispersion box by the negative chamber pressure generated by the exhaust fan. A removable orifice plate with a 6.4- x 29.2-cm (2-1/2 x 11-1/2 inch) rectangular opening is positioned midway in the 2.4-meter-long air supply duct. The orifice plate is used with a differential pressure meter to indicate the air flow to the chamber. The air supply duct and orifice plate were constructed from the same acrylic plastic material used for the construction of the chamber. The available space above the chamber and the thickness of the plastic had to be considered in designing the size of the duct and dispersion box.

The static pressure tap locations for the rectangular orifice plate were found experimentally using a magnehelic pressure gauge with a 6.4-mm (1/4-inch) diameter tube probe. An inexpensive water manometer could have been used for the pressure gauge, however. From the center line of the rectangular orifice plate, the high pressure tap was located 20.3 cm (8 inches) upstream and the low pressure tap at a point 10.2 cm (4 inches) downstream. The differential pressure measured between the pressure taps was 14.5 mm (0.57 inch) of water for an air flow rate of 367 cfm measured with a Velometer. All of the equipment that was available to measure air velocities and pressure drops used the British system of units; therefore, conversion to metric units was made after all air velocities and pressure drop measurements were made and the airflow calculated.

If a Velometer is not available, the approximate air flow through the orifice can be computed from the simplified equation:

$$Q = 60A\sqrt{1705P_d}$$

Where: "Q" is the approximate air flow (in cubic feet per minute).

"A" is the area of the orifice opening (in square feet).

"P_d" is the pressure drop between the high and low pressure taps for the orifice (in inches of water).

For a round orifice of diameter D, the duct diameter should be 2D, the low pressure tap should be the distance D downstream, and the high pressure tap should be a distance 2D upstream from the orifice.[1,2]

The air flow through the chamber determined from the above formula is 373 cfm where the Velometer-measured air flow was 367 cfm or 367 cfm times 28.32 liters per cfm which equals 10,393 liters per minute.

Because the ambient pollutant concentrations in Chapel Hill are less than 10 percent of the chamber exposure levels, the cost of an absolute filter system for the chamber air supply duct was not justified. A standard furnace type dust filter was placed across the entrance of the air supply duct, however, to remove normal airborne dust.

The air resistance of the dust filter and orifice plate creates a negative pressure of 0.67 inch of water in the chamber when referenced to the outside air pressure. A drop in pressure of 0.67 inch of water is equal to 0.0235 pound per square inch reduction in pressure.

The temperature and humidity conditions in the chamber are dependent on the conditioned makeup air supply to the laboratory area in which the chamber is housed. Solid state thermistor and lithium chloride sensors,[3] located in the chamber, through electronic signal conditioners provide linear 0 to 1 volt DC signals that are directly proportional to the temperature and dew point in the chamber.

OZONE GENERATION AND FLOW CONTROL

Normally, pollutant gases are purchased in pressurized cylinders in either the pure form or mixed with other gases. Pressurized cylinders of O_3 dissolved in "Freon-13" can be purchased but are very unstable, having a half-life of only 3 days at 20°C and 8 days at 15°C. The cylinders of O_3 must be packed with dry ice in an insulated container for shipment and storage.[4] The disadvantage of being unstable, however, is surmounted by the extreme ease of generating ozone.[3,4] Both laboratory-constructed and commercially available generators consist of a closed chamber through which dry air or oxygen flows past an ultraviolet light source or nonarcing electrodes connected to a 1,000- to 10,000-volt AC source. The latter corona discharge or silent arc ozone generation method was selected for the present study. Bottled oxygen was used in the O_3 generator to prevent the formation of nitric oxide (NO) and NO_2 from the nitrogen in dry air.

The generation capacity of the silent arc ozonator was defined by the chamber air flow of 10,393 liters per minute and the requirement that 1 liter per minute of oxygen (O_2) through the ozonator produce a 1 ppm O_3 gas concentration in the chamber. Using a ratio of concentrations and flows, the minimum required ozonator output was computed to be 10,394 ppm.

$$\text{Ozonator Output (ppm)} = \frac{O_3\text{ ppm }[O_2\text{ Flow (cm}^3\text{/min)} + \text{Air Flow (cm}^3\text{/min)}]}{O_2\text{ Flow (cm}^3\text{/min)}}$$

Where: "O_3ppm" is the chamber concentration (in parts per million).

"Air Flow" is the chamber air flow (in cubic centimeters per minute).

"O_2 Flow" is the oxygen flow to the ozonator (in cubic centimeters per minute).

For reduced O_2 flow rates, the output concentration of the ozonator will increase because a longer residence time in the generator converts a larger percentage of O_2 to O_3.

As shown in Figure 2, a double regulator is used to reduce the 8637-liter O_2 cylinder pressure to a line pressure of 10 pounds per square inch gauge (psig) to remain within the manufacturer's specifications for the ozonator.

Downstream of the regulator is a cylinder switching manifold consisting of a shutoff valve on each of the two O_2 cylinders and a three-way valve used to switch between the cylinders. With this arrangement, an empty cylinder can be replaced without disruption of the flow of O_2 gas.

As a safety precaution, two devices are used to restrict the flow of O_2 gas and, consequently, the O_3 gas. A normally closed solenoid valve is used to shut off the flow of gas to the chamber in the event of a power failure or an alarm condition. Power must be applied to this valve for it to remain open. (The conditions for an alarm will be explained later). A 20-turn micrometer valve with a coefficient of velocity (CV) of 0.028 is the second flow restrictor. Used as a throttling device, the valve was adjusted to a setting of three turns restricting the O_2 flow to 600 cm^3/min with all other valves in the maximum open position. The limited O_2 flow through the O_3 generator will prevent a chamber O_3 concentration above 0.6 ppm.

All components in the O_2 gas flow path are maintained as fixed value passive elements except for the servo-driven micrometer valve on the output of the "Pollutant Level Error Detector and Processor." (See Figure 2). Changes in the O_2 flow are made by the servo-motor-driven valve inversely to changes in the analogue DC voltage output of the O_3 gas analyzer monitoring the chamber atmosphere. Except for the motor drive coupling, this valve is identical to the flow restrictor valve. Uncontrolled variables in the exposure chamber system that may influence the chamber pollutant level are compensated for by the negative feed back of the "Pollutant Level Error Detector and Processor" between the output of the O_3 gas analyzer and the servo-motor-driven valve. Typical of the uncontrolled variables are:

1. Changes in the air flow through the chamber resulting from outside wind conditions, fan speed, leaks, and filter loading.
2. Absorption of the pollutant gas by the subjects, particulates, and materials in the chamber.
3. Changes in the gas generation system.

With automatic closed loop control of the O_2 flow and subsequently the O_3 flow, the O_3 concentration at any point in the chamber can be held within $\pm$ 10 percent of 0.4 ppm exclusive of the accuracy of the O_3 analyzer. Any inaccuracies or drift in the calibration of the O_3 analyzer directly affect the chamber concentration through control of the O_2 servo-driven valve.

The block diagram of the "Pollutant Level Error Detector and Processor," Figure 3, and the discussion that follows will give an idea of the operation of the pollutant flow controller. The input device to the flow controller circuit is a meter relay with the meter movement electrically activated by the 1-volt DC output of the gas analyzer that monitors the chamber atmosphere.[5] The two set point switches, which are photoelectrically operated by the meter movement, are set at 5 percent below and at 5 percent above the desired O_3 exposure level. For the present exposure level of 0.4 ppm, the full scale output range of the O_3 analyzer is set at 1 volt DC, which is equivalent to 0.5 ppm at the input. The meter relay set point switches determine the direction of rotation of the valve servo motor by applying a 5-volt DC positive logic level to the data input of the clockwise (CW) or counterclockwise (CCW) Flip-Flop.

If the meter relay indication is higher than the upper set point, a logic high 5-volt DC level will appear on the data input of the counterclockwise Flip-Flop. When a clock pulse arrives at the clock input, the Flip-

Flop will be triggered, resulting in a logic high level on the output. An electronic switch connected to the output of the Flip-Flop will apply power to the CCW rotation input power phase of the motor. The servo valve will be driven in a CW direction toward the closed position with a reduction in the flow of O_2 gas to the O_3 generator. The valve rotation is opposite that of the motor because of the gear reduction coupling between the motor and the valve. If the meter relay indication was below the lower set point, the CW Flip-Flop would be triggered by the clock pulse resulting in the servo valve being driven further open.

An astable multivibrator, or Correction Interval Clock, with an adjustable period of 1 to 3 minutes provides the clock pulses for the CW and CCW Flip-Flops. The clock period is set to exceed the measured time between a step change in the O_3 flow to the chamber and the indication of the step change on the O_3 gas analyzer monitoring the chamber. Thus, incremental changes in the O_3 flow are time-spaced to allow the O_3 analyzer to detect the chamber concentration. For an O_3 chamber concentration of 0.4 ppm, the measured time between the start of the O_3 flow to the chamber and the point at which the concentration reached 63% of 0.4 ppm was 2 minutes, 32 seconds. After stabilizing at 0.4 ppm, the O_3 concentration dropped to 37% of 0.4 ppm in 1 minute, 50 seconds after the O_3 flow had stopped. Thus, the astable multivibrator period was set for 3 minutes. The accuracy of this setting is not important as long as the period is longer than the detected step change in the O_3 flow to the chamber.

To generate incremental changes in the O_3 flow, the "Correction Increment Monostable" multivibrator is triggered by the outputs of the CW and CCW Flip-Flops through an AND gate that subsequently resets the Flip-Flops 0.1 to 3.0 seconds after the clock pulse (Figure 3). This delay time or correction time is set to allow the servo-motor-driven valve to rotate sufficiently to permit an incremental change in the O_2 flow to the ozonator, and consequently the O_3 flow, that will bring the meter relay indicator from a limit reading to a value midway between the limits. With a valve rotation speed of 1 revolution every 6 seconds, a reset dalay time of 0.6 seconds will change the 220 cm^3/min O_2 flow 8 percent for the desired 5 percent change in the chamber 0.4 ppm O_3 concentration. Figure 4 indicates the relationship between the rotation of the servo-motor-driven valve and the O_2 flow through the O_3 generator with the resulting O_3 chamber concentration. Intermittent operation of the servo motor is necessary because the servo-driven valve can change the O_3 flow at a faster rate than the gas measurement subsystem can follow.

High and low limit comparators detect the limits of the feed back potentiometer on the valve servo motor shaft and present a logic low reset level through the OR gate to the Flip-Flop that causes the servo motor to be driven beyond the limit (Figure 3). A high limit alarm is also set off when the servo valve is driven to the maximum O_3 flow limit. For the present exposure study, this limit was 5 turns of the valve for a maximum flow of 590 cm^3/min. Rotation of the valve beyond 5 turns increased the flow only 10 cm^3/min because of the low O_2 line operating pressure. If a servo-driven valve with a lower CV was available, a larger number of valve turns would be usuable.

To adjust the initial O_3 flow to the chamber, the input of the servo valve motor drive amplifier is switched by the double-pole, double-throw switch to the output of an analogue servo amplifier. A manually operated, 10-turn potentiometer is positioned to the required flow setting. If the feedback potentiometer on the valve servo motor shaft is in a different position, an error voltage will occur at the summing point of the servo amplifier. The amplified error voltage will activate the motor drive amplifier thereby energizing the motor phase to rotate the feedback potentiometer in the direction that will reduce the error signal.

The O_2 flow controller (shown in Figure 2) is followed by a rotameter that is used as a relative O_2 flow indicator for the O_3 generator. Calibration of the rotameter is not actually required because the flow of O_2 is based on the quantity of O_3 in the chamber and the rotameter is used only as an indicator of flow.

Finally, O_2 is converted into O_3 in a corona silent discharge arc ozonator in which the O_2 is subjected to a 60-hertz alternating electric field between electrodes connected to a high voltage transformer. Ozone is formed by collision of a free oxygen atom with an O_2 molecule. The high electric field provides the medium for the transfer of energy to form a stable O_3 molecule.[6]

In order that the oxygen flow will be the major factor in controlling the O_3 concentration, the two variables of power input and temperature of the ozonator are held reasonably constant. A 40-watt incadescent lamp is used as a fixed ballast on the power input to the ozonator. The lamp provides some regulation by holding the ozonator input voltage within 5 percent for a 10 percent line voltage change. The temperature of the cooling water for the ozonator is held at a constant 22°C within a half degree by a water bath. Without the water bath, a 5°C change will alter the 0.4 ppm chamber concentration by 1 percent.

A 6.4-mm (1/4-inch) outside diameter stainless steel tube 4.6 meters (15 feet) long is used to transport the O_3 directly from the ozonator the the location of the low pressure tap of the orifice plate in the chamber air supply.

CHAMBER OZONE LEVEL MEASUREMENT

The pollutant level in the chamber is measured by drawing chamber air samples through 6.1 meters (20 feet) of 6.4-mm (1/4-inch) diameter Teflon tubing with a vacuum pump connected to the output of a chemiluminescence O_3 analyzer.[6] The upstream input end of the sample tube is located 1.5 meters (5 feet) from the floor of the chamber and normal to the center of the aluminum dispersion grill in the ceiling of the chamber. This sampling location was selected because it places the input end of the sample tube at the center of the chamber input air stream and at the height of the nose of the average subject sitting on a bicycle ergometer. The subject's electrocardiogram is measured at rest and during periods of exercise on a bicycle ergometer during the O_3 exposure.

Calibration of the O_3 analyzer is accomplished by the gas phase titration method as described in Tentative Method for the Calibration of Nitric Oxide, Nitrogen Dioxide, and Ozone Analyzers, an EPA publication.[7]

The 1-volt DC electrical output signals from the O_3 gas analyzer are recorded concurrently with the temperature and dew point sensor signals on a multipoint strip chart recorder. A digital voltmeter is also used to display the output of the analyzer, thus improving the reliability of the meter reading by the operator.

SAFETY ALARM SYSTEM

Electrical signals from the ozone gas analyzer, the chamber air supply flow monitor, the pollutant gas flow controller, and the fire and combustion gas level monitors are used to set off audible alarms and turn on indicator lamps under the following conditions:

1. If a fire develops in the chamber, the area around the chamber, or in the outside gas cylinder storage house, the gas supply and chamber air supply will be automatically shut off to help prevent spreading the fire. When activated, heat and explosive gas detectors close normally open switches.

2. If the flow rate of the fresh air supply to the chamber drops below a preset level or if the chamber door is opened when the O_3 gas is flowing, the alarm will sound, the O_3 gas will be shut off, and the exhaust fan will go into high speed purge operation. A differential pressure gauge connected to the high and low pressure taps of the chamber air supply duct orifice plate will close a switch when the pressure drop goes to zero.

3. If the O_3 pollutant gas concentration in the chamber goes above the 0.5 ppm limit set for a normal exposure level of 0.4 ppm, a switch connected to the multipoint strip chart recorder pen drive will activate an alarm stopping the pollutant gas flow.

4. When the O_3 pollutant gas flow controller has reached the maximum preset gas flow limit of 590 cm^3/min into the chamber, an alarm switch is closed and the gas flow is stopped. This will occur when the servo driven valve has rotated open 5 turns. Thus the alarm will sound even in the O_3 gas analyzer output signal to the meter relay remains below the low chamber concentration limit causing the flow controller to compensate by increasing the O_3 flow when in reality the O_3 concentration was above the limit.

Under all of the above alarm conditions, power will be removed from the O_3 generator and the normally closed solenoid valve on the O_2 gas supply cylinder thereby stopping the flow of O_3 gas.

MEASURED PERFORMANCE CHARACTERIZATION

Before human subjects were permitted in the chamber, sequential validation and characterization tests were performed to measure the air supply volumetric flow rate and to determine the pollutant flow volume so that the desired chamber concentration, the required incremental change in pollutant flow rate to adjust for system variables, and the necessary distribution the pollutant throughout the chamber would be provided.[8]

The volumetric air flow of 10,393 liters/minute through the chamber was determined by averaging six velocity measurements with a Velometer in front of the chamber air supply duct filter and multiplying by the cross sectional area of the duct. For the exposure volume of 12,432 liters, one complete air exchange will occur every 72 seconds. Five-percent variations in the pressure drop across the orifice plate caused by outside wind conditions have been observed. Any adjustments required in the chamber pollutant concentration attributable to wind-caused air flow deviations were well within the $\pm$ 5 percent of 0.4 ppm correction range of the automatic pollutant gas flow controller, however.

Before the oxygen flow through the ozone generator could be determined for the required exposure level, the power line input current to the generator had to be set at a stable value. The initial step in the procedure was to adjust the O_2 gas cylinder output pressure to the 10 psig maximum operating pressure of the generator.

With the input current set at zero, the O_2 flow was adjusted to provide 1 liter/min through the generator. The input current was then increased slowly from zero until the chamber concentration reached approximately the design limit of 1 ppm, which occurred at a value of 0.16 amperes. Both the generator current and the chamber concentration were monitored for at least 2 hours. Compensation for slight adjustments made in the generator to improve the input current stability was accomplished by altering the O_2 flow.

After calibration of the ozone gas analyzer, ozone was introduced to the chamber for evaluation and characterization of gas control subsystem. The flow controller valve was adjusted to the maximum open position, and the micrometer flow restrictor valve was adjusted to produce a flow that created a chamber pollutant level at the experimental design safety limit. For a maximum chamber O_3 concentration limit of 0.6 ppm, the valve was opened 3 turns, which allowed an O_2 flow through the gas subsystem of 6000 cm^3/min with an O_2 cylinder line pressure of 10 psig.

A curve of O_3 flow and the chamber O_3 concentration versus rotation of the servo driven valve was plotted for the flow controller (Figure 4). Information from this curve was used to determine the initial flow setting and the length of the correction time that the servo motor is energized. The correction time was computed from the formula:

$$\Delta t = \frac{\Delta f \times S/r}{\Delta R}$$

Where: "Δt" is the correction time (in seconds).
"Δf" is the cc/min change in O_3 flow (in cubic centimeters per minute) that will produce a 5 percent

change in the part per million chamber concentration of ozone.

"S/r" is the time (in seconds) for each revolution.

"ΔR" is the change in O_3 flow (in cubic centimeters per revolution) for each revolution of the 20-turn servo valve.

The period between correction times of the controller is a matter of minutes based on the chamber air exchange rate, the pollutant monitoring cycle or settling time, the transport time of the pollutant gas to the chamber and the time for a gas sample to flow from the chamber to the pollutant monitor.

Two calibrated ozone gas analyzers were used to define the profile of the exposure chamber from six locations equally spaced on two planes (2 feet and 5 feet above the floor respectively). The sample probe for the reference analyzer remained stationary 5 feet above the floor at the center line of the perforated aluminum grill covering the dispersion box. At the start, the movable probe for the second analyzer was placed at the stationary location to ascertain differences between the two O_3 analyzers. When the movable probe was placed at other locations, a lower concentration was measured with a mean distribtuion deviation of 3.4 percent of 0.4 ppm. If space had permitted a larger input grill area, the distribution would have been better. No hot spots of highly concentrated gas were found even with a probe at the exit of the chamber supply duct. The gas and air supply were well mixed by the turbulence in the rectangular supply duct.

SECTION 3

COMMENT

The exposure system described here is presently used for 4-hour exposures of human subjects to an O_3 concentration of 0.4 ppm ± 10 percent. The major concern in designing the system was the safety of the exposure subjects. Safety features of the system include the automatic closed loop control of the pollutant flow, the alarms to alert operating personnel, and the automatic shutdown of the pollutant flow if out-of-tolerance conditions develop. Controls similar to those described for O_3 will be employed when human volunteers are exposed to concentrations of NO_2 and SO_2 in future exposure chamber studies. A procedure similar to that described for O_3 will also be used for NO_2 and SO_2 characterization of the chamber system. An additional step will be to determine the interaction of one residual gas on the other when switching between pollutants. In all cases, the chamber atmosphere will be monitored simultaneously for O_3, NO, NO_2, NO_x, and SO_2.

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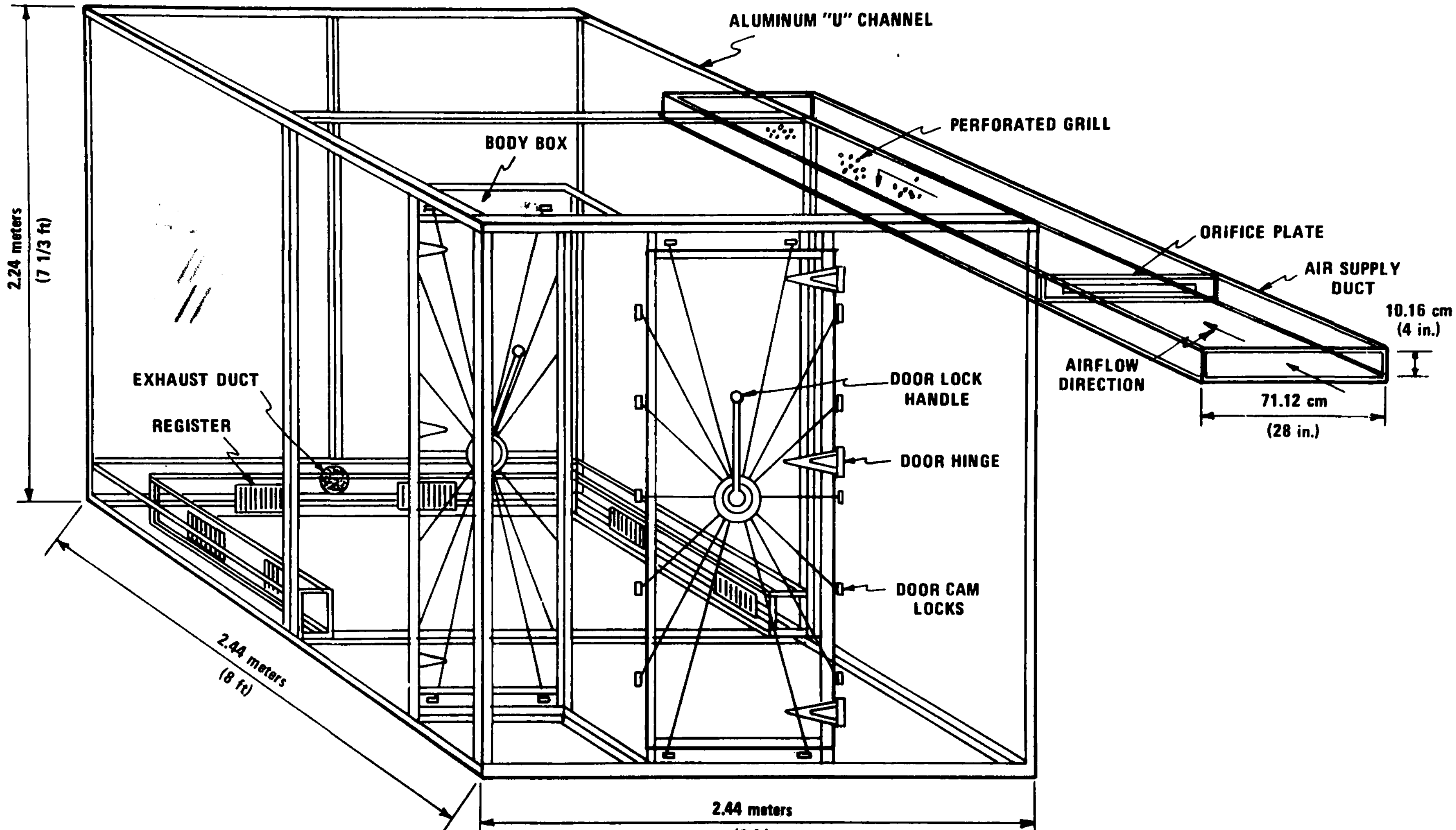

Figure 1. Ozone and nitrogen dioxide human exposure chamber.

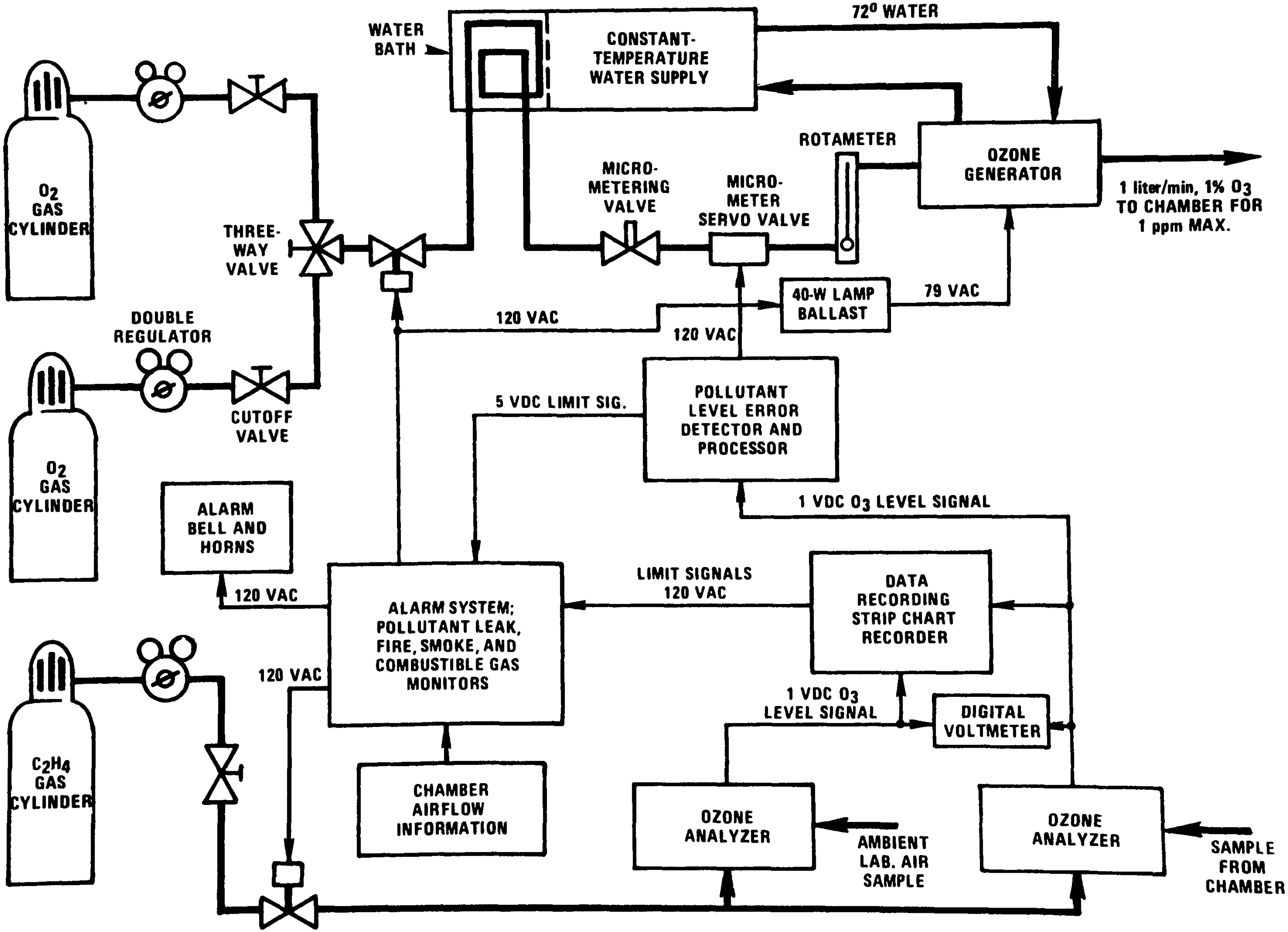

Figure 2. Ozone generation and control system.

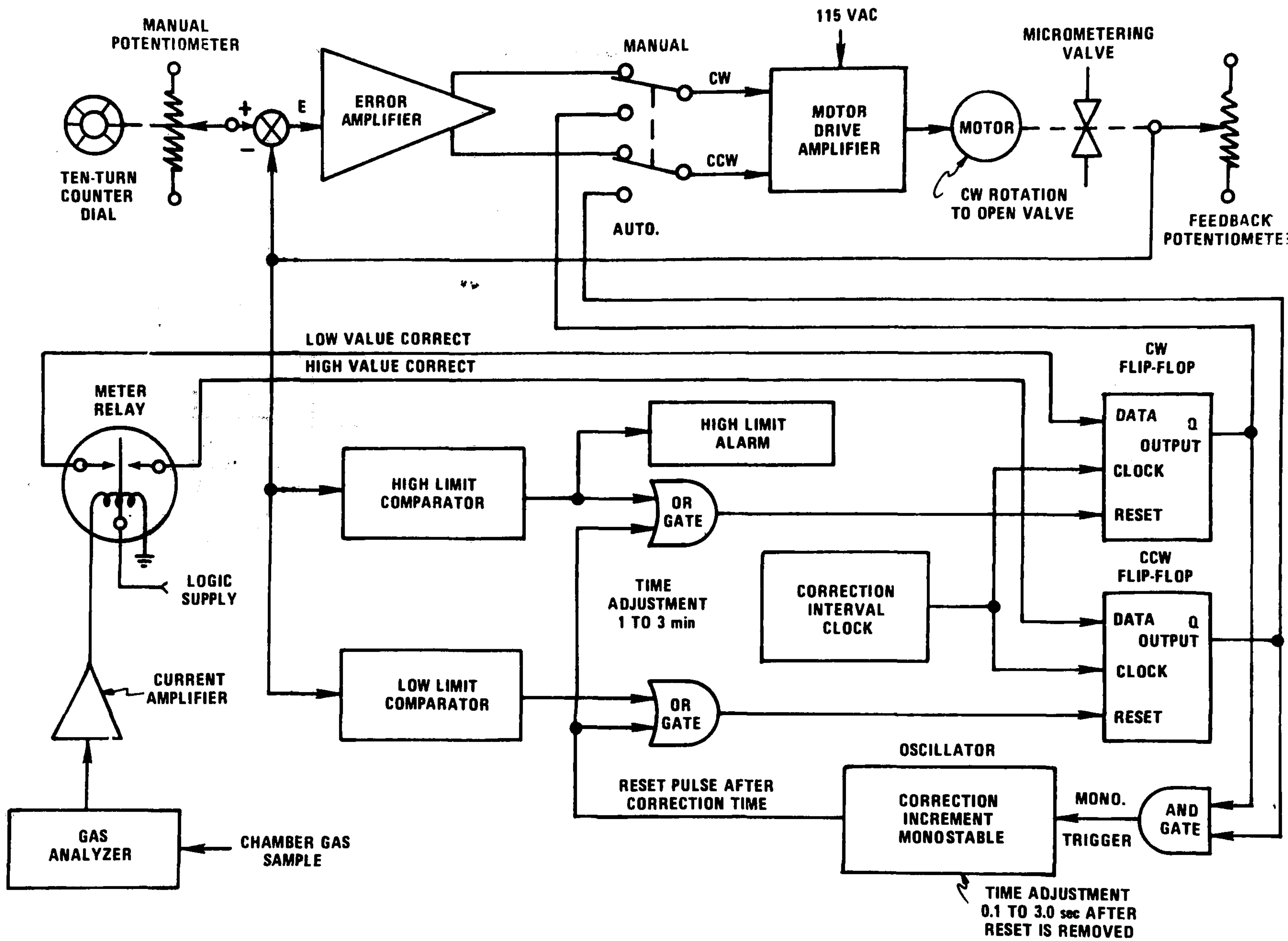

Figure 3. Pollutant level error detector and processor.

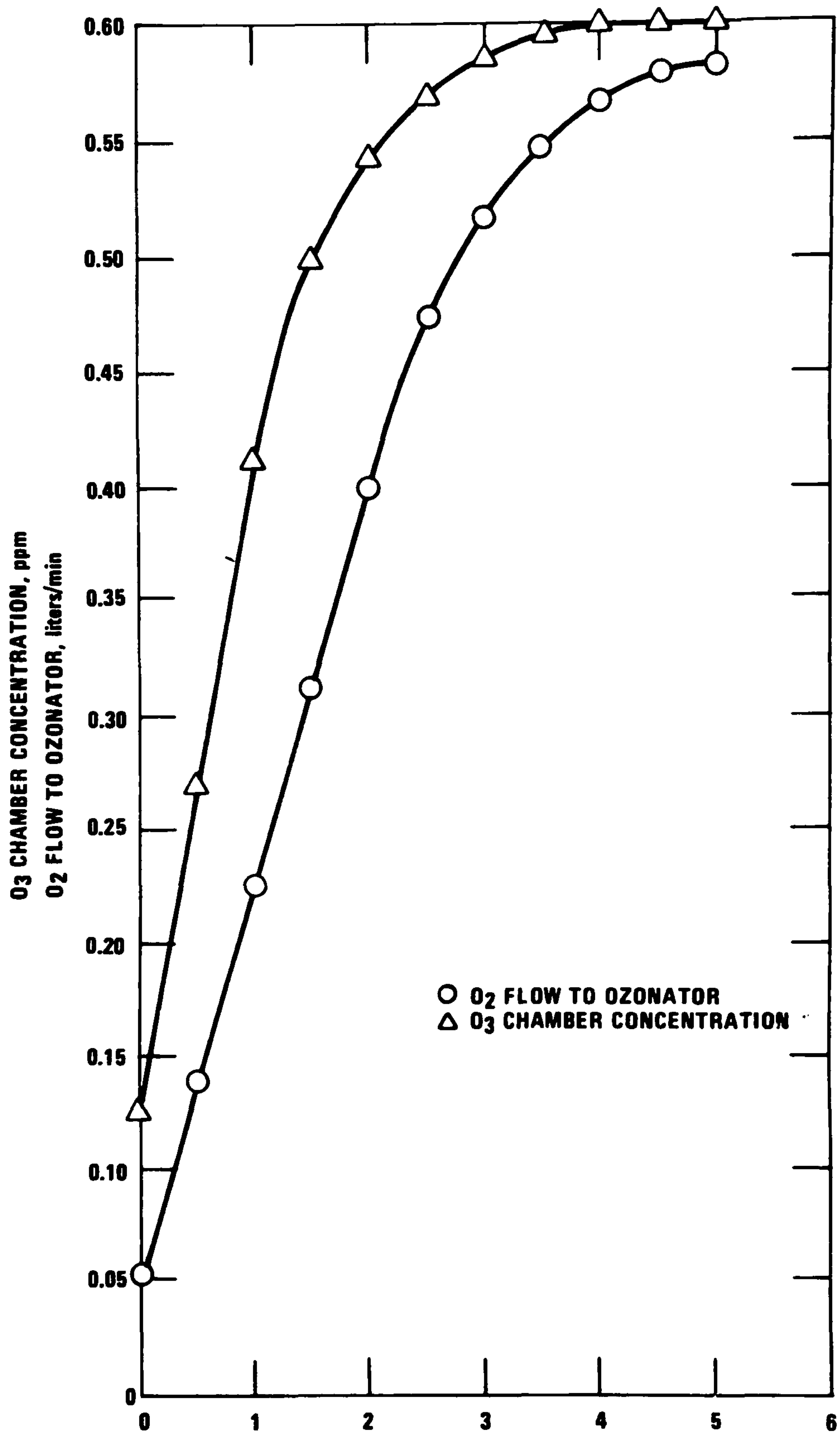

Figure 4. Measured oxygen flow to the ozonator and the ozone chamber concentration as a result of the rotational position of the servo-driven valve.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/1-77-048	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE HUMAN EXPOSURE SYSTEM FOR CONTROLLED OZONE ATMOSPHERES		5. REPORT DATE October 1977
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Arthur A. Strong, Robert Penley and John H. Knelson		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Clinical Studies Division Health Effects Research Laboratory Research Triangle Park, N.C. 27711		10. PROGRAM ELEMENT NO. 1AA601
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Health Effects Research Laboratory RTP,NC Office of Research and Development U.S. Environmental Protection Agency Research Triangle Park, N.C. 27711		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE EPA 600/11
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

An experimental exposure system for health effects research in environmental pollutants that permits the introduction and control of ozone (O_3) to an acrylic plastic chamber in which a human subject actively resides is described. Ozone is introduced into the chamber air intake and is controlled by an electro-mechanical feedback system operating from the electrical output of an O_3 gas analyzer.

A continuous record of O_3 concentration, temperature, and dew point is provided by an analog multipoint strip chart recorder. If the chamber O_3 levels exceed preset limits, an alarm system automatically stops the O_3 flow and switches the chamber exhaust to purge operation.

A complete air exchange occurs every 72 seconds. In an emergency, the chamber can be purged in 190 seconds. Chamber temperature and humidity are dependent upon conditoned laboratory air.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
test chambers environmental tests ozone tests humans		06 F, L 14 B

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 22
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)