DESIGN OF A SIMPLE PLANT EXPOSURE CHAMBER

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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ABSTRACT

The chambers used in plant exposure studies at the National Center for Air Pollution Control utilize a dynamic, negative-pressure, single-pass flow system with uniformity of toxicant flow, mixing, and distribution in the chamber. The simple design, described herein, permits easy installation of numerous chambers in a single air-handling system while still permitting individual control of chambers.

Key Words: Exposure, Chamber, Plants, Air Pollution

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PRINCIPLES OF CHAMBER DESIGN

The effects of phytotoxic air pollutants on vegetation have been studied in a variety of exposure chambers. Many early chambers were either closed-system designs or small greenhouses redesigned for exposure studies. Certain basic design features of the chambers discussed in this paper have been reported.[1,2,3]

Ideal chamber design permits maintenance of natural environmental conditions during plant exposures. Good design can be achieved by closely following design specifications that consider the plants to be studied and the purpose of the research. The most desirable flow characteristics, the toxicants to be used, and the degree of environmental control desired are other important considerations. Versatility combined with simplicity should be the overriding consideration.

Chambers should be fabricated from materials having low adsorption characteristics to avoid possible reactions with the interior of the chamber, since such side reactions could produce injury not directly related to the toxicant being studied. The chambers should be either easily cleanable or inexpensive, so that they may be discarded and replaced.

Dynamic air systems are superior to static air systems, and can be of a negative- or positive-pressure type. The negative systems, however, eliminates the potential hazard of toxicant release into the area in which the exposure chamber is situated.

Toxicant and air must be well mixed before the exposure "atmosphere" enters the exposure chamber. Air movement in the chamber may be laminar or turbulent, but design for a laminar flow system is exacting, since the plants in the chamber interrupt the laminar flow and cause a modified-turbulent flow. A turbulent flow system (with essentially instantaneous mixing with air already in the exposure chamber) can be constructed rather simply.

Air can be recycled on a percent basis or completely exhausted from the system. Recycled air can cause corrosion or deposit particles on the air-handling equipment, and substances in the air may interact with certain chemical components of the air-handling equipment to form products capable of producing abnormal plant injury. A single-pass system eliminates most of the problems encountered with a recycling system and makes monitoring and control of chamber levels of specific toxicants easier. The single-pass system also adds to the simplicity of total design.

Gases that are potentially phytotoxic should be added in a diluted form in the intake duct. The duct should be designed to aid in the mixing of air and toxicant and should be capable of accommodating several toxicants at a level at which they would normally interact no more than under ambient conditions.

Lines carrying the toxic substances should be chemically inert and heat resistant to allow the use of high-temperature liquids in the low-ppm vapor phase. When toxicants readily adsorb on chamber materials, lines and chambers should be well cleaned or changed before other toxicants are used.

The degree of environmental control depends on the basic purpose of the experiment. Chambers should be usable outdoors, in greenhouses, or as inserts into special plant-growth chambers. Where chambers are used under natural conditions, exposures should be considered only on days conductive to producing injury, unless environmental variations are part of the experiment.

When comparisons are desired, most exposures require environmental control. Although greenhouse conditions often suffice, lighting must be controlled in most geographical locations for a planned program. Close environmental control can be obtained by the use of a special plenum on the inlet of each exposure chamber, by insertion of the chamber into a plant growth chamber, or by inserting an exposure chamber equipped with the special plenum into a plant growth chamber.

Simplified construction and appropriate air-handling allow the use of a number of chambers in parallel without reducing the utility of the specific chamber design.

DESIGN AND CONSTRUCTION DETAILS

The type of chamber used in experiments for the past 3 years utilizes a dynamic, negative-pressure, single-pass flow system. Flow, toxicant mixing, and air are uniform, and several toxicants can be injected at once. Simplicity of design permits easy installation of numerous chambers in a single air-movement system and individual control of chambers. With minor modifications, these exposure chambers have been used in plant growth chambers to study effects of pollution on vegetation under rigid control of environmental conditions. Cost breakdown for these chambers is detailed in the appendix.

GENERAL CONSTRUCTION

A bank of eight chambers (Figures 1 and 2) was constructed with a single air-handling system. Construction details for the two chamber sizes used (Figure 3) are identical, and flow characteristics and performance data are similar. The large chambers are 30 by 36 by 30 inches high. For the sake of brevity, only the smaller chambers, which are 24 by 24 by 30 inches in size, are discussed here.

Details of construction are shown in Figures 3 and 4. The chamber frame is made of 3/4-inch-thick plywood. Plywood ties at all corners join the front and back. The base is made of 1/2-inch-thick plywood. All joints are nailed and glued, and wood surfaces are sanded and finished with several coats of white gloss enamel. A false floor of 1/4-inch pegboard that has been painted on both sides is placed 6 inches from the bottom of the chamber.

The frame is covered with 1-mil Mylar* film attached with heavy cloth tape. The Mylar is wrapped around the sides and back, and a separate piece placed on the top. The plywood-frame door is also covered with Mylar. Four wood strips are used to position the door on the front frames, and a clamp is centered on each strip. The door gasket is fashioned from 3/8-inch-OD Tygon plastic tubing with heat-fused ends. This gasket has good resiliency and has lasted for several years.

*Mention of product or company name does not constitute endorsement by the Public Health Service or the Department of Health, Education, and Welfare.

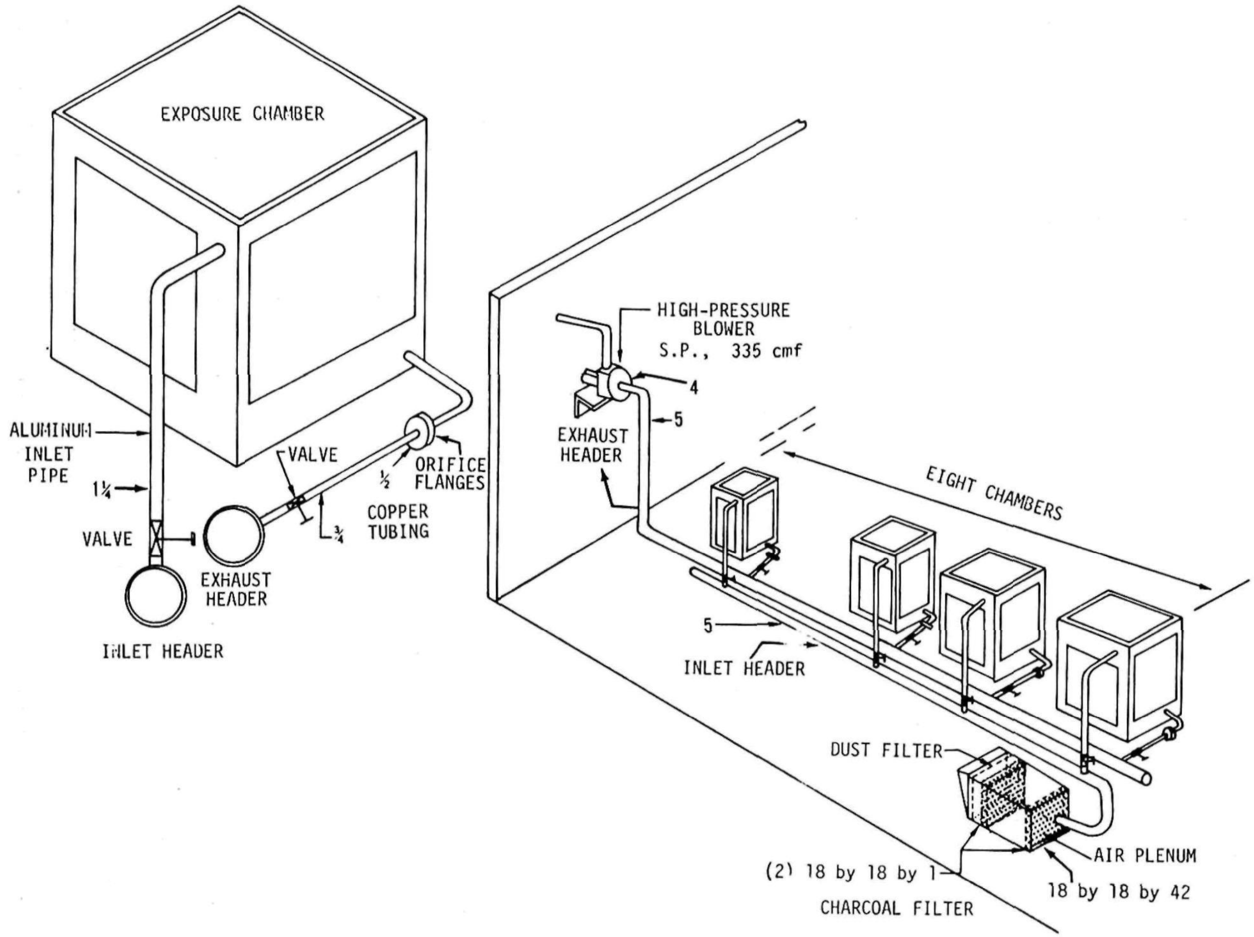


Figure 1. Schematic showing general orientation and construction of exposure chambers in greenhouse. (All dimensions shown are in inches.)

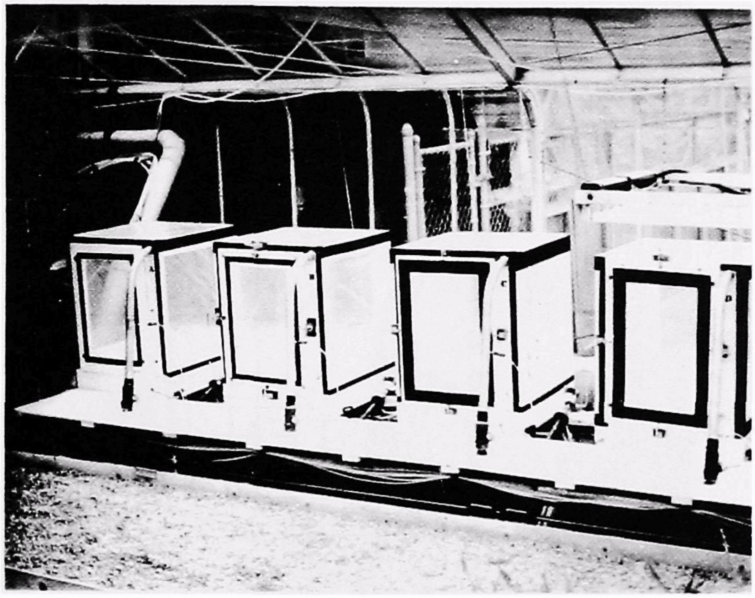


Figure 2. Exposure chamber set up in greenhouse.

The basic chamber is fitted for specific attachments. A 1/2-inch opening is made in the upper front right-hand corner for the air inlet; a 3/4-inch opening on the right side is available for sampling probes; a 1/4-inch opening at the lower right rear provides for temperature-sensing elements; a 7/8-inch opening in the rear on the lower right-hand side accommodates the air outlet; and just below the latter, a 1/4-inch opening is provided for filling the wet-bulb pan.

AIR-HANDLING SYSTEM

The air-handling system for chambers used in greenhouses is detailed in Figure 1. A high-pressure blower on the exhaust side of the chambers maintains 4-inch negative static pressure in the exhaust header. All headers are galvanized downspout material, and all joints are soldered and taped to reduce air leakage. The system has a 3/4-inch-diameter exhaust duct with a gate valve and a calibrated orifice plate, which has pressure taps to control and measure airflow through the chamber. This design maintains a negative pressure of 0.1 to 0.2 inch of water in the exposure chambers at an airflow of 5 cfm (one change every 2 minutes).

Air enters the chamber through a 1-1/4-inch-ID aluminum duct from an inlet leader at a linear rate of approximately 600 feet per minute. This high-

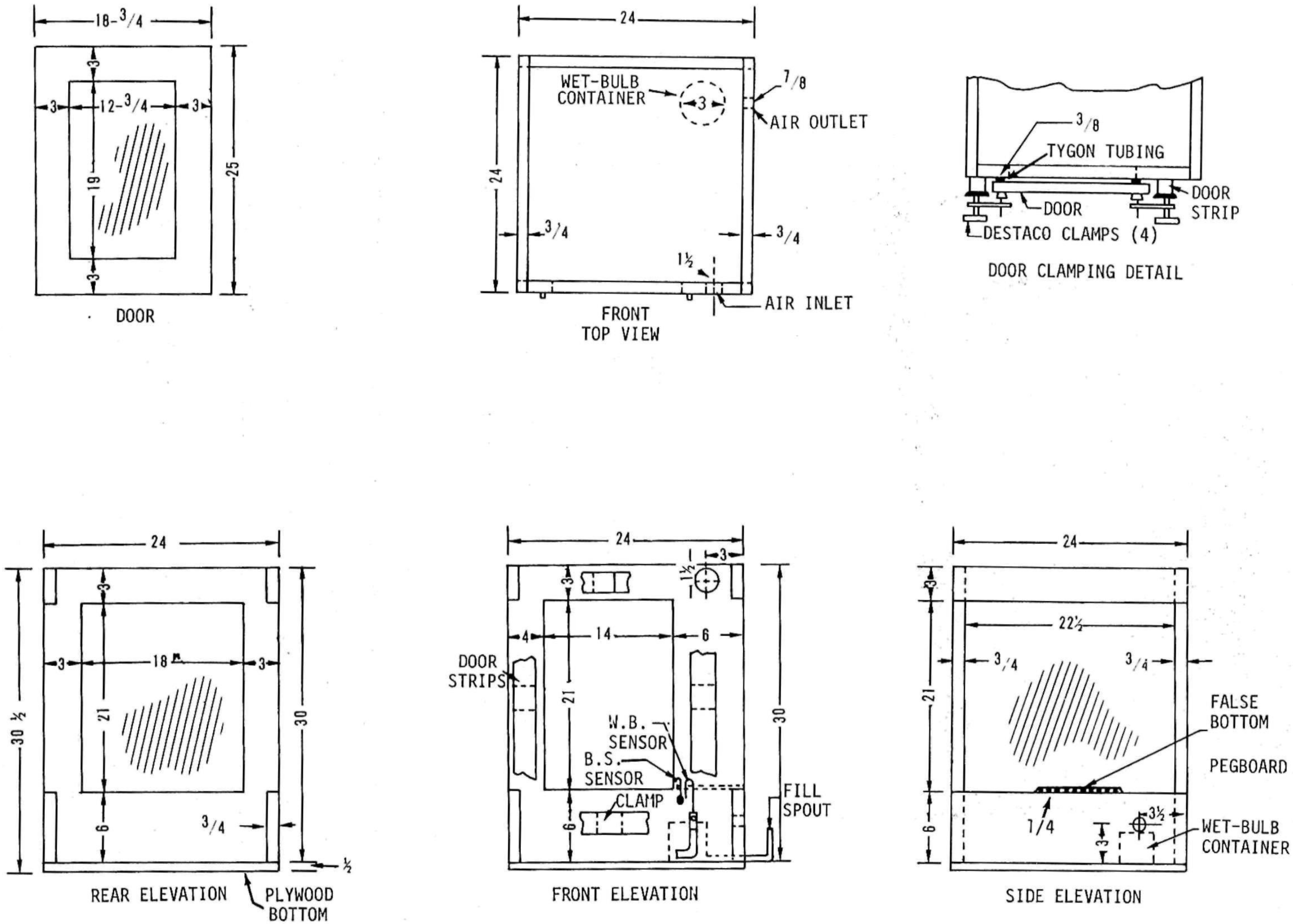


Figure 3. Details of exposure chamber design. (All dimensions shown are in inches.)

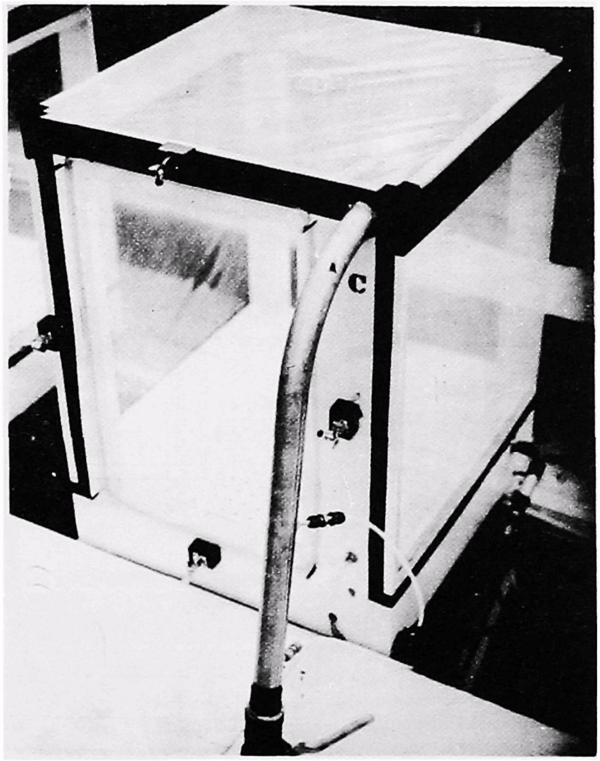
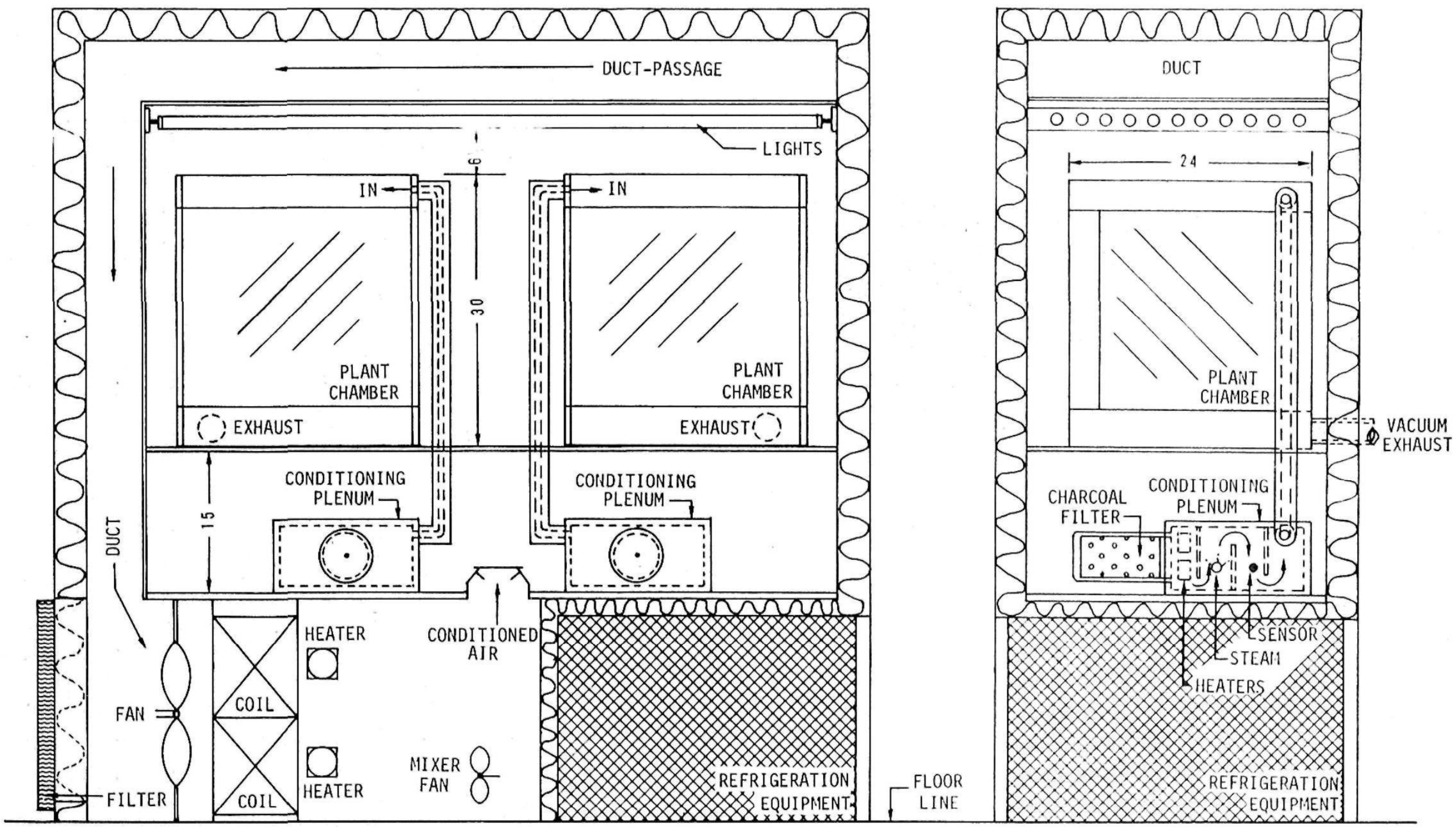


Figure 4. Greenhouse exposure chamber details.

speed linear flow produces violent turbulence in the chamber and causes essentially "instantaneous" mixing. The air passes into the bottom of the chamber through the pegboard separator. When all the chambers are running, a single chamber can be opened without upsetting the airflow in the remaining chambers by closing a ball valve in the individual chamber inlet duct. Air passes into the inlet header through a cleaning plenum equipped with an initial dust filter and a charcoal filter. After the air is filtered, it is ozonated to remove reactive substances; and then it passes through a charcoal filter to remove the added ozone.

The air-handling system for controlled exposure has a 2-inch exhaust duct with a damper and a calibrated orifice plate, which has pressure taps to control and measure airflow through the chamber. The exposure chamber design and air movement are the same as those for the greenhouse system (Figures 5 and 6). The inlet system is modified so that each chamber has an individual inlet. The inlet duct connects to a special plenum, which is designed for close control of temperature and humidity (Figures 7 and 8). Air enters the plenum through a



FRONT SECTION VIEW　　　　SIDE SECTION VIEW

Figure 5. Schematic showing two exposure chambers with conditioning plenums inside a plant growth chamber, front and side views. (All dimensions shown are in inches.)

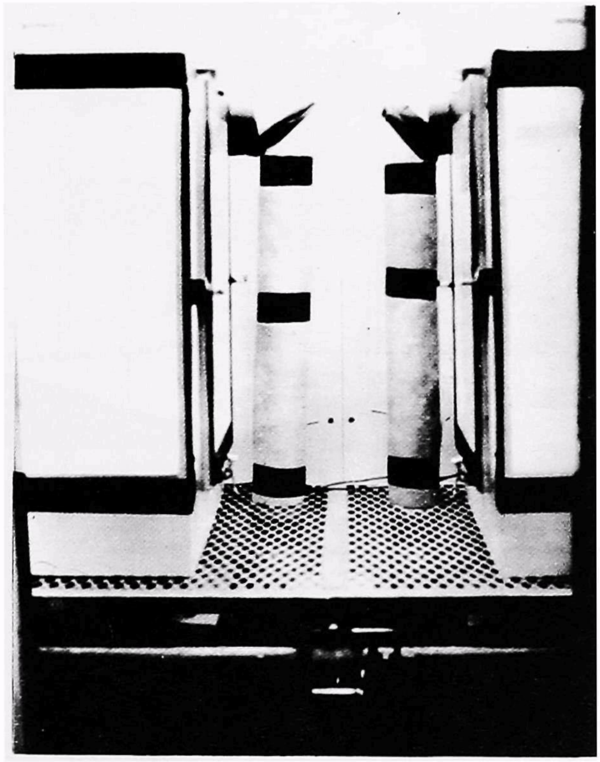


Figure 6. Exposure chamber inserts in plant growth chamber.

charcoal filter (to which an ozonating device may be attached), then passes over a set of heaters, through a steam humidifying unit, over the temperature-sensing device that controls the heaters, and into the inlet duct. The control plenum and inlet duct are well insulated with one-inch fiberglas insulating material.

TOXICANT ADDITIONS

Toxicants are added through ports in the inlet duct from various toxicant dispensing systems. The dispensing systems have an initial dilution system, so that toxicants enter the inlet duct in concentrations of about 100 to 1. A fluted piece of aluminum foil within the duct above the point of toxicant addition gives the air-toxicant mix a circular motion before it enters the exposure chamber. Present inlet duct construction limits the number of toxicants that can be added, but a design change will allow up to 10 different toxicants to be added and mixed before entering the chamber.

ENVIRONMENTAL CONTROL

Greenhouse exposure chambers are normally maintained at greenhouse

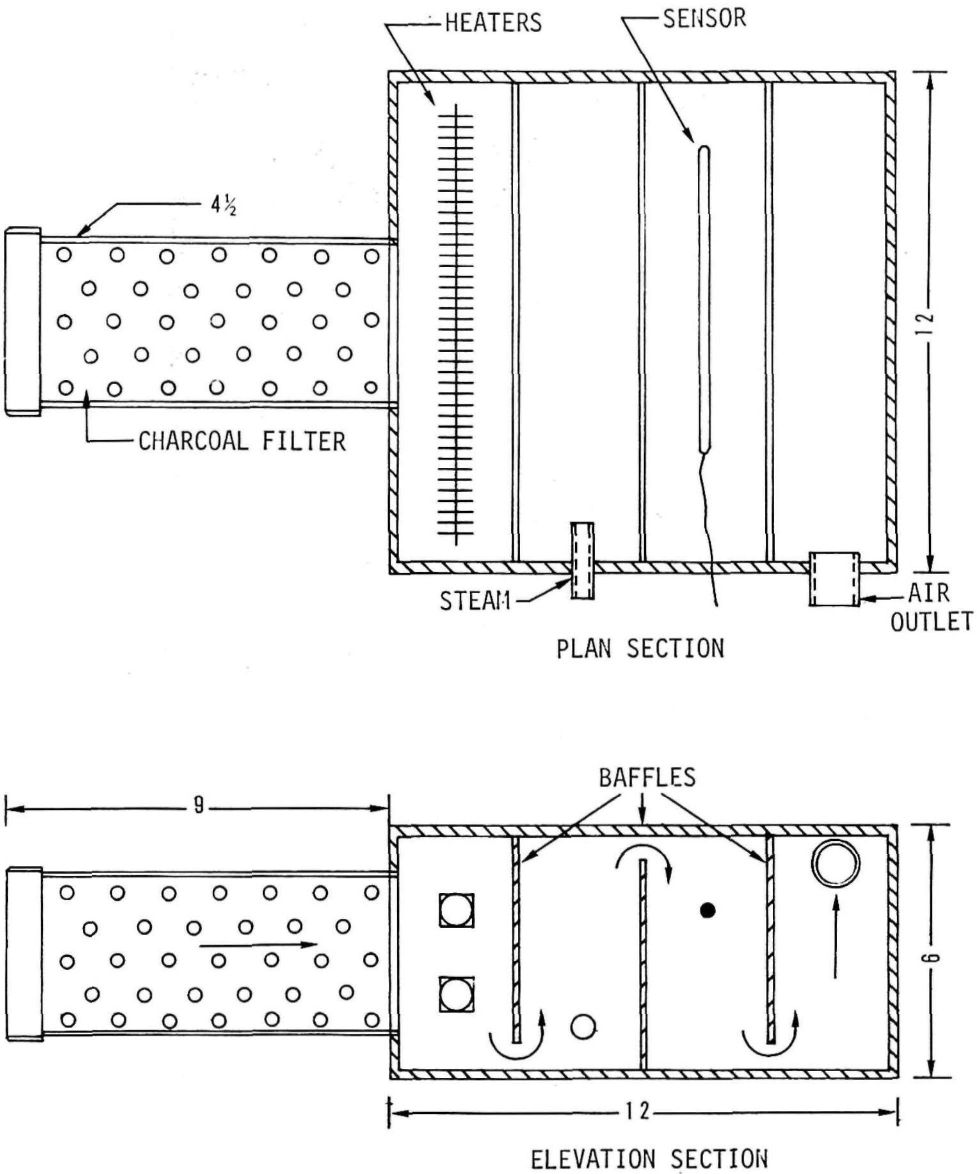


Figure 7. Details of conditioning plenum for exposure chambers located within plant growth chambers. (All dimensions shown are in inches.)

conditions. On a cloudy day these conditions include low light, low temperature, and high humidity. On a sunny day a chamber receives about 80 percent of the light intensity of the greenhouse, is 4° to 6°F warmer, and has about the same humidity as the greenhouse. All of the experiments with ozone and sulfur dioxide exposure at the National Center for Air Pollution Control have shown that supplemental light is essential to obtain statistically significant results when parameters

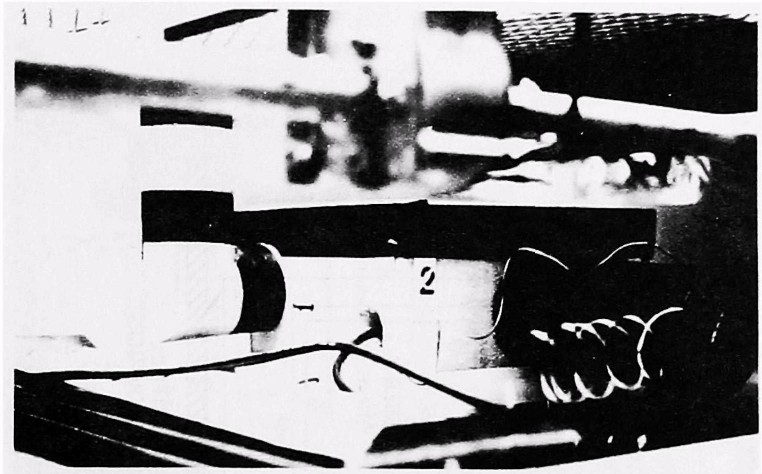


Figure 8. Plenum attachment to exposure chamber inserts in plant growth chamber.

other than light are considered. An eight-lamp bank of 8-foot-long, 235-degree reflector, VHO lamps mounted on a 2-inch aluminum angle frame with no top is used. Ballasts are mounted on the frame. This bank covers three chambers and gives 1800 to 2200 foot-candles of light in the center of each chamber (Figures 9 and 10). Airflow can be varied from 2 to 10 cfm through the small chambers and from 5 to 20 cfm through the large chambers.

The controlled-exposure chambers are mounted as inserts inside standard plant growth chambers. Inside dimensions of growth chambers currently in use are 30 by 30 by 66 inches. Each chamber permits the use of two exposure chamber inserts. Lights can be controlled to give intensities up to about 6,000 foot-candles. Both incandescent and fluorescent lighting can be used; however, the incandescent generally has not been used because of the higher heat load. Light intensity in the two inserts in a given growth chamber can be varied by shading one chamber with cheese cloth or another material. Temperature, humidity, and toxicant are controlled independently in the two exposure chamber inserts. Temperature and humidity are initially controlled in the growth chamber, where temperatures are maintained at levels at least 10°F below the lowest insert temperature desired and humidity is kept as low as possible. Air is conditioned in each insert plenum for close control of temperature and humidity within the exposure chambers. Airflow can be varied from 3 to 40 cfm through each insert.

Wet- and dry-bulb thermistors are situated in front of the exhaust duct in each chamber to monitor temperature and humidity.

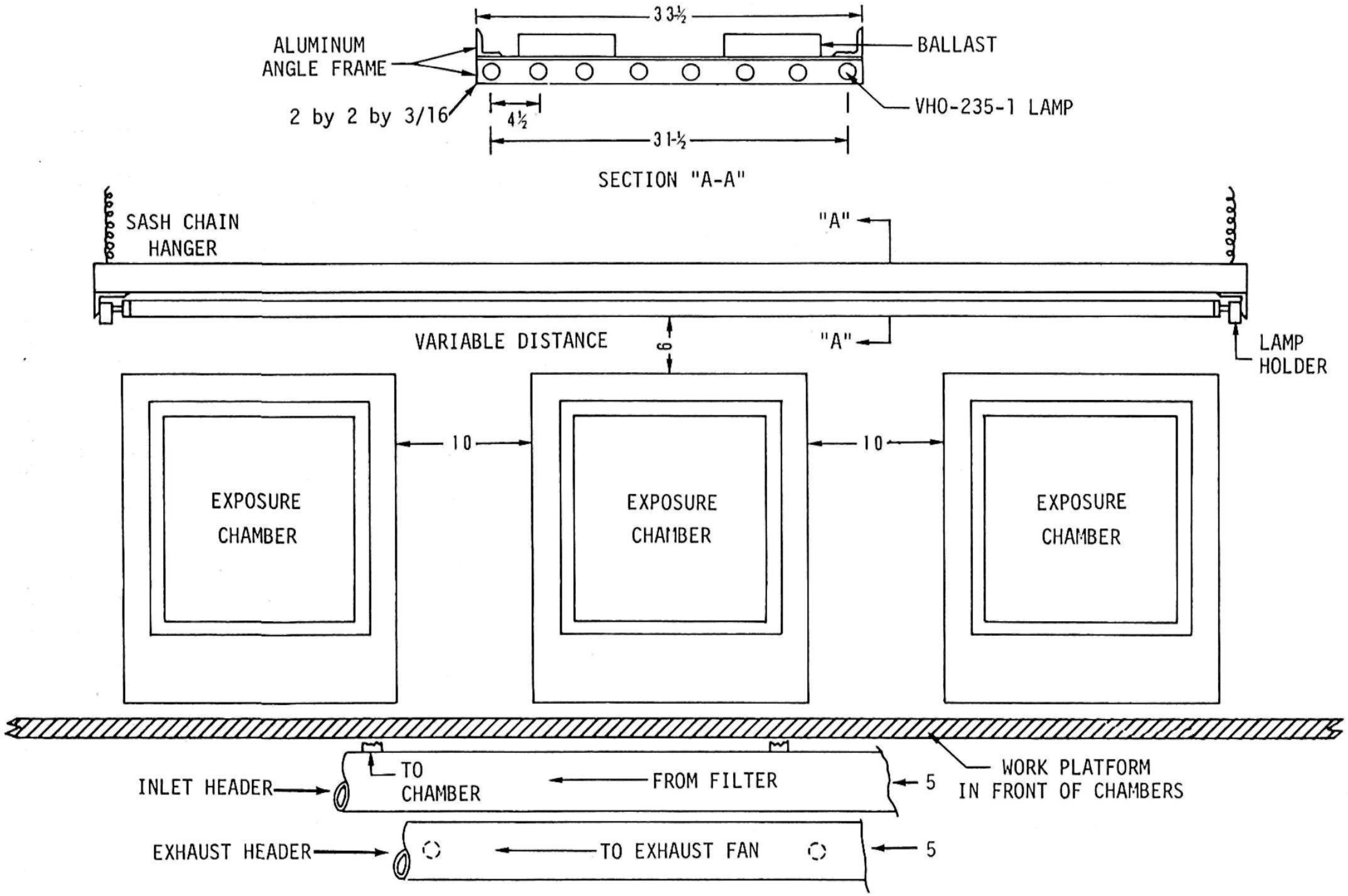


Figure 9. Details of supplemental lighting system for greenhouse exposure. (All dimensions shown are in inches.)

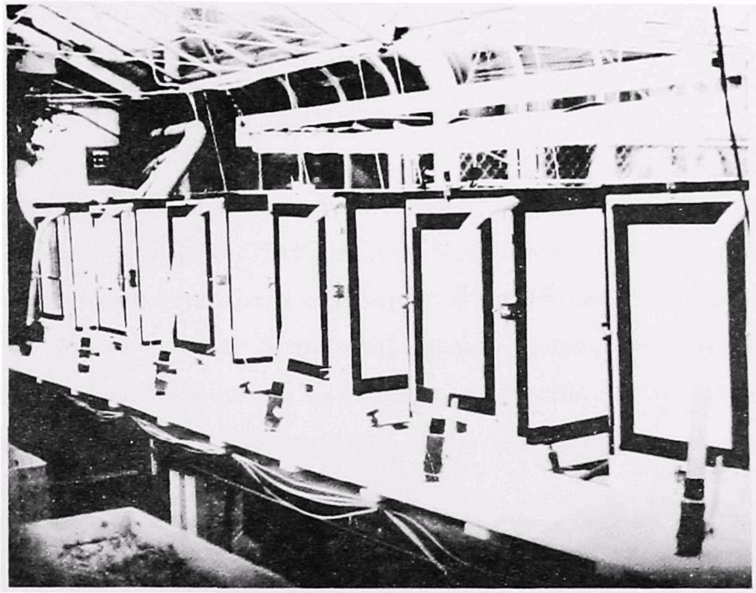


Figure 10. Details of lamp bank over greenhouse exposure chambers.

PERFORMANCE DATA

The value of any instrument is measured by its performance under actual operating conditions. The principal concern with the exposure chambers discussed here is maintaining uniform toxicant and environmental conditions throughout the chamber, and the ability to maintain consistent values over a given period of time. The former is an indirect indication of chamber flow characteristics and the latter is a measure of the stability of the toxicant dispensing and environmental control systems.

To determine the operating performance of the exposure chambers discussed, ozone was used as a test toxicant. The chambers were checked empty, with a plant load, and at several ozone concentrations. Ozone was chosen for several reasons, but the prime consideration was its reactive nature. If ozone mixing is at an acceptable level, other toxicants should show an equal or better distribution pattern.

Preliminary measurement of toxicant uniformity was made shortly after the small chamber system was completed. Variations within the chamber were less than ±4 percent both empty and with a plant load. Chamber concentrations were compared with inlet levels and expressed as percentage values. Empty chamber values were close to inlet values; loaded chamber values ranged from as low as 50 percent to as high as nearly 100 percent of inlet values. The percentage values of loaded chambers seemed to be related to plant sensitivity. On days of high sensitivity, a probe held against the lower leaf surface of tobacco or pinto bean plants within the chamber showed a value of as low as 20 to 30 percent of the inlet value. Much of the ozone reduction is possibly due to absorption into leaf tissues. This is currently being investigated.

Environmental conditions similar to those found in greenhouses exist within greenhouse exposure chambers. Under bright sunlight, the chamber temperatures run from 4° to 6°F above greenhouse temperatures at an airflow rate of one change every 2 minutes. Measurements at several points within the chamber have been markedly consistent.

Environmental control is particularly important within exposure chamber inserts to plant growth chambers. A preliminary design similar to the one herein discussed, was set up to determine what was necessary for close temperature and humidity control. At an airflow rate of 20 cfm with two changes per minute, there was less than ±0.5°F temperature fluctuation at a given level in the chamber. Difference in temperature between top and bottom of chambers was approximately 2°F at a chamber temperature of 70°F. This was a consistent variation. At higher temperatures the difference was less. At any given location no temperature or humidity variations could be picked up by using a wet-bulb, dry-bulb thermistor sensing device.

A more detailed measurement of ozone uniformity in both the large and small greenhouse exposure chambers was recently conducted (Table 1). Four

Table 1. UNIFORMITY OF OZONE DISTRIBUTION IN EXPOSURE CHAMBERS[a]

Chamber and conditions	No. of runs	Chamber positions[b]				
		A	B	C	D	E
Large chamber, empty, no perforated delivery tube	9	100	97	92	93	93
Large chamber, empty, with perforated delivery tube	4	97	99	95	100	97
Large chamber, light plant load, with perforated delivery tube	5	100	97	96	96	89
Small chamber, empty	3	98	100	96	97	97
Small chamber, light plant load	2	100	98	98	100	100

[a]The values were obtained as comparative values for a given run, and then all values in a run were compared, the highest value being given the arbitrary value of 100. This was done because of variations between runs.

[b]Positions A-D were located 2 inches from the corners at the vertical centerline of the chamber. Position A at the inlet corner and the other positions occurring counter clockwise around the chamber. Position E was centrally located at the same height as the other positions.

probes were centered vertically in each chamber within 2 inches of the four corners (A-D); and a fifth probe was placed in the center of each chamber (E). Results for each probe location were originally calculated on the basis of the percentage of the inlet concentration. Results of ozone uniformity for the different runs varied so much, because of environmental conditions and chamber loading, that all values were corrected so that the highest value would read 100 (Table 1).

The large chambers were checked empty both with and without a perforated delivery tube installed. (The inlet duct was connected to a 1-1/4-inch Plexiglas tube extending across the inside of the chamber. This tube had eight 1/4-inch holes for more uniform dispersion of air across the chamber.) Results show more uniform dispersion with the tube added. The ozone uniformity level at the center of the chamber was definitely below that at the four chamber corners when the chamber was tested under plant load conditions. This is probably a plant response. The perforated tube was not used in the small chambers, and no chamber center effect was noted. Results show excellent uniformity of mixing within chambers of both sizes.

Determination of the rate of chamber equilibration after starting or stopping toxicant flow into the chambers is also of interest. The rates of equilibration for ozone were determined for all five probe positions for both chamber sizes. Average values for the five probe positions are shown for the large chambers in Figure 11. Results for the small chambers were similar. The equilibration rate after starting the dispensing system and the decay rate after stopping the dispensing system are the same. Thus, the length of the exposure can be determined by knowing the time of starting and stopping the dispensing system. The time period for equilibration is so short that for runs of one or more hours, the lower concentrations during equilibration and decay should not have a major effect on plant response. The lower concentration during the equilibration and decay time periods could have an effect on plant response for exposure periods under one hour. The shorter the exposure period the greater effect these lag periods would have.

SUMMARY

The construction details of a simple, flexible plant exposure chamber have been described. The chamber utilizes a dynamic, negative-pressure, single-pass flow system, which provides uniformity of flow, toxicant mixing, and chamber distribution. Environmental control of exposure inserts into plant growth chambers can be maintained with no apparent light, temperature, or humidity fluctuations. Chamber uniformity of ozone concentration is excellent, and uniformity of less labile toxicants should be greater.

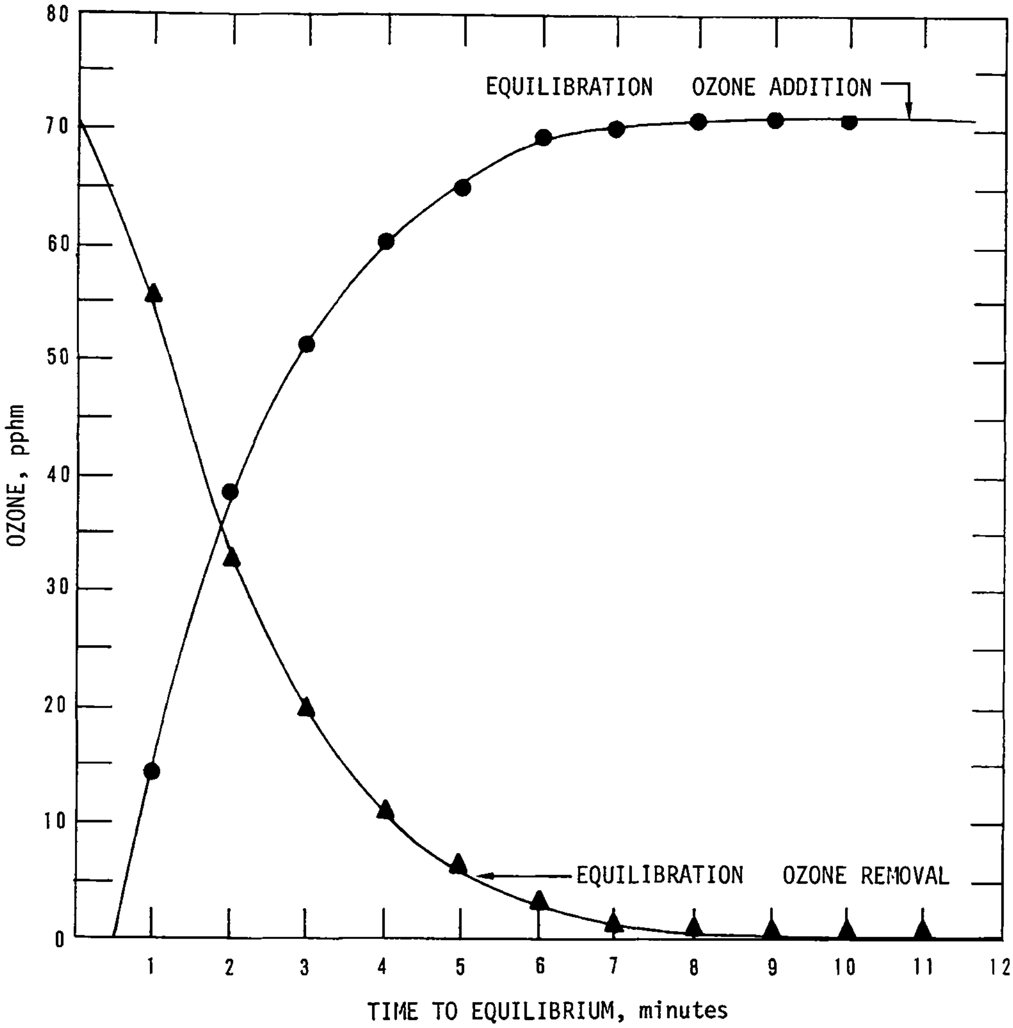


Figure 11. Rate of equilibration and removal of ozone for large chambers (average of 5 probe positions).

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APPENDIX

CONSTRUCTION COSTS FOR EXPOSURE FACILITIES

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1. Construction of an eight-exposure chamber setup for use in the greenhouse. (Figure 1)

1 gallon of white enamel paint	$ 8.00
2 charcoal panel filters, 18 by 18 by 1-inch @ $7.00	14.00
4 sheets of 3/4-inch plywood, @ $8.00 (4- by 8-foot sheet)	32.00
1 sheet of 1/4-inch pegboard (4- by 8-foot sheet)	5.00
100 feet of 3/8-inch-OD Tygon* tubing for gasketing and connections	10.00
32 toggle clamps. No. 205-U DeStaCo, @ $1.80	58.00
1 Dayton high-pressure blower, 530 cfm, 1-inch static	54.00
60 feet of 5-inch round downspout, $3.12/10 feet	20.00
8 calibrated orifice plates adapted to 3/4-inch copper tubing, estimate $30.00 each	240.00
24 feet of 1-1/2-inch-OD aluminum tubing	14.00
20 feet of 3/4-inch-OD copper tubing	4.00
1 roll of 1-mil clear Mylar film	10.00
1 roll Mystic tape	5.00
8 ball valves, 1 1/4-inch @ $9.00	72.00
8 gate valves, 3/4-inch No. 607 Hammond, @ $3.11	25.00
1 inclined manometer, 3-inch Meriam Inst. No. 40GE4	50.00
8 wet-bulb containers, @ $5.00	40.00
Labor for construction, covering, setup, and installation	300.00
	$961.00

2. Construction of a single exposure chamber without connections. (Figure 3)

Paint	$ 1.00
Plywood	4.00
Pegboard	.60
Tygon tubing	.40
Toggle clamps	7.40

*Mention of a trade name or company is for identification only and does not imply endorsement by the USDHEW.

Mylar film	$ 1.00
Mystic tape	.60
Wet-bulb container	5.00
Construction and covering	25.00
	45.00

3. Construction of a single 8-foot supplemental lighting system for greenhouse exposure chambers. (Figure 9)

8 sockets, No. 492 and 493 Levitron, @ $2.40	$ 19.20
25 feet of 2- by 2- by 3/16-inch aluminum angle	25.00
8 fluorescent tubes, FR96T12/CWVHO-235-1, @ $5.75	46.00
4 ballasts, GE No. 7G1201, @$27.75	111.00
Labor: construction, wiring, etc.	25.00
	$226.20

4. Construction of a single exposure chamber insert for use in a plant growth chamber. (Figure 5)

Chamber construction (#2)	$ 45.00
2-inch round downspout	1.00
Conditioning plenum (#5)	87.00
Calibrated orifice plates adapted to 2-inch copper tubing	30.00
Insulation	4.00
Installation	50.00
	$217.00

5. Construction of a single conditioning plenum. (Figure 7)

Sheet metal	$ 5.00
4-1/2-inch diameter charcoal canister filter	14.00
2 heaters, strip, @ $5.65	11.00
Thermostat for heaters, Chromalox AR-2534	22.00
Steam connection with needle valve	10.00
Construction	25.00
	$ 87.00