FINAL REPORT
FOR
ARB AGREEMENT A6-162-30

The Impact of Sulfur Dioxide On Vegetation: A Sulfur Dioxide-Ozone Response Model

R. J. Oshima, Plant Pathologist, CDFA

Statewide Air Pollution Research Center
University of California, Riverside, CA
March 15, 1978

LIBRARY
AIR RESOURCES BOARD
P. O. BOX 2815
SACRAMENTO, CA 95812

ABSTRACT

The objective of this project was to determine the effect of oxidant alone and in combination with 10 pphm sulfur dioxide upon red kidney bean, a commercial California crop. A major portion of the effort was expended in the construction of an adequate exposure facility to study the effects of air pollution on vegetation. Followinbg the construction of the facility, red kidney beans were studied using exposure conditions that were characterized and validated as being similar to ambient conditions. Red kidney beans were grown in exposure chambers with 0%, 25%, 50%, 75% and 100% carbon filtered air alone and in combination with 10 pphm SO_2. Additionally, 2 ambient plots were utilized. The levels of ambient ozone in the nonfiltered chambers were 17 to 21% lower than ambient measurements because of ozone loss within the blowers and ducting system.

An interaction with ozone and SO_2 was documented in the 50% carbon filtered treatment (5144 pphm-hrs) and produced a significant reduction in yield and plant biomass. The data also indicated the suggestion of an interaction in the 75% filtered treatment (2822 pphm-hrs) but at an unacceptable level of significance (p=.20 level). No reductions in yield or plant biomass were detected on red kidney beans exposed to equivalent doses of ambient ozone alone. Ambient ozone alone produced significant reduction in yield ($\geq$ 65%) but only at doses exceeding 5144 pphm-hrs. Sulfur dioxide at 10 pphm did not produce detectable plant or yield responses alone and did not have an interactive effect at ozone doses exceeding 5144 pphm-hrs.

This report was submitted in fulfillment of Agreement A6-162-30 by Statewide Air Pollution Research Center under sponsorship of The California Air Resources Board. Work was completed as of March 15, 1978.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

List of Tables Continued

ACKNOWLEDGMENTS

This program was funded by the California Air Resources Board under Agreement A6-162-30.

I am indebted to Richard Flagler, Staff Research Associate I, and Ingrid Carmean, Laboratory Assistant I, for their diligence in carrying out the experiment. This work could not have been completed without their dedication.

Special thanks is extended to O. C. Taylor for his advice, Patricia Braegelmann and Minn Poe for their efforts with the computer analysis and data processing, Donna Shaw for her efforts in typing and compiling the Final Report, Ervin Mateer and Mike Kienitz for their help in designing and constructing the fumigation facility and to the many students who contributed their efforts.

CONCLUSIONS

Sulfur dioxide at 10 pphm interacted with ambient ozone dose at 5144 pphm-hrs > 0 pphm (50% Riverside ambient) to produce a significant reduction in red kidney bean yield and plant biomass. No detectable response occurred at the same ozone dose without the inclusion of SO_2. No other interactions were detected at ambient ozone doses greater than 5144 pphm-hrs or at 2822 or 1175 pphm-hrs > 0 pphm. The SO_2/ozone interaction occurred at an ozone dose just below the threshold of red kidney bean yield response to ozone alone.

The effect of ambient ozone alone and 10 pphm SO_2 in combination with 5144 pphm-hrs > 0 pphm ambient ozone reduced red kidney bean yield in terms of weight of seed, number of seed and number of filled pods. Its primary effect was to reduce the total weight of seed produced. The size of seed was not affected.

An analysis of ozone doses characterized by 0, 3, 5, 8, 10, 15 and 20 pphm calculation thresholds was inconclusive in determining the best dose representation. A dose calculated as the product of ozone and SO_2 hourly averages was less significantly correlated with red kidney bean yield response than the ozone dose calculated from summing hourly averages > 0 pphm.

RECOMMENDATIONS

The SO_2/ambient ozone interaction should be quantified to allow prediction of yield responses. The following experiments are recommended to determine the range of pollutant doses which contributes to the interaction and to quantify a dose response surface to serve as a model.

1. A 3 x 3 analysis of variance design should be initiated using 25, 50 and 75% filtered ambient ozone and 5, 10 and 15 pphm SO_2. This would allow quantification of an interaction term and initially test the range of doses and SO_2 concentrations involved.
2. A 4 x 5 regression design utilizing no treatment replication should be run after the 3 x 3 analysis of variance experiment to quantify the dose response surface. The 3 x 3 design would provide a data base to select both ambient oxidant doses and SO_2 concentrations.

DISCLAIMER

"The statements and conclusions in this report are those of the contractor and not necessarily those of the California Air Resources Board. The mention of commercial products, their source or their use in connection with material reported herein is not to be construed as either an actual or implied endorsement of such products."

Introduction

This experiment was designed to determine the impact of 10 pphm SO_2 in combination with several doses of ambient ozone on red kidney beans. The selected experimental design allowed the following specific objectives to be investigated:

1. Determine whether 10 pphm SO_2 and 0, 25, 50, 75 and 100% filtered ambient Riverside ozone in combination would produce a detectable interactive response.
2. Define the yield response function for 0, 25, 50, 75 and 100% filtered ambient ozone alone and in combination with 10 pphm SO_2.
3. Define which yield components were affected by the gradient of ambient ozone doses alone and in combination with 10 pphm SO_2.
4. Evaluate an analysis of dose representations utilizing various calculation thresholds to determine which, if any, best characterized dose in terms of plant response.

An ambient fumigation facility utilizing FEP teflon exposure chambers was required. It was designed to minimize chamber differences with ambient meteorological variables.

The overall objective of this experiment was to develop a data set which would indicate whether potential future increases in ambient SO_2 levels would have a serious impact on crops being already exposed to a gradient of ambient ozone doses.

Materials and Methods

Fumigation Facility

1. General schematic (Figure 1)

The facility consists of 20 Teflon exposure chambers divided into 2 replicate 10 chamber sets. Each set of chambers is connected to a common air handling system, consisting of ambient and filtered ducts. An instrument shack is centrally located between chamber sets to minimize sampling line lengths.

2. Air Handling System (Figure 2)

This system consists of 2 sets of 2 backward-curved blowers powered by 2 H.P. 220 V motors. Each set consists of a filtered (three-2' x 2' x 8" activated carbon filters) and an unfiltered blower, central underground plenums of 12" PVS (polyvinyl-coated steel spirallok pipe), and 6" PVS pipes with butterfly valves leading to each of 10 chambers. All PVS pipe, electrical, and water lines, and butterfly valves are underground. The proportion of filtered to ambient air going to each chamber is controlled by the 6" butterfly valves. A comparison of replicate 0% filtered chambers with ambient ozone indicated that 17 to 21% of the ozone was lost in the air handling system.

3. Exposure Chambers (Figure 3)

The exposure chambers are a modification of the constant-stirred reactor (2) designed by Hugo Rogers, USDA, North Carolina State University, Raleigh North Carolina. Each chamber consists of a 7' x 7' PVC schedule 80 frame bolted to a concrete ring. A 5 mil FEP Teflon envelope is suspended from the uppermost ring and anchored to the concrete with a 1/2" PVC ring. A small 1/120 H.P. shade pole 110 V motor is mounted at the apex of the PVC

Figure 1. General schematic of fumigation facility.

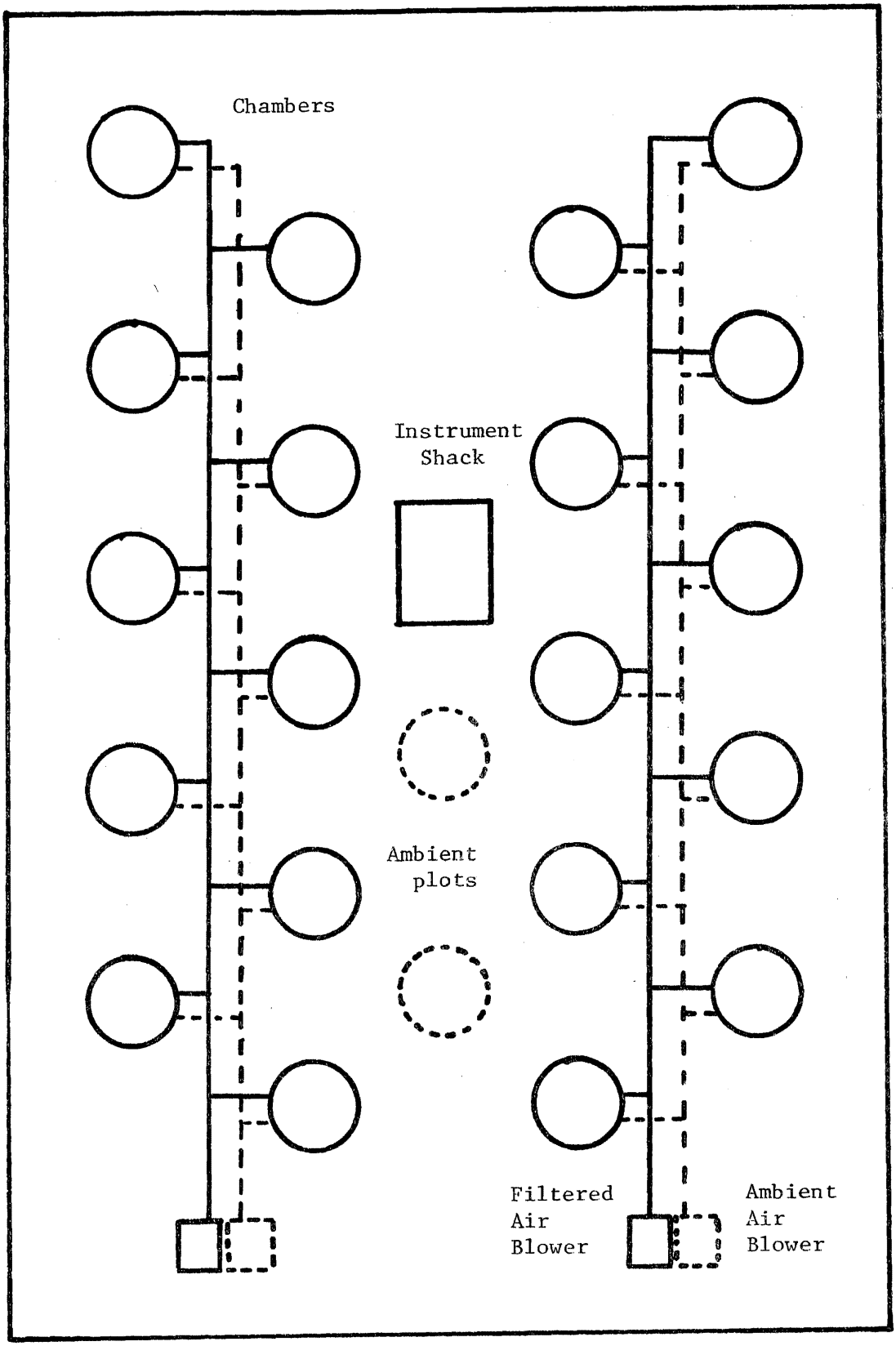


Figure 2. Detail of air handling system for fumigation chambers.

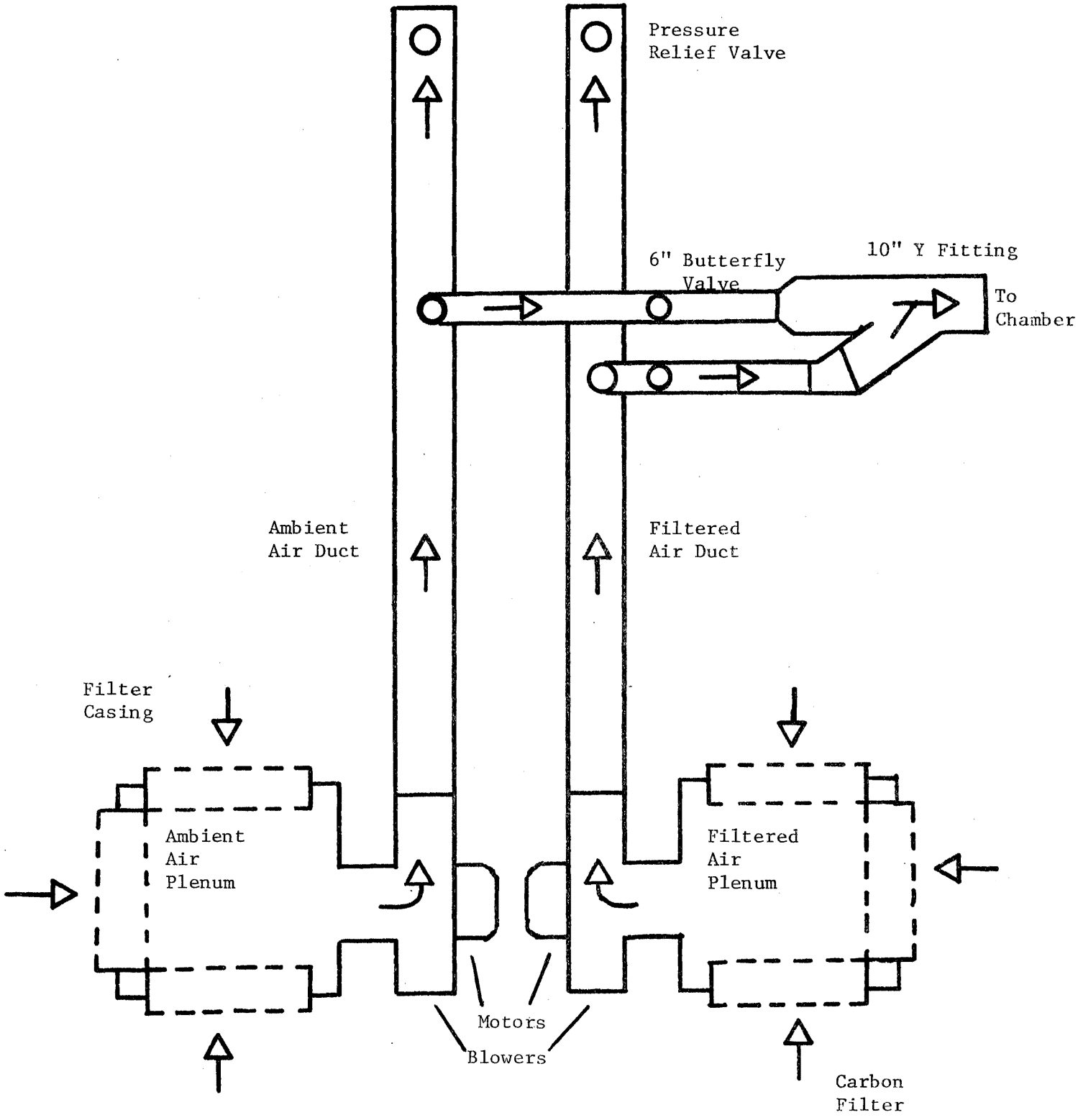
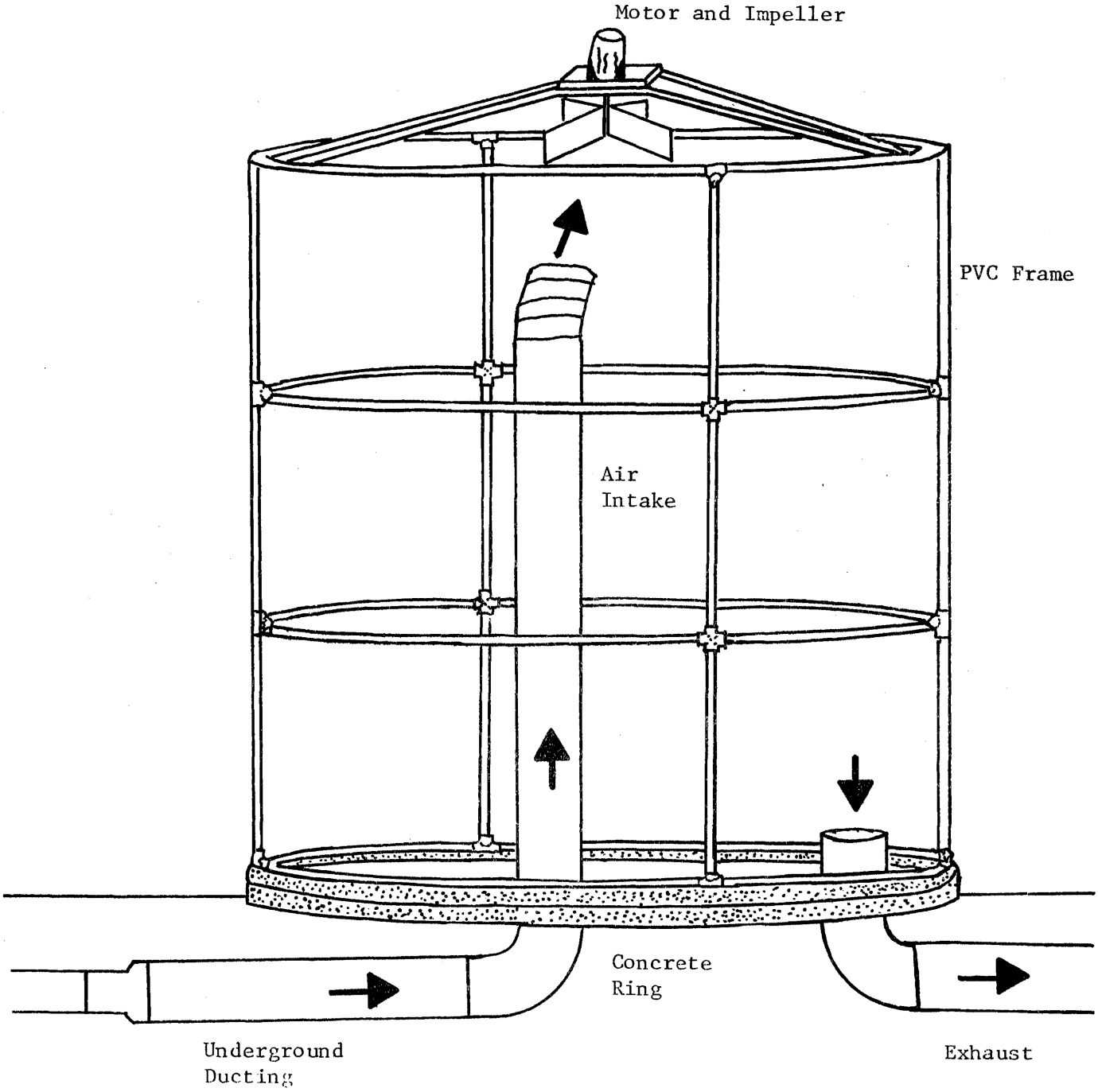


Figure 3. Diagram of chamber showing structural components. Chamber dimensions are 7' x 7'.



frame and anchors the uppermost portion of the Teflon envelope. An extension shaft from the motor protrudes through the Teflon envelope and supports a 6-blade impeller which rotates at 60 rpm. The mixture of filtered and nonfiltered air enters the chamber via a 10" PVS underground duct which then extends 5 ft vertically and directs the air stream directly at the impeller. Chamber exhaust is vented through a 10" PVS "U" tube directly into the atmosphere.

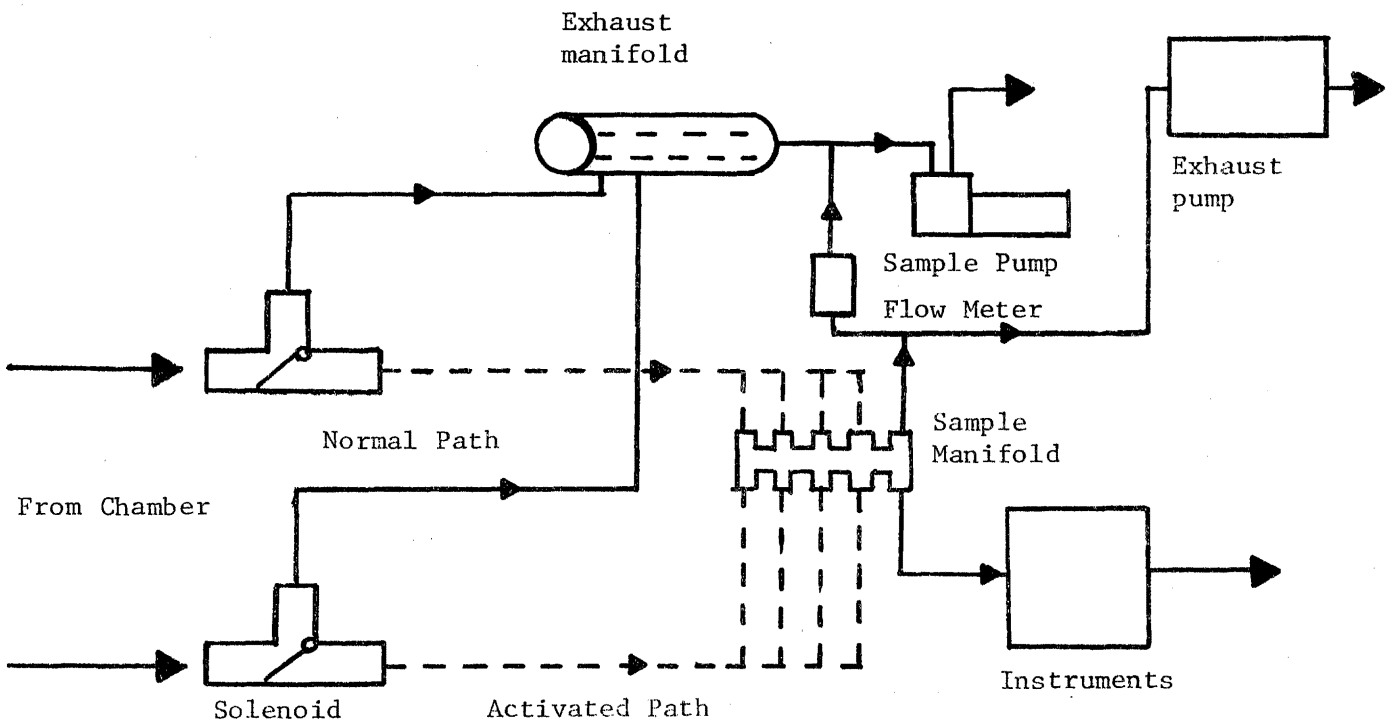
4. Fumigant Sampling System (Figure 4)

Seventy ft 1/4" FTE Teflon lines run from each chamber. The air sample is pulled through a 3-way Teflon solenoid valve to an exhaust manifold. An electrical control box regulates solenoid activation. Once activated, the solenoid valve diverts the flow to a sampling manifold from which the ozone and SO_2 instruments sample. This system continually pulls about 30 liters/min. through sampling lines. Different chambers can therefore be monitored with a minimal lag time for purging the sampling manifold. All gas lines, solenoids and sampling manifolds are Teflon. All other valves, connectors and fittings are stainless steel. The entire sampling system, exclusive of the sampling lines, electronic control box and pumps, is contained in an insulated, thermally regulated box kept at 100°F.

Ozone was monitored by 2 Dasibi Model 1003-AH ozone monitors which use an ultraviolet absorption method for detection. Sulfur dioxide was monitored by 2 Thermoelectron Model 43 SO_2 analyzers which use a pulsed flourescence method of detection.

Ozone calibrations were conducted using an additional Dasibi ozone monitor as a transfer standard. This calibration instrument was verified at the ARB facility in El Monte, California by ultra violet photometry and kept solely as a calibration standard for the Statewide Air Pollution Research Center.

Figure 4. Flow diagram of gas sampling system.



The Thermoelectron Model 43 SO_2 analyzers were calibrated using a monitor labs calibrator with a permeation tube. The calibrations were then verified using a known gas standard of SO_2 in nitrogen.

5. SO_2 Dispensing System (Figure 5)

The SO_2 dispensing system consists of 10 independent SO_2 generators housed in insulated, heated 40 gal trash cans. Each generator contains a 6.7 liter tank of liquid SO_2 (99.8%), a pressure regulator, a 7 μ in-line filter, a Teflon solenoid valve, a 29 inch length of .005 in I.D. stainless steel capillary tubing, and a manual shut-off valve. All fittings and tubing are stainless steel. The SO_2 flow is diverted into the exposure chamber inlet duct to be diluted before entering the exposure chamber. Flow adjustments can be accomplished by changing the setting on the pressure regulator.

Fumigation Facility Calibration

The complete series of calibrations and testing carried out on the fumigation facility is presented in the Appendix. The facility performed to expectations, providing excellent uniformity between chambers and closely approximating ambient conditions.

Plant Selection and Cultivation

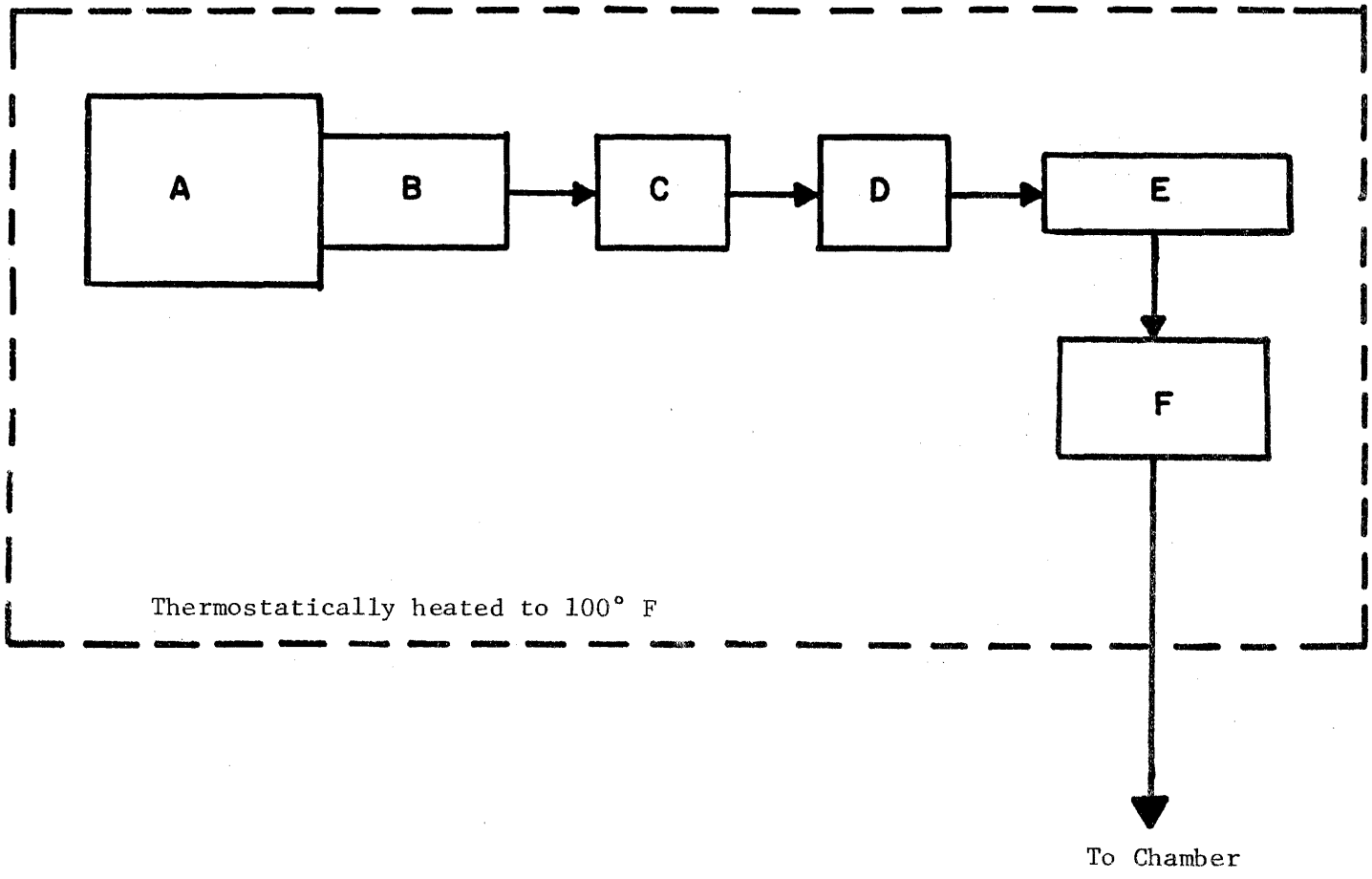
1. Selection and screening:

Five hundred 4" pots of red kidney beans were seeded July 26, 1977. Four seeds were used in each pot then thinned to 461 most uniform individuals during transplanting into the exposure chambers on August 4, 1977. A total of 21 bean plants were transplanted in each of the exposure chambers and ambient plots.

2. Fertilization:

All chambers received an equal amount of fertilizer in the form of calcium nitrate during growth. The seasonal application was equivalent to commercial practices.

Figure 5. Flow diagram for sulfur dioxide dispensers. The flow of SO_2 starts at the tank (A) and continues through the regulator (B), a solenoid (C), a 7 μ filter (D), a capillary tube (E), and through a shut off valve (F) to the chamber.



3. Irrigations:

Plants were irrigated uniformly through a drip system. Irrigation was initiated when irrometers measured 20 to 30 millibars vacuum. All treatments were given a standard amount of water when soil moisture level triggered irrometer readings.

4. Pest control:

Cygon was applied twice during the experimental period to control insects. The exposure chambers proved to do an excellent job excluding insect pests. Insect predation was not a significant variable in the experiment.

5. Soil:

The planting medium was produced by the Riverside Agricultural Station and delivered by project personnel. The formula and soluble sulfate analysis is presented in the Results section.

Soil Samples

1. Soluble sulfate samples:

Core samples were taken from each can and mixed together to form one composite sample for each chamber and each of the two ambient plots. The samples were then sent to an independent laboratory for analysis.

2. Salinity samples:

Core samples were taken from each can at two depths (0-8 inches and 8-16 inches) to determine the concentration of soluble salts. The analysis was performed using the electrical conductivity method (1).

Harvest Procedures

Plants were cut at soil level and individually localized in paper bags. All samples were collected and transported to the laboratory. Each plant was then separated into unfilled pods, filled pods and the residual plant structure and the following evaluation carried out:

1. Unfilled pods: These were counted, oven dried at 70° C for 48 hours and weighed.

2. Filled pods: These were counted, oven dried and processed as follows:

   a. Each pod was shelled and the number of seeds counted.

   b. Dry weights of pods and seeds were taken.

3. Harvested plants: These were oven dried at 70° C for 48 hours and weighed. Plant dry weight refers to oven dried weight of attached leaves plus stems and branches (without pods or seed).

Exposure Schedule

The exposure schedule for 10 pphm SO_2 fumigations is given in Table 1. Red kidney beans were exposed to a total of 335.6 hours of 10 pphm SO_2.

Dose Calculation

Doses for ambient ozone and SO_2 were calculated individually using:

$$\text{dose} = \sum \text{pphm-hrs for the experiment.}$$

Dose therefore represented the sum of all hourly averages for the experimental period. The series of ozone doses using concentration thresholds of 3, 5, 8, 10, 15 and 20 pphm were calculated using the following calculations:

$$\text{dose} = \sum \text{pphm-hrs} - \text{threshold concentration}$$

The use of the concentration thresholds effectively remove the hourly averages below the threshold from the calculated dose. This calculation method was identical to the dose calculations previously submitted in final reports for 1973, 1974, 1975 and 1976 studies.

Results

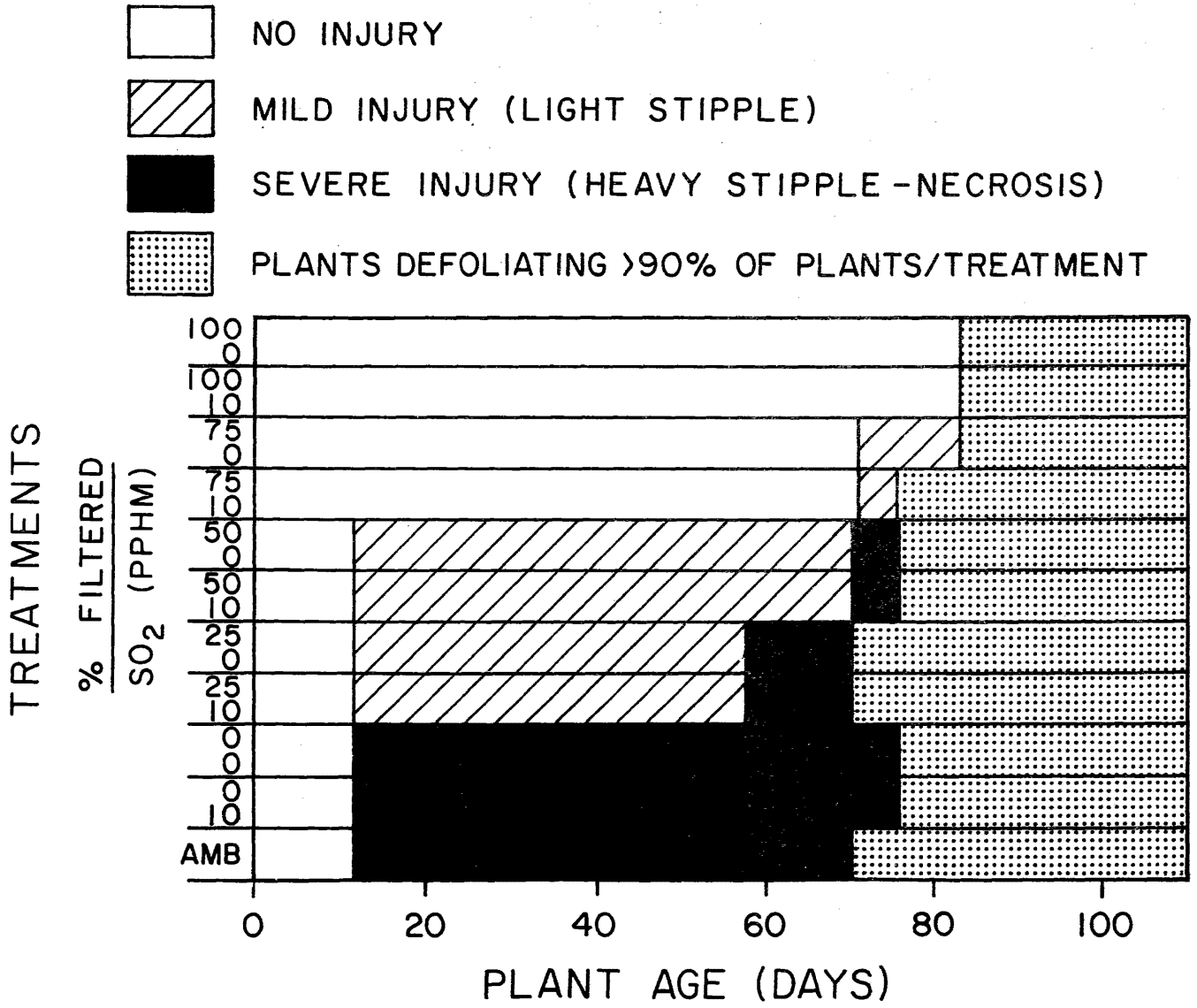
Foliar injury: Ozone injury was observed on plants in the 50%, 25%, and 0% filtered treatments starting 16 days after stand establishment (Figure 6). An evaluation of the extent of injury was recorded only as an arbitrary index of no injury, mild or severe. No differentiation between SO_2 and non-SO_2 treatments could be distinguished on this basis although the unfiltered and

Table 1. Fumigation Schedule for Sulfur Dioxide at 10 pphm.

Date	Start	End	Duration (Hours)	Date	Start	End	Duration (Hours)
8-5	0900[1]	1500	6	9-15	0900	1500	6
8-8	0900	1600	7	9-16	0900	1600	7
8-9	0945	1545	6	9-19	0900	1500	6
8-10	1000	1600	6	9-20	0900	1500	6
8-11	0930	1530	6	9-21	0900	1500	6
8-12	0900	1500	6	9-22	0800	1400	6
8-13	1200	1800	6	9-28	0900	1500	6
8-15	0900	1250	3.6	9-29	0900	1500	6
8-20	0900	1500	6	9-30	0900	1500	6
8-23	1030	1630	6	10-1	0900	1500	6
8-24	0900	1500	6	10-2	1100	1700	6
8-25	0900	----	-	10-4	1100	1700	6
8-26	----	0900	24	10-5	0900	1500	6
8-29	0900	1500	6	10-7	0900	1500	6
8-30	0900	1500	6	10-10	0900	1500	6
8-31	0900	1500	6	10-11	0900	1500	6
9-1	0900	1500	6	10-12	0900	1500	6
9-2	0900	1500	6	10-13	1000	1800	8
9-7	0900	----	-	10-14	0900	1500	6
9-9	----	0900	48	10-17	0900	1500	6
9-10	0900	1800	9	10-18	0900	1500	6
9-11	0900	1500	6	10-19	0900	1500	6
9-13	0900	1600	7	10-20	0900	1500	6
9-14	0900	1500	6	TOTAL			335.6

[1]All times are Pacific Standard Time.

Figure 6. Comparison of foliar injury and time of natural defoliation between treatments



ambient treatments were observed to have severe injury as early as the 16th day. Plants exposed to various treatments of ozone and SO_2 appeared to defoliate earlier than 100% filtered treatments.

Flower production: Bean plants exposed to 100% filtered air and the lower ozone doses appeared to flower earlier than those exposed to higher ozone doses (Figure 7). These plants also ended the flowering period earlier than those plants in the higher ozone dose treatments. Sulfur dioxide exposures did not appear to influence flowering trends.

Pod set: As expected, the pod set of plants followed the trend observed in flower production (Figure 8). The 100% filtered and low ozone dose treatments set pods earlier than high dose treatments. The application of SO_2 did not appear to influence pod set.

Anova analysis (3): The Table of Means (2) and Doses (3) summarize the data used in the (5 x 2) 2-way anova analysis of harvest parameters. The anova analysis was used only with doses > 0 and not with the doses utilizing calculated thresholds. An analysis and evaluation of the relationship of the doses from calculated thresholds and yield is presented later in the results section.

Six variables were measured at final harvest: 1) plant dry weight; 2) number of filled pods; 3) number of unfilled pods; 4) total weight of filled pods; 5) total weight of seeds; 6) total number of seeds. The following derived variables were calculated and also used in the analysis: 7) average number of seeds per pod; 8) average filled pod weight; 9) average seed weight.

A test comparing the variation within individual plants with treatment variation was conducted to determine whether the analysis could utilize them as experimental units. This test (3) indicated that the variations were not equivalent and the analysis was run using chambers as the experimental units.

Figure 7. Comparison of flower production at various plant ages between treatments.

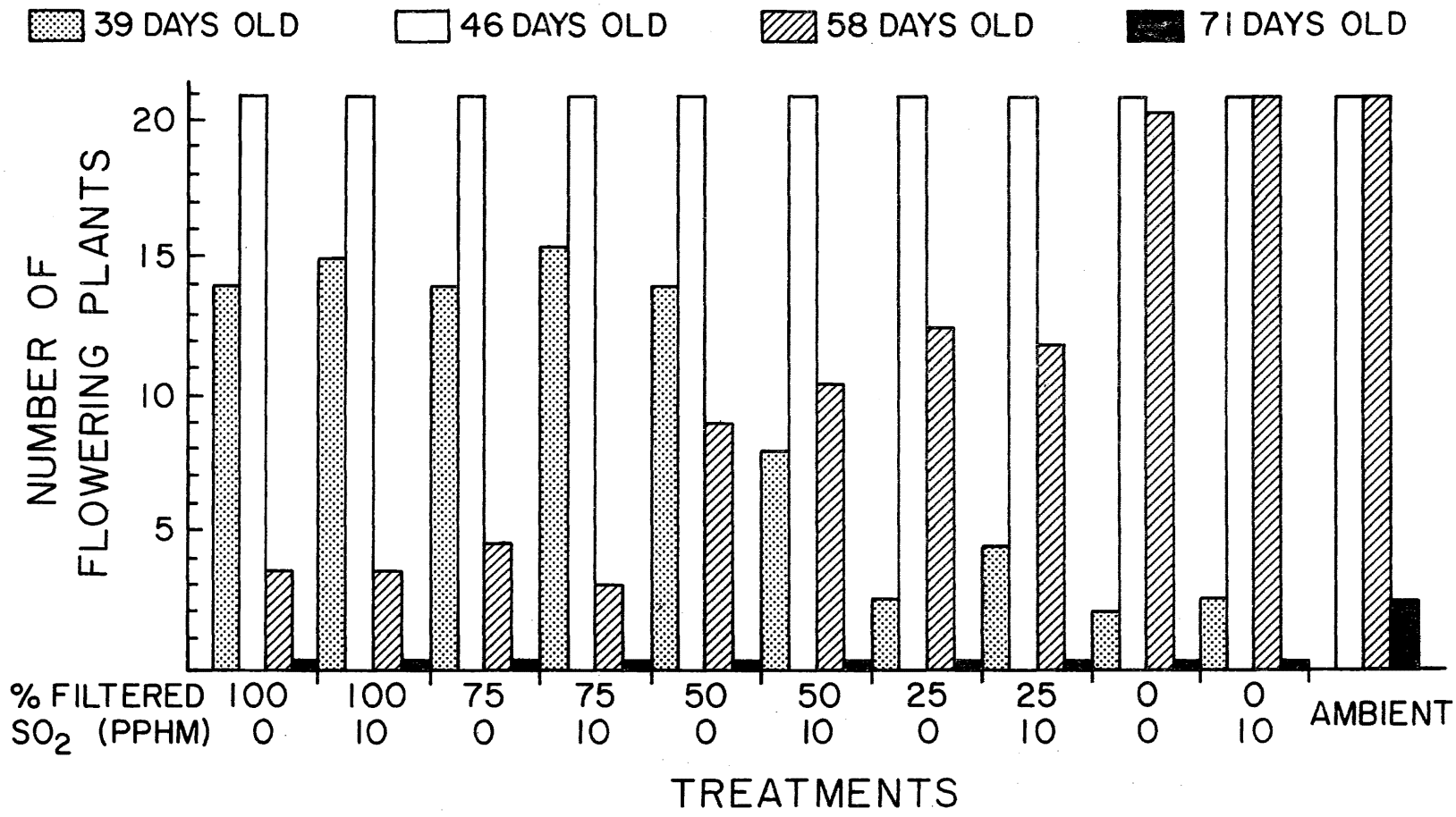


Figure 8. Comparison of pod set at various plant ages between treatments.

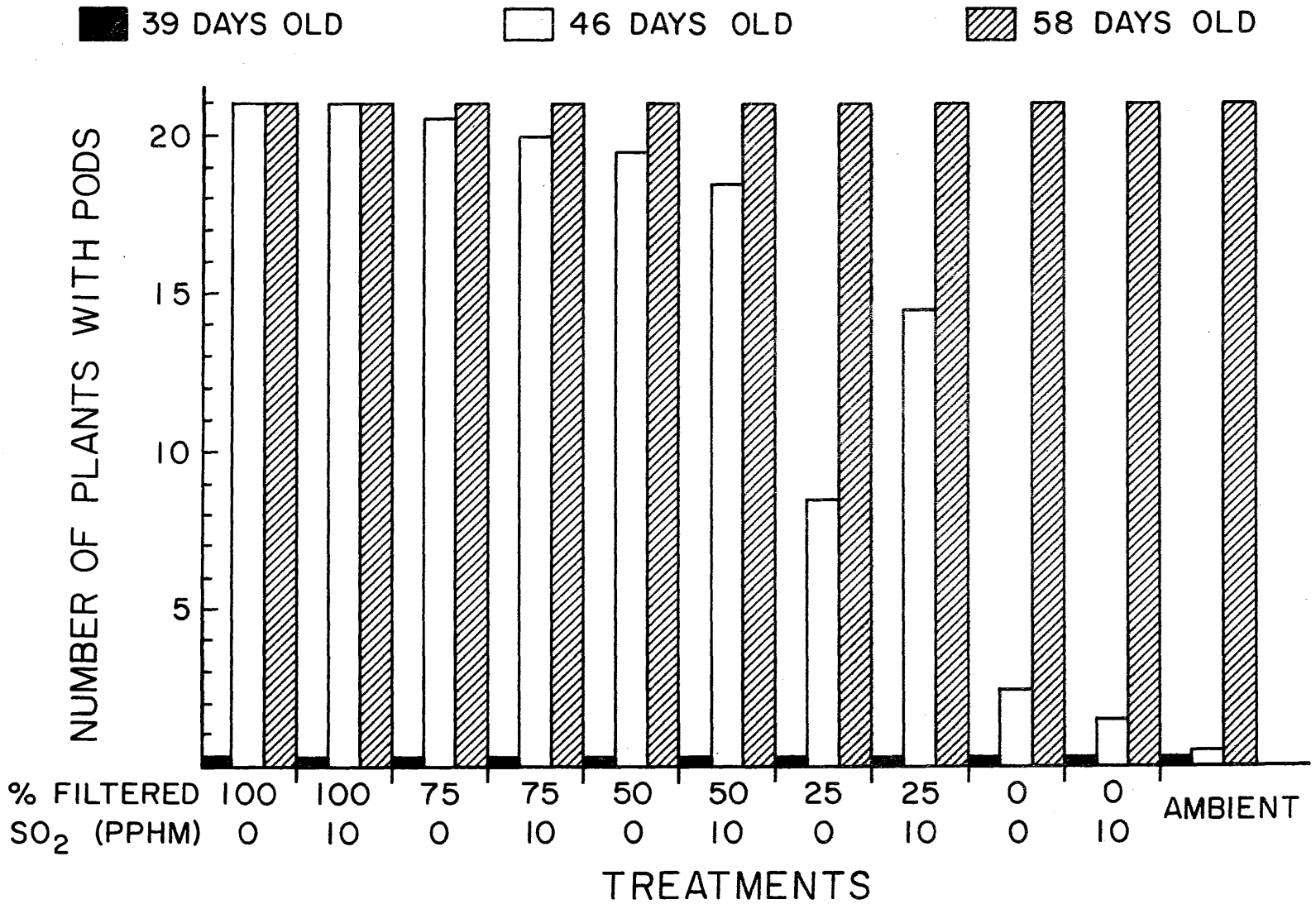


Table 2. Table of Means (ANOVA)

Filtered ambient air (%)	Level SO_2 pphm	Plant dry wt. (g)	# Filled pods	Total wt. pods (g)	Total wt. seeds (g)	Total # seeds	Avg. # seeds/pod	Avg. filled pod wt. (g)
0	0	3.05	5.95	7.98	5.26	13.95	2.40	1.40
25	0	3.39	9.45	12.44	8.28	22.95	2.50	1.34
50	0	6.66	20.65	34.22	24.11	62.60	3.05	1.65
75	0	6.06	19.50	35.26	25.66	61.85	3.15	1.85
100	0	7.39	19.05	33.68	23.66	59.30	3.10	1.77
0	10	3.71	7.70	9.69	6.37	16.50	2.25	1.30
25	10	3.86	9.35	13.33	9.20	24.80	2.70	1.46
50	10	4.68	14.75	22.79	16.10	43.00	3.00	1.56
75	10	5.88	16.70	29.25	20.71	53.70	3.20	1.76
100	10	6.65	18.65	33.04	23.42	59.10	3.15	1.75

Table 3. Table of Doses (ANOVA)

Filtered ambient air (%)	Level SO_2 pphm	Dose >0 pphm-hrs	Dose >3 pphm-hrs	Dose >5 pphm-hrs	Dose >8 pphm-hrs	Dose >10 pphm-hrs	Dose >15 pphm-hrs	Dose >20 pphm-hrs
0	0	8361	4895	3475	1938	1232	340	61
25	0	6902	3591	2317	1033	564	87	6
50	0	5161	1840	852	203	67	8	2
75	0	2794	402	71	1	0	0	0
100	0	1012	2	0	0	0	0	0
0	10	8298	4831	3414	1890	1183	313	48
25	10	6929	3612	2309	1041	569	83	6
50	10	5144	2029	1006	275	95	4	0
75	10	2822	450	83	3	0	0	0
100	10	1175	3	0	0	0	0	0

The complete anova analysis consisted of the following:

Sources of variation	df	
blocks (B)	1	
ozone (O)	4	
sulfur dioxide (S)	1	
O x S	4	
S_2 (O_1)		1
S_2 (O_2)		1
S_2 (O_3)		1
S_2 (O_4)		1
S_2 (O_5)		1
O x B	4	
B (O_1)		1
B (O_2)		1
B (O_3)		1
B (O_4)		1
B (O_5)		1
S x B	1	
B (S_1)		1
B (S_2)		1
Error	4	
Total	19	

Where: O_1 = 0% filtered; O_2 = 25% filtered; O_3 = 50% filtered; O_4 = 75% filtered; O_5 = 100% filtered; S_1 = 0 pphm SO_2; S_2 = 10 pphm SO_2; B = blocks.

The partitioning of the O x B and S x B interaction terms were included only to insure that potential differences in the ozone gradient could not be due to block (chamber replicate) differences. This was confirmed as neither the O x B, S x B interaction terms nor the individual treatment contrasts within them were significant. Their degrees of

freedom were then added to the error term and the following analysis carried out:

Sources of variation	df	
blocks (B)	1	
ozone (0)	4	
sulfur dioxide (S)	1	
0 x S	4	
S_2 (0_1)		1
S_2 (0_2)		1
S_2 (0_3)		1
S_2 (0_4)		1
S_2 (0_5)		1
Error	9	
Total	19	

The 0 x S interaction was partitioned into individual df contrasts to better scrutinize potential component interactions. This practice increased the power of the analysis because the components of the interaction term were evaluated individually and were not diluted by the remaining components.

The standard practice of using asterisks to denote statistical significance is utilized in all tables and figures: (*) indicates significance at the .05 level; (**) indicates significance at the .01 level; (***) indicates significance at the .001 level.

The analyses indicated that 2 variables, number of unfilled pods and average weight of seeds, were not influenced by the 0_3 and/or SO_2 treatments. The remaining 7 variables were then further evaluated.

1) Plant dry weight - The anova analysis indicated that 0_3 significantly reduced plant dry weight (Table 4), a measure of total plant growth. Sulfur dioxide alone had no effect but an interaction with 0_3 at the 50%

Table 4. Analysis of Variance of Variable I - Plant Dry Wt.

Source of Variation	df	SS	MS	F	Coefficient of variation
B	1	0.10368	0.10368	0.18	
O	4	39.65237	9.91309	16.79***	
S	1	0.61952	0.61952	1.05	
O x S	4	4.54873	1.13718	1.93	
SO_2 (O_1)	1	0.44223	0.44223	0.75	
SO_2 (O_2)	1	0.22562	0.22562	0.38	
SO_2 (O_3)	1	3.92040	3.92040	6.64*	
SO_2 (O_4)	1	0.03240	0.03240	0.05	
SO_2 (O_5)	1	0.54759	0.54759	0.93	
Error	9	5.31402	0.59045		15.0%
TOTAL	19	50.23832			

Combination	Count per mean	Subclass O	S	B	Means
B	10				
		0	0	1	5.06
		0	0	2	5.20
O	4				
		1	0	0	3.38
		2	0	0	3.62
		3	0	0	5.67
		4	0	0	5.97
		5	0	0	7.02
S	10				
		0	1	0	5.31
		0	2	0	4.96
O x S	2				
		1	1	0	3.05
		2	1	0	3.39
		3	1	0	6.66
		4	1	0	6.06
		5	1	0	7.39
		1	2	0	3.71
		2	2	0	3.86
		3	2	0	4.68
		4	2	0	5.88
		5	2	0	6.65

filtered dose signficantly reduced plant dry weight beyond the effect of O_3 alone.

2) Number of filled pods - Ozone significantly reduced the number of filled pods (Table 5). Again, sulfur dioxide alone had no effect but an interaction occurred at the 50% filtered dose reducing the number of pods below the level of the ozone effect.

3) Total weight of filled pods - The anova Table (6) shows that the same effects described in variables 1 and 2 occurred again.

4) Total weight of seeds - Table 7 again shows the same effects as variables 1, 2, and 3.

5) Total number of seeds - The same effect described in variables 1, 2, 3 and 4 were observed (Table 8).

6) Average number of seeds per pod - The analysis of this derived variable was statistically similar to the other variables (Table 9). Ozone reduced the number of seeds per pod and 2 interactions with SO_2 were observed. Unfortunately, the statistical inference does not have much biological significance. The interaction indicated that a difference of 0.1 seeds between treatments was significant. This value was too small to be biologically significant given the range of responses that have been demonstrated for different fertilizer treatments, irrigation methods, or environmental variables.

7) Average filled pod weight - The analysis of this derived variable indicated that ozone was the only significant factor influencing reduced average pod weights (Table 10). The reduced average filled pod weights and the lack of reduction in the average bean weight indicated that this effect could be attributed to differences in weights of shelled pods, a parameter with little economic significance.

Table 5. Analysis of Variance of Variable II - No. Filled Pods

Source of Variation	df	SS	MS	F	Coefficient of variation
B	1	0.22050	0.22050	0.07	
O	4	508.31650	127.07910	40.60***	
S	1	11.58242	11.58242	3.70	
O x S	4	34.79053	8.69763	2.78	
SO_2 (O_1)	1	2.95837	2.95837	0.95	
SO_2 (O_2)	1	0.01445	0.01445	0.00	
SO_2 (O_3)	1	35.16490	35.16490	11.24**	
SO_2 (O_4)	1	8.03723	8.03723	2.57	
SO_2 (O_5)	1	0.19820	0.19820	0.06	
Error	9	28.16760	3.12973		12.5%
TOTAL	19	583.07750			

Combination	Count per mean	Subclass O	S	B	Means
B	10				
		0	0	1	14.07
		0	0	2	14.28
O	4				
		1	0	0	6.82
		2	0	0	9.39
		3	0	0	17.68
		4	0	0	18.13
		5	0	0	18.87
S	10				
		0	1	0	14.94
		0	2	0	13.42
O x S	2				
		1	1	0	5.96
		2	1	0	9.45
		3	1	0	20.65
		4	1	0	19.55
		5	1	0	19.10
		1	2	0	7.68
		2	2	0	9.33
		3	2	0	14.72
		4	2	0	16.72
		5	2	0	18.65

Table 6. Analysis of Variance of Variable III - Total Wt. Pods

Source of Variation	df	SS	MS	F	Coefficient of variation
B	1	6.72800	6.72800	0.40	
0	4	2138.39600	534.59890	31.66***	
S	1	53.72642	53.72642	3.18	
0 x S	4	128.88960	32.22240	1.91	
SO_2 (O_1)	1	2.90723	2.90723	0.17	
SO_2 (O_2)	1	0.79224	0.79224	0.05	
SO_2 (O_3)	1	130.75920	130.75920	7.74*	
SO_2 (O_4)	1	47.74829	47.74829	2.83	
SO_2 (O_5)	1	0.40991	0.40991	0.02	
Error	9	151.97360	16.88594		17.7%
TOTAL	19	2479.71300			

Combination	Count per mean	Subclass O	S	B	Means
B	10				
		0	0	1	22.68
		0	0	2	23.84
0	4				
		1	0	0	8.83
		2	0	0	12.88
		3	0	0	28.50
		4	0	0	32.71
		5	0	0	33.36
S	10				
		0	1	0	24.90
		0	2	0	21.62
0 x S	2				
		1	1	0	7.98
		2	1	0	12.44
		3	1	0	34.22
		4	1	0	36.16
		5	1	0	33.68
		1	2	0	9.69
		2	2	0	13.33
		3	2	0	22.79
		4	2	0	29.25
		5	2	0	33.04

Table 7. Analysis of Variance of Variable IV - Total Wt Seeds

Source of Variation	df	SS	MS	F	Coefficient of variation
B	1	5.46012	5.46012	0.55	
O	4	1125.46600	281.36650	28.30***	
S	1	24.93144	24.93144	2.51	
O x S	4	65.92553	16.48137	1.66	
SO_2 (O_1)	1	1.24390	1.24390	0.13	
SO_2 (O_2)	1	0.84631	0.84631.	0.09	
SO_2 (O_3)	1	64.16011	64.16011	6.45*	
SO_2 (O_4)	1	24.55200	24.55200	2.47	
SO_2 (O_5)	1	0.05530	0.05530	0.01	
Error	9	89.48623	9.942913		19.4%
TOTAL	19	1311.26900			

Combination	Count per mean	Subclass O	S	B	Means
B	10				
		0	0	1	15.75
		0	0	2	16.80
O	4				
		1	0	0	5.81
		2	0	0	8.74
		3	0	0	20.11
		4	0	0	23.18
		5	0	0	23.54
S	10				
		0	1	0	17.39
		0	2	0	15.16
O x S	2				
		1	1	0	5.26
		2	1	0	8.28
		3	1	0	24.11
		4	1	0	25.66
		5	1	0	23.66
		1	2	0	6.37
		2	2	0	9.20
		3	2	0	16.10
		4	2	0	20.71
		5	2	0	23.42

Table 8. Analysis of Variance of Variable V - Total No. Seeds

Source of Variation	df	SS	MS	F	Coefficient of variation
B	1	17.09400	17.09400	0.41	
O	4	6824.34900	1706.08700	41.42***	
S	1	110.59100	110.59100	2.68	
O x S	4	349.92740	87.48186	2.12	
SO_2 (O_1)	1	6.40137	6.40137	0.16	
SO_2 (O_2)	1	3.51660	3.51660	0.09	
SO_2 (O_3)	1	384.55220	384.55220	9.34*	
SO_2 (O_4)	1	66.01685	66.01685	1.60	
SO_2 (O_5)	1	0.03442	0.03442	0.00	
Error	9	370.74970	41.19441		15.4%
TOTAL	19	7672.71100			

Combination	Count per mean	Subclass O	S	B	Means
B	10				
		0	0	1	40.85
		0	0	2	42.70
O	4				
		1	0	0	15.22
		2	0	0	23.89
		3	0	0	52.77
		4	0	0	57.80
		5	0	0	59.19
S	10				
		0	1	0	44.12
		0	2	0	39.42
O x S	2				
		1	1	0	13.95
		2	1	0	22.96
		3	1	0	62.57
		4	1	0	61.86
		5	1	0	59.29
		1	2	0	16.48
		2	2	0	24.83
		3	2	0	42.96
		4	2	0	53.74
		5	2	0	59.10

Table 9. Analysis of Variance of Variable VI - Avg No. Seeds/Pod

Source of Variation	df	SS	MS	F	Coefficient of variation
B	1	0.023805	0.023805	1.37	
0	4	2.234230	0.558557	32.19***	
S	1	0.000005	0.000005	0.00	
0 x S	4	0.124870	0.031217	1.80	
SO_2 (0_1)	1	0.052901	0.052901	3.05	
SO_2 (0_2)	1	0.065025	0.065025	3.75	
SO_2 (0_3)	1	0.005625	0.005625	0.32	
SO_2 (0_4)	1	0.001226	0.001226	0.07	
SO_2 (0_5)	1	0.000100	0.000100	0.01	
Error	9	0.156145	0.017349		4.6%
TOTAL	19	2.539055			

Combination	Count per mean	Subclass 0	S	B	Means
B	10				
		0	0	1	2.82
		0	0	2	2.89
0	4				
		1	0	0	2.33
		2	0	0	2.60
		3	0	0	3.00
		4	0	0	3.20
		5	0	0	3.13
S	10				
		0	1	0	2.85
		0	2	0	2.85
0 x S	2				
		1	1	0	2.45
		2	1	0	2.47
		3	1	0	3.04
		4	1	0	3.19
		5	1	0	3.13
		1	2	0	2.22
		2	2	0	2.73
		3	2	0	2.96
		4	2	0	3.22
		5	2	0	3.14

Table 10. Analysis of Variance of Variable VII - Avg. Filled Pod Wt.

Source of Variation	df	SS	MS	F	Coefficient of variation
B	1	0.00800	0.00800	1.30	
O	4	0.67328	0.16832	27.30***	
S	1	0.00648	0.00648	1.05	
O x S	4	0.03452	0.00863	1.40	
SO_2 (O_1)	1	0.01000	0.01000	1.62	
SO_2 (O_2)	1	0.01440	0.01440	2.34	
SO_2 (O_3)	1	0.00810	0.00810	1.31	
SO_2 (O_4)	1	0.00810	0.00810	1.31	
SO_2 (O_5)	1	0.00040	0.00040	0.06	
Error	9	0.05550	0.00617		5.0%
TOTAL	19	0.77778			

Combination	Count per mean	Subclass O	Subclass S	Subclass B	Means
B	10				
		0	0	1	1.56
		0	0	2	1.60
O	4				
		1	0	0	1.35
		2	0	0	1.40
		3	0	0	1.60
		4	0	0	1.80
		5	0	0	1.76
S	10				
		0	1	0	1.60
		0	2	0	1.56
O x S	2				
		1	1	0	1.40
		2	1	0	1.34
		3	1	0	1.65
		4	1	0	1.85
		5	1	0	1.77
		1	2	0	1.30
		2	2	0	1.46
		3	2	0	1.56
		4	2	0	1.76
		5	2	0	1.75

Functional analysis (3): The two derived variables, average number of seeds per pod and average weight of filled pods, did not have sufficient biological or economic value to be continued in the analysis and were discarded. Plots of the remaining five harvest variables and ozone dose alone and in combination with SO_2 were constructed (Figures 9). The ozone and ozone plus SO_2 treatments were partitioned into orthogonal polynomials to assist functional analysis. A computer program was utilized to calculate the polynomial coefficients since the doses were not strictly orthogonal. Tables (11-24) summarize this analysis.

1) Plant dry weight - The ozone response only had a linear component despite the apparent curvilinear distribution. The responses at the 100, 75, and 50% filtered treatments (1000, 2700, and 5100 pphm-hrs ozone dose) were not significantly different from a 0 slope when evaluated as a function and the linear component was represented only by the 50, 25, and 0% filtered treatments. No quadratic, cubic or quartic component proved to be significant.

The ozone plus SO_2 response was found to have a highly significant linear component but no other curvilinear components.

2) Number of filled pods - The ozone treatment response had a highly significant linear component based on the 3 high dose points. No curvilinear components were significant.

The ozone + SO_2 treatment response was observed to have only a highly significant linear component.

3) Total weight of filled pods - The ozone treatment response again had only a significant linear component.

The ozone + SO2 treatment response had only a significant linear component.

Figure 9. Responses of red kidney beans with seasonal ozone dose alone and in combination with 10 pphm SO_2.

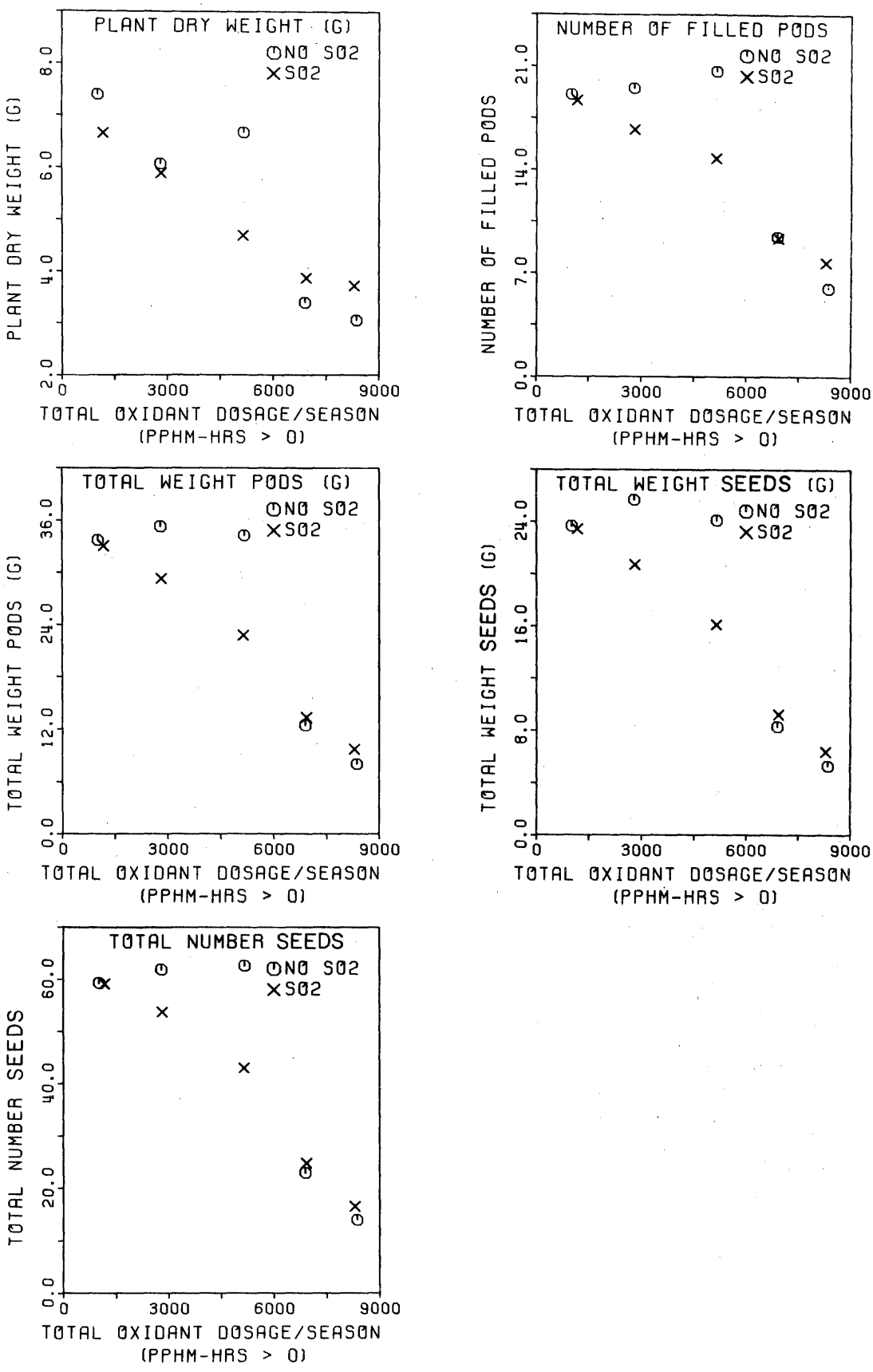


Table 11. Analysis of Variance of Variable I - Plant Dry Wt., O_3 Dose >0 pphm-hrs, SO_2 = 0 pphm.

Source of Variation	df	SS	MS	F	Coefficient of variation
0	4	31.09446	7.77361	6.32	
Linear	1	26.98093	26.98093	21.92**	
Quadratic	1	0.26694	0.26694	0.22	
Cubic	1	0.31288	0.31288	0.25	
Quartic	1	3.53368	3 53368	2.87	
B	1	0.01600	0.01600	0.01	
Error	4	4.92370	1.23092		20.9%
TOTAL	9	36.03416			

Table 12. Analysis of Variance of Variable I - Plant Dry Wt., O_3 Dose >0 pphm-hrs, SO_2 = 10 pphm.

Source of Variation	df	SS	MS	F	Coefficient of variation
0	4	13.10664	3.27666	35.44**	
Linear	1	12.36998	12.36998	133.79***	
Quadratic	1	0.66873	0.66873	7.23	
Cubic	1	0.04450	0.04450	0.48	
Quartic	1	0.02342	0.02342	0.25	
B	1	0.10816	0.10816	1.17	
Error	4	0.36984	0.09246		6.1%
TOTAL	9	13.58464			

Table 13. Analysis of Variance of Variable II - No. Filled Pods, O_3 Dose >0 pphm-hrs, SO_2 = 0 pphm.

Source of Variation	df	SS	MS	F	Coefficient of variation
0	4	363.86690	90.96672	15.25*	
Linear	1	288.02340	288.02340	48.30**	
Quadratic	1	45.86856	45.86856	7.69	
Cubic	1	12.82058	12.82058	2.15	
Quartic	1	17.15401	17.15401	2.88	
B	1	1.14921	1.14921	0.19	
Error	4	23.85514	5.96378		16.3%
TOTAL	9	388.87130			

Table 14. Analysis of Variance of Variable II - No. Filled Pods, O_3 Dose >0 pphm-hrs, SO_2 = 10 pphm.

Source of Variation	df	SS	MS	F	Coefficient of variation
0	4	179.24010	44.81001	55.71***	
Linear	1	176.27480	176.27480	219.16***	
Quadratic	1	0.20955	0.20955	0.26	
Cubic	1	1.28632	1.28632	1.60	
Quartic	1	1.46941	1.46941	1.83	
B	1	0.16641	0.16641	0.21	
Error	4	3.21734	0.80433		6.7%
TOTAL	9	182.62380			

Table 15. Analysis of Variance of Variable III - Total Wt. Pods, O_3 Dose >0 pphm-hrs., SO_2 = 0 pphm.

Source of Variation	df	SS	MS	F	Coefficient of variation
0	4	1464.80200	366.20040	11.50*	
Linear	1	1220.85500	1220.85500	38.34**	
Quadratic	1	112.75710	112.75710	3.54	
Cubic	1	98.95384	98.95384	3.11	
Quartic	1	32.23340	32.23340	1.01	
B	1	7.93881	7.93881	0.25	
Error	4	127.35780	31.83945		22.7%
TOTAL	9	1600.09800			

Table 16. Analysis of Variance of Variable III - Total Wt. Pods, O_3 Dose >0 pphm-hrs SO_2 = 10 pphm.

Source of Variation	df	SS	MS	F	Coefficient of variation
0	4	802.48350	200.62090	35.38**	
Linear	1	797.19970	797.19970	140.59***	
Quadratic	1	0.21493	0.21493	0.04	
Cubic	1	4.83313	4.83313	0.85	
Quartic	1	0.23619	0.23619	0.04	
B	1	0.72361	0.72361	0.13	
Error	4	22.68134	5.67033		11.0%
TOTAL	9	825.88840			

Table 17. Analysis of Variance of Variable IV - Total Wt. Seeds, O_3 Dose >0 pphm-hrs SO2 = 0 pphm.

Source of Variation	df	SS	MS	F	Coefficient of variation
0	4	766.10370	191.52590	10.34*	
Linear	1	635.69360	635.69360	34.32**	
Quadratic	1	58.44855	58.44855	3.16	
Cubic	1	55.76494	55.76494	3.01	
Quartic	1	16.19656	16.19656	0.87	
B	1	5.01264	5.01264	0.27	
Error	4	74.08906	18.52226		24.7%
TOTAL	9	845.20540			

Table 18. Analysis of Variance of Variable IV - Total Wt. Seeds, O_3 Dose >0 pphm-hrs, SO_2 = 10 pphm.

Source of Variation	df	SS	MS	F	Coefficient of variation
0	4	425.28780	106.32190	28.91**	
Linear	1	422.84230	422.84230	114.99***	
Quadratic	1	0.01395	0.01395	0.00	
Cubic	1	2.29498	2.29498	0.62	
Quartic	1	0.13651	0.13651	0.04	
B	1	1.13569	1.13569	0.31	
Error	4	14.70896	3.67724		12.6%
TOTAL	9	441.13250			

Table 19. Analysis of Variance of Variable V - Total No. Seeds, O_3 Dose >0 pphm-hrs, SO_2 = 0 pphm.

Source of Variation	df	SS	MS	F	Coefficient of variation
0	4	4486.54700	1121.63600	14.68*	
Linear	1	3645.12000	3645.12000	47.71**	
Quadratic	1	426.48730	426.48730	5.58	
Cubic	1	242.58330	242.58330	3.17	
Quartic	1	172.35040	172.35040	2.26	
B	1	6.56100	6.56100	0.09	
Error	4	305.61710	76.40427		19.8%
TOTAL	9	4798.72500			

Table 20. Analysis of Variance of Variable V - Total No. Seeds, O_3 Dose >0 pphm-hrs, SO_2 = 10 pphm.

Source of Variation	df	SS	MS	F	Coefficient of variation
0	4	2687.73000	671.93240	41.43**	
Linear	1	2664.34300	2664.34300	164.29***	
Quadratic	1	5.54985	5.54985	0.34	
Cubic	1	16.78029	16.78029	1.03	
Quartic	1	1.05402	1.05402	0.06	
B	1	10.79521	10.79521	0.67	
Error	4	64.87044	16.21761		10.2%
TOTAL	9	2763.39500			

Table 21. Analysis of Variance of Variable VI - Avg. No. Seeds/Pod, O_3 Dose >0 pphm-hrs, SO_2 = 0 pphm.

Source of Variation	df	SS	MS	F	Coefficient of variation
0	4	1.06096	0.26524	40.13**	
Linear	1	0.92000	0.92000	139.18***	
Quadratic	1	0.02426	0.02426	3.67	
Cubic	1	0.10546	0.10546	15.95*	
Quartic	1	0.01125	0.01125	1.70	
B	1	0.00676	0.00676	1.02	
Error	4	0.02644	0.00661		2.9%
TOTAL	9	1.09416			

Table 22. Analysis of Variance of Variable VI - Avg. No. Seeds/Pod, O_3 Dose >0 pphm-hrs, SO_2 = 10 pphm.

Source of Variation	df	SS	MS	F	Coefficient of variation
0	4	1.29814	0.32453	22.98**	
Linear	1	1.12682	1.12682	79.77***	
Quadratic	1	0.14143	0.14143	10.01*	
Cubic	1	0.00106	0.00106	0.08	
Quartic	1	0.02883	0.02883	2.04	
B	1	0.09025	0.09025	6.39	
Error	4	0.05660	0.01412		4.2%
TOTAL	9	1.44489			

Table 23. Analysis of Variance of Variable VII - Avg. Filled Pod Wt., O_3 Dose > 0 pphm-hrs, SO_2 = 0 pphm.

Source of Variation	df	SS	MS	F	Coefficient of variation
0	4	0.39896	0.09974	10.84*	
Linear	1	0.32598	0.32598	35.43**	
Quadratic	1	0.00002	0.00002	0.00	
Cubic	1	0.07288	0.07288	7.92*	
Quartic	1	0.00008	0.00008	0.01	
B	1	0.00100	0.00100	0.11	
Error	4	0.03680	0.00920		6.0%
TOTAL	9	0.43676			

Table 24. Analysis of Variance of Variable VII - Avg. Filled Pod Wt., O_3 Dose >0 pphm-hrs, SO_2 = 10 pphm.

Source of Variation	df	SS	MS	F	Coefficient of variation
0	4	0.30546	0.07636	15.96*	
Linear	1	0.29252	0.29252	61.13**	
Quadratic	1	0.00213	0.00213	0.45	
Cubic	1	0.00055	0.00055	0.12	
Quartic	1	0.01025	0.01025	2.14	
B	1	0.00841	0.00841	1.76	
Error	4	0.01914	0.00478		4.4%
TOTAL	9	0.33301			

4) Total weight of seeds - The ozone treatment had only a significant linear component.

The ozone + SO_2 treatment had only a significant linear component.

5) Total number of seeds - The ozone treatment had only a significant linear component.

The ozone + SO_2 treatment had only a significant linear component.

Regression Analysis (3): The Tables of Means (25), Doses (26) summarize the data for this analysis. All plant harvest variables and doses are presented but the regression analysis incorporates only the principal yield component, total weight of seeds. Peak ozone concentrations (Table 27) and peak SO_2 concentrations (Table 28) are presented for information only.

1) Ozone effect - Ozone was by far the most significant factor defined in the anova analysis in reducing the total weight of seeds harvested. The functional analysis indicated that the response was linear, and reduced yields occurred when the dose was greater than 5160 pphm-hrs. A regression of weight of seeds per plant and doses greater than 4739 pphm-hrs produced the following:

$$\text{wt of seeds} = 43.839 + (-.00445 \times \text{dose})$$
$$r = .90454^{**}$$

A plot of the data points (Figure 10) revealed that the addition of the ambient data points had extended the dose range to 9880 pphm-hrs and appeared to produce a curvilinear function. A log transformation was used and produced a better fit.

$$\text{wt of seeds} = 306.7 + (-33.317 \times \log_e \text{dose})$$
$$r = .9449^{**}$$

2) SO_2 effect - The ozone dose + 10 pphm SO_2 response (Figure 10) was extremely linear as predicted by the functional analysis and closely associated

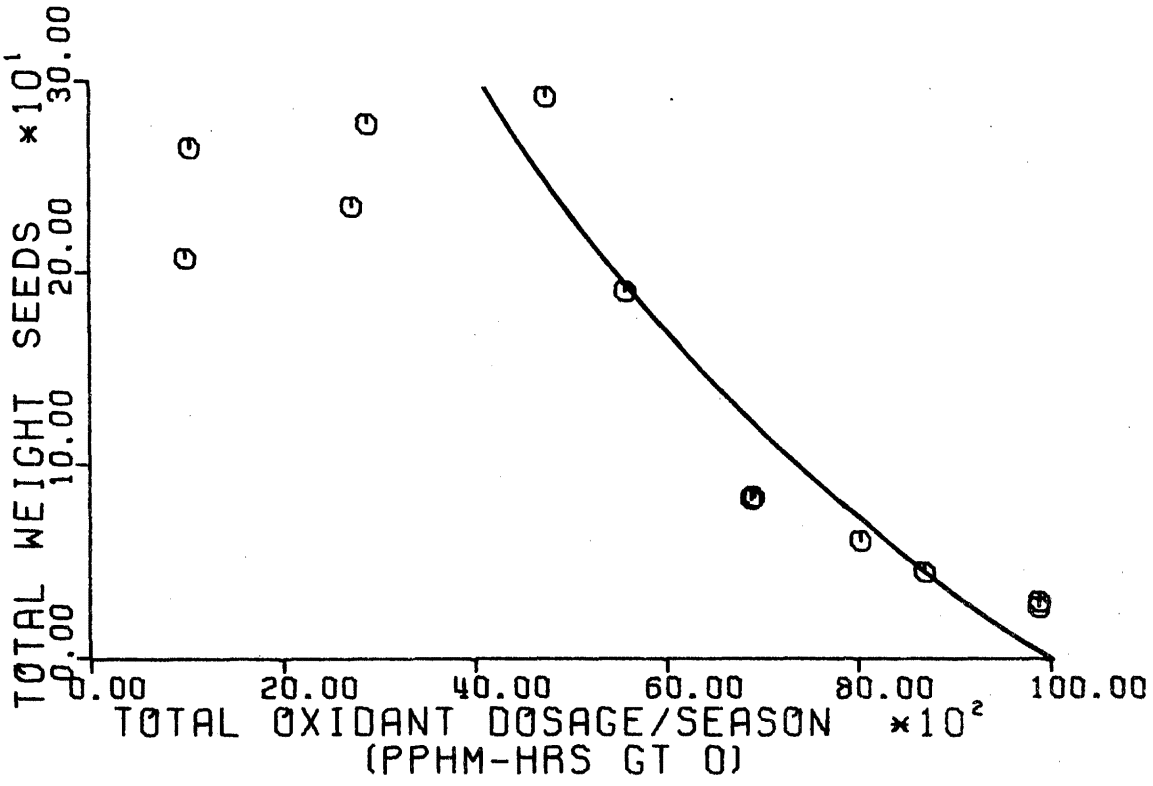
Table 25. Table of Means (Regression)

Chamber #	Block	Level SO_2 pphm	Filtered ambient air (%)	Plant dry wt. (g)	# Filled pods	Total wt. pods (g)	Total wt. seeds (g)	Total # seeds	Avg. # seeds/ pod	Avg. filled pod wt.(g)
3	1	0	0	3.32	6.9	9.01	6.08	15.9	2.4	1.40
8	1	0	25	3.29	9.5	12.39	8.23	22.8	2.5	1.33
9	1	0	50	5.72	17.4	27.44	19.04	51.6	3.0	1.58
5	1	0	75	5.52	19.0	33.69	23.50	61.4	3.2	1.77
2	1	0	100	8.49	20.1	37.49	26.57	64.9	3.2	1.86
1	1	10	0	3.52	8.3	10.17	6.70	17.2	2.2	1.27
6	1	10	25	3.94	8.9	12.50	8.52	22.8	2.6	1.44
10	1	10	50	4.81	15.4	22.76	15.82	41.8	2.8	1.49
7	1	10	75	5.74	17.2	31.03	22.01	56.1	3.2	1.80
4	1	10	100	6.25	18.0	30.28	21.06	54.0	3.0	1.67
14	2	0	0	2.77	5.0	6.95	4.43	12.0	2.4	1.4
16	2	0	25	3.48	9.4	12.48	8.33	23.1	2.5	1.34
19	2	0	50	7.60	23.9	41.00	29.18	73.6	3.1	1.71
17	2	0	75	6.60	20.0	38.63	27.82	62.3	3.1	1.92
11	2	0	100	6.29	18.0	29.87	20.74	53.7	3.0	1.67
12	2	10	0	3.90	7.1	9.20	6.04	15.8	2.3	1.33
18	2	10	25	3.78	9.8	14.15	9.88	26.8	2.8	1.47
20	2	10	50	4.55	14.1	22.81	16.38	44.2	3.2	1.62
15	2	10	75	6.02	16.2	27.47	19.40	51.3	3.2	1.71
13	2	10	100	7.05	19.3	35.80	25.78	64.2	3.3	1.83
AMB1	--	--	---	1.95	3.3	4.00	2.67	7.0	2.2	1.25
AMB2	--	--	---	2.20	3.6	4.38	2.93	7.8	2.2	1.27

Table 26. Table of Doses (Regression)

Chamber #	Block	Level SO2 pphm	Filtered ambient air (%)	Dose >0 pphm/hrs	Dose >3 pphm/hrs	Dose >5 pphm/hrs	Dose >8 pphm/hrs	Dose >10 pphm/hrs	Dose >15 pphm/hrs	Dose >20 pphm/hrs
3	1	0	0	8033	4625	3211	1730	1061	270	39
8	1	0	25	6892	3680	2404	1116	619	104	9
9	1	0	50	5582	1991	955	248	85	11	3
5	1	0	75	2706	455	93	1	0	0	0
2	1	0	100	1032	3	0	0	0	0	0
1	1	10	0	8010	4603	3189	1716	1045	261	32
6	1	10	25	6722	3510	2237	998	553	78	4
10	1	10	50	5254	2146	1099	333	125	4	0
7	1	10	75	2825	563	122	5	0	0	0
4	1	10	100	1310	6	0	0	0	0	0
14	2	0	0	8688	5164	3739	2146	1403	410	83
16	2	0	25	6912	3502	2229	949	509	70	3
19	2	0	50	4739	1688	748	158	48	4	0
17	2	0	75	2881	349	48	0	0	0	0
11	2	0	100	992	0	0	0	0	0	0
12	2	10	0	8586	5059	3638	2063	1320	364	64
18	2	10	25	7136	3713	2381	1084	584	87	7
20	2	10	50	5033	1912	913	217	65	3	0
15	2	10	75	2818	337	44	0	0	0	0
13	2	10	100	1040	0	0	0	0	0	0
AMB1	--	--	---	9880	6465	4935	3170	2270	854	273
AMB2	--	--	---	9880	6465	4935	3170	2270	854	273

Figure 10. Relationship of ambient ozone and ambient ozone plus 10 pphm SO_2 with total weight of seeds produced by red kidney beans.



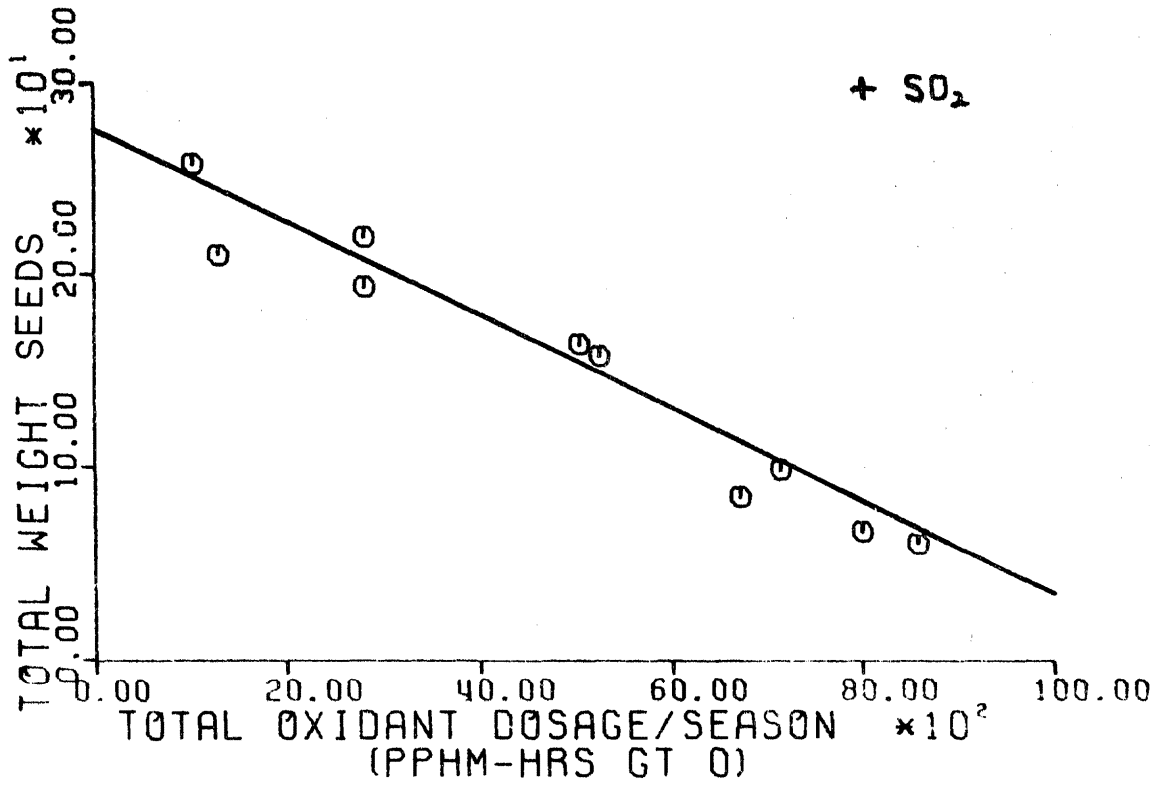


Table 27. Peak ambient ozone concentration with calculated chamber concentrations.

% Filtered	Chamber #	8/19/77 (ppm O_3)	10/14/77 (ppm O_3)	10/15/77 (ppm O_3)
ambient	---	.300	.300	.360
0	1	.246	.246	.295
100	2	.016	.016	.016
0	3	.246	.246	.295
100	4	.016	.016	.016
75	5	.061	.061	.074
25	6	.185	.185	.221
75	7	.061	.061	.074
25	8	.185	.185	.221
50	9	.123	.123	.148
50	10	.123	.123	.148
100	11	.016	.016	.016
0	12	.246	.246	.295
100	13	.016	.016	.016
0	14	.246	.246	.295
75	15	.061	.061	.074
25	16	.185	.185	.221
75	17	.061	.061	.074
25	18	.185	.185	.221
50	19	.123	.123	.148
50	20	.123	.123	.148

Table 28. Three fumigated SO_2 concentrations and averages within fumigation chambers. Ambient SO_2 concentrations never exceeded .06 ppm peak concentration and were never monitored as a significant intrusion in chambers without SO_2 generators.

Chamber #	SO_2 ppm-hr	SO_2 6 hr avg.	SO_2 24 hr avg[1]
1	.14, .14, .13	.13, .12, .11	.10, .09
4	.14, .14, .14	.13, .13, .13	.11, .12
6	.14, .14, .14	.12, .12, .12	.12, .10
7	.13, .12, .12	.12, .12, .12	.09, .09
10	.13, .13, .13	.12, .12, .12	.11, .10
12	.15, .14, .14	.12, .12, .12	.12, .10
13	.14, .14, .13	.13, .13, .12	.12, .10
15	.13, .13, .13	.12, .12, .11	.10, .08
18	.13, .12, .12	.11, .11, .10	.09, .08
20	.14, .14, .14	.12, .12, .11	.12, .10

[1]only 2 24 hr. fumigations were run

with the weight of seeds harvested (r = -.9727). The regression equation describing the functional relationship follows:

$$\text{wt seeds} = 27.22 + (-.0024 \times \text{dose})$$

The SO_2/ozone interaction described in the anova analysis at 5160 pphm-hrs dose reduced the yield to produce the highly linear function.

Dose Analysis (3): Ozone doses were calculated utilizing several concentration thresholds to determine which representation was best. The various dose representations were then regressed with the total weight of harvested seeds per plant to test for closeness of fit and to determine whether significant differences between functions were detectable.

1) Doses without SO_2 - These doses which included the ambient plots were tested separately because of the lack of signficant slopes at doses less than 4739 pphm-hrs. The analysis follows:

Threshold pphm	Intercept	Slope	r
0	43.8	.00445	.905**
3	29.1	.00453	.890**
5	24.8	.00506	.877**
8	20.5	.00653	.832*
10	18.7	.00831	.793*
15	16.0	.01810	.693 n.s.
20	14.1	.04650	.595 n.s.

slopes = 1.93 n.s.

intercepts = 7.88**

No significant differences between slopes of functions were detected but a significant difference between intercepts was observed. A significant relationship between weight of harvested seeds per plant and the 0, 3, 5, 8 and 10 pphm dose representation was determined. Only the 15 and 20 pphm dose representations were not significantly related.

2) Doses with SO_2 - ozone doses in the SO_2 treatments were tested using the same methods as discussed for doses without SO_2. The analysis follows:

Threshold pphm	Intercept	Slope	r
0	27.2	.00248	.973**
3	20.5	.00437	.977**
5	22.3	.00337	.978**
8	16.8	.00585	.951**
10	15.8	.00852	.938**
15	14.0	.02610	.853*
20	9.3	.05541	.883 n.s.

F slopes = 9.75**

A highly significant difference was determined between slopes of the various dose representations and the weight of harvested seeds per plant. The intercepts could not be tested because of the significant difference in slopes. Six of the 7 functions were found to have a significant relationship.

3) Dose calculated $(SO_2)(O_3)$ - The doses were calculated for the SO_2 treatments using O_3 pphm-hrs (for non-fumigated period) + $(O_3)(SO_2)$ pphm-hrs (for fumigated periods). The resultant doses were as follows:

Chamber	dose	Chamber	dose
1	23,483	12	26,300
4	3,567	13	3,497
6	22,337	15	7,120
7	8,641	18	18,029
10	16,081	20	13,516

These doses were regressed with weight of seeds per plant and produced the following:

$$\text{weight of seeds} = 26.71 + (-.0081 \times \text{dose})$$
$$r = .96512^{**}$$

The correlation coefficient indicated an excellent fit but less than the 9727 for the ozone dose >0 correlation with the same dependent variable. This method of dose calculation creates some problems in calculation and application. The product of the 2 gases is not representative of the total exposure since large periods of time were not utilized for SO_2 exposures. The SO_2 treatment plants were exposed only to various levels of ambient ozone during nonfumigated periods. The combination of the product representation of dose and ozone dose alone creates a problem with units:

(pphm-hr)(pphm-hr) vs. pphm-hr

The ozone doses appear to be a more representative method of calculation.

Soil Analyses: A soluble sulfate analysis (4) indicated high variability among chambers at harvest (Table 29). No relationship with SO_2 treatment chambers was apparent. The initial soil mix constituents are given in Table 30. No indications of sulfur deficiency were observed.

Salinity: Soil salinity readings taken after harvest indicated extremely uniform low readings which would not interfere with the experiment (Table 31). Salinity would have had to exceed 1.5 millimhos per cm to influence the bean yields.

Table 29. Soluble Sulfate From Soil - 1977.

Chamber	% Filtered	SO_2 (ppm)	SO_4 (ppm)
1	0	0.10	40
2	100	0	45
3	0	0	5
4	100	0.10	25
5	75	0	15
6	25	0.10	10
7	75	0.10	20
8	25	0	10
9	50	0	10
10	50	0.10	10
11	100	0	20
12	0	0.10	5
13	100	0.10	5
14	0	0	0
15	75	0.10	0
16	25	0	0
17	75	0	0
18	25	0.10	0
19	50	0	10
20	50	0.10	0
A1[1]	--	--	35
A2	--	--	0
UC[2]	--	--	80

[1]Ambient plot.

[2]Standard University of California Soil Mix.

Table 30. Constituents of Experimental Soil Tabulated per Cubic Yard of Mix.

Soil	14	ft^3
Canadian Peat Moss	7	ft^3
Redwood Shavings	7	ft^3
Single Super Phosphate	2.5	lbs
KNO_3	4.0	oz
K_2SO_4	4.0	oz
Dolomite Limestone	3.75	lbs
Oyster Shell Lime	1.50	lbs
Micronutrients		
Cu	30	ppm
Zn	10	ppm
Mn	15	ppm
Fe	15	ppm

Table 31. Average Soil Salinity for Chamber: Measured as Electrical Conductivity.

Chamber Number	Electrical Conductivity[1] (millimhos/cm)	
	Top[2]	Bottom
1	0.26	0.29
2	0.33	0.30
3	0.31	0.27
4	0.31	0.37
5	0.29	0.31
6	0.29	0.29
7	0.28	0.42
8	0.26	0.28
9	0.35	0.34
10	0.33	0.31
11	0.31	0.31
12	0.32	0.34
13	0.31	0.30
14	0.30	0.26
15	0.29	0.30
16	0.34	0.29
17	0.26	0.31
18	0.29	0.25
19	0.28	0.27
20	0.30	0.33
A1	0.28	0.23
A2	0.33	0.27

[1]Entries are the mean of 7 samples

[2]Top denotes upper 8 inches of soil in can, bottom denotes lower 8 inches.

Discussion

SO_2 Effect

Sulfur dioxide alone or in combination with 25, 75 and 100% ambient oxidant did not produce a statistically significant response on red kidney beans. The only detectable response was the interaction in combination with 50% ambient oxidant.

Ozone effect

The primary yield parameter, total weight of seeds harvested per plant, was reduced by ambient ozone at a rate of 33.3 grams per increment of $\log_e$ dose beyond a dose level of 5160 pphm-hrs (dose > 0 pphm-hrs). This rate was taken from the regression of total weight of seeds on ozone dose > 0 pphm:

$$\text{wt of beans} = 306.7 + (-33.317 \times \log_e \text{dose})$$

This equation was derived using the ambient plots in combination with the 50, 25 and 0% filtered treatments. The intercept was not functional as a statistical control since the 24.1 grams total weight of beans is indicative of yield at 5160 pphm-hrs (dose > 0 pphm), an equivalent response with the 100% filtered treatment. The 33.3 slope value could be used, however, to predict yield to a maximum dose of 9880 pphm-hrs.

The dose analysis of ozone treatments indicated that the variation in the slopes of the significant functions using calculation thresholds of 0, 3, 5, 8, and 10 pphm and weight of seed harvested, were not different. Only the comparison of calculated intercepts were statistically different. A choice of which dose representation was most accurate would be particularly hazardous. A simple choice of the highest r value would not be definitive

since 5 dose representations were significant at the .05 level and 3 significant at the .01 level.

Ozone + SO_2 Effect

An ambient ozone/SO_2 interaction was clearly defined across all but two measured harvest parmeters in the 50% filtered treatment. Plant growth, pod set, pod weight, and weight and number of harvested seeds were all reduced by this reponse defined in the partitioned interaction term in the anova analysis. The overall interaction term was not significant because of the dilution effect of the 4 nonsignificant components. There is some suggestion that the interaction on the yield components may extend to the next lowest dose level (75% filtered) since the F values of these components are substantial. This must, however, remain speculative since the statistical analysis did not substantiate it at a high enough level of probability ($p = .20$).

The ozone/SO_2 interaction with weight of seeds effectively reduced this yield parameter at a dose (5160 pphm-hrs > 0 pphm) where no effect was observed for ozone alone (Figure 10). The SO_2/ozone response function predicted a loss of 3.4 mg seed weight for each pphm-hr of ozone dose > 0 pphm. The interaction effectively accentuated the ozone response in the 50% filtered treatment. Characteristically, it reduced the number of seeds produced but did not affect the size of seeds.

It was of interest that the interaction was present only at the specific ozone dose range which just preceded plant response. No interaction occurred when the ozone dose was high enough to initiate a response by itself. Plants impacted by these higher doses were not affected by the presence of 10 pphm SO_2.

The dose analysis utilizing several calculation thresholds plus SO_2 regressed with total weight of harvested seeds per plant differed from the previous analysis using no SO_2 treatments. The analysis indicated that slopes of the various functions were significantly different indicating altered rates of response. Six of the 7 functions were significant at .05 or better.

REFERENCES

1. Branson, R. L. 1972. Soluble Salts, Exchangeable Sodium, and Boron in Soils. Proceedings of Statewide Conference on Soil and Tissue Testing. Dept. of Agronomy, Univ. of Calif., Davis. pp. 120-129.

2. Rogers, H. H., H. E. Jeffries, E. P. Stahel, W. W. Heck, L. A. Ripperton, and A. M. Witherspoon. 1978. Measuring Air Pollutant Uptake by Plants: A Direct Kinetic Technique. J. Air Pollut. Control Assoc. 27(12): 1192-1197.

3. Sokal, R. R. and F. J. Rohlf. 1969. Biometry, W. H. Freeman Co., San Francisco, CA p. 776.

4. Nelson, R. E. 1970. Proceedings of the Soil Science Society of America 74:343-345.

APPENDIX

Calibration data and test specifications

for fumigation facility built under

ARB Agreement A6-162-30.

The figures and tables contained in this appendix represent the testing and calibration data obtained from the fumigation facility built under ARB Agreement A6-162-30. The 20 chambers each consist of an FEP Teflon bag suspended from a rigid PVC frame. The chambers were tested for a variety of variables, including: ability to approximate ambient conditions; homogeneity of conditions within individual chambers; and homogeneity among chambers.

Several tests were performed to find out if the chambers approximated ambient conditions. The chambers were compared with ambient conditions in the following areas: amount of available PAR, temperature, relative humidity, and levels of pollutants and aerosol.

Individual chambers were tested to be certain that internal conditions were homogeneous. Tests were conducted to determine if any differences could be found in spacial distribution of temperature, pollutants, and PAR.

Finally, all chambers were tested to be certain that they were homogeneous among each other. Tests were conducted to determine if any real differences existed in total PAR, levels of pollutants (among replicate chambers), temperature, and relative humidity.

The specific calibrations follow:

1) FEP Teflon transmission spectrum: Figures 1, 2, 3, and 4 were provided by E.I. DuPont de Nemours, Inc.

2) Photosynthetically active radiation (PAR): Transmission (400-700 nm) readings were taken at 1/2 hour intervals both inside and outside of a chamber on five separate days to determine if any differences existed (Figures 5, 6, 7, 8, 9, and Table 1). Shadows from the motor mount or supporting frames sometimes caused sharp drops in transmission but were not a significant factor on a seasonal basis.

3) PAR transmission differences among chambers: No significant dif-

ferences were detected among four randomly selected chambers at midday (Table 2).

4) Chamber air exchanges: Chamber air exchanges are held uniform by adjustments of the butterfly valves previously described in the air handling system. All flows are checked weekly using a hot wire anemometer calibrated against a peto tube and velometer. To date, only minor adjustment on a few chambers has been necessary. Current air flows allow ~1.3 changes per minute at 1800 linear ft./min. through the 6 in. ducting. Chambers are extremely uniform in their linear flow rates. This factor combined with the excellent spacial concentration homogeneity insure uniform fumigant fluxes in replicate chambers.

5) Spacial fumigant gradient tests: Three chambers were randomly selected to test for internal concentration gradients. Twelve sampling points within each chamber (Figure 10) were monitored and replicated four times using a given SO_2 concentration. Results indicate the chamber design maintains an extremely homogeneous fumigant concentration throughout its interior (Table 3).

6) Sample line efficiency for sulfur dioxide: One chamber was randomly selected to measure the sulfur dioxide concentration directly in the chamber and simultaneously through the 70 foot sample line. The test was replicated six times. The results indicate that the chamber concentration of sulfur dioxide was for all intents the level monitored through the 70 foot sample line (Table 4).

7) Chamber exhaust sampling-sulfur dioxide: One chamber was randomly selected to measure the sulfur dioxide concentration at varying distances above, downwind, and upwind from the exhaust outlet. The test was replicated three times. The results indicate that the sulfur dioxide is dispersed

adequately into the atmosphere and there is virtually no chance of gas being recirculated through the air handling system (Table 5).

8) Paired replicate chamber concentration tests: The replicate ozone concentration from each chamber set was tested to determine chamber differences. The results (Tables 6 and 7) indicate close replication of ozone concentration. Statistical significance testing detected differences among some chambers but the magnitude of the differences was inconsequential relative to plant response.

9) Sample line efficiency-ozone: Ten chambers (1/treatments) were selected to measure the ozone concentration directly in each chamber and simultaneously through the 70 foot sample line that runs to the instrument shed. Results indicate that the level of ozone actually in each chamber is extremely close to the value monitored through the 70 foot sample line (Table 8). A comparison of replicate 0% filtered chambers with ambient ozone indicated that 17-21% of the ozone was lost in the air handling system (Figure 11).

10) Aerosol mass loading experiment to determine chamber alterations: A cooperative experiment was run by T. Mischke of Dr. D. Grosjean's SAPRC Aerosol program, Dr. J. N. Pitts, Jr., Director. The results are given in Table 9.

11) Relative humidity: Monitored relative humidity readings between chambers were found to range from 0 to 7% RH (Table 10). However, the accuracy of such measurements leave much to be desired since relative humidity constantly varies during the day and is influenced by soil moisture level and the amount of transpiring biomass with the chamber.

12) Spacial temperature gradient tests within chambers: Twelve of the 20 chambers were tested for possible interior temperature gradients. Fifteen sampling points within each chamber (Figure 12) were monitored. A total

of 6 replicate readings were taken at each location. Temperatures were found to be extremely homogeneous within chambers with measured differences within 1.5°F with rare exceptions. Again, some statistical separation was possible (Table 11) but acutal differences between locations were inconsequential.

13) Temperature differences between chambers: Initial measurements of chamber temperatures indicated that a 2 to 3°F differential existed between internal and ambient temperature. This proved to be erroneous. Interior temperature measurements were subsequently found to be related to thermocouple position (shaded or unshaded), radiation shielding variations, or effectiveness of the thermocouple weld. Tables 12, 13, 14, and 15 indicate the range of fluctuation on 2 very hot days (August 14, 15) and 2 moderate days (August 27, 28). One can see from the data that chamber to chamber variation often straddles ambient day temperature. Chamber temperatures sometimes fall below ambient during the day and inevitably rise above ambient at night. Hot and cool chamber trends can be altered by moving thermocouple positions, readjusting the foil shielding, or rewelding thermocouples.

FIGURES

TABLES

Figure 1. ABSORPTION SPECTRUM FOR "TEFLON" FEP FILM

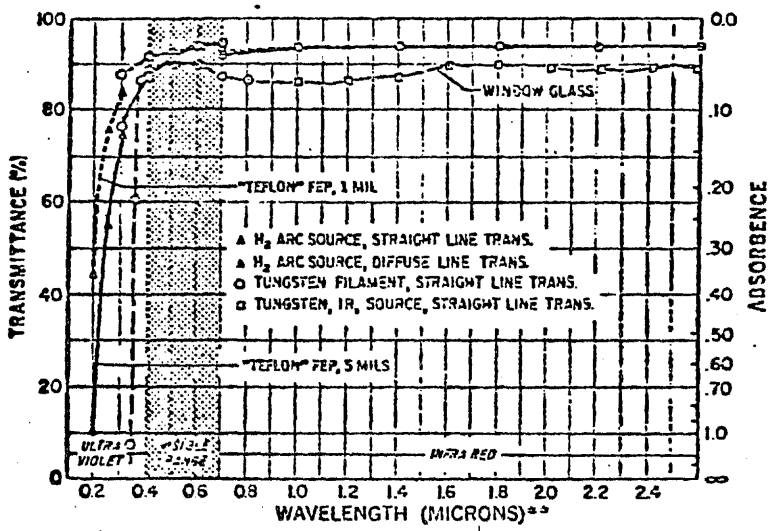
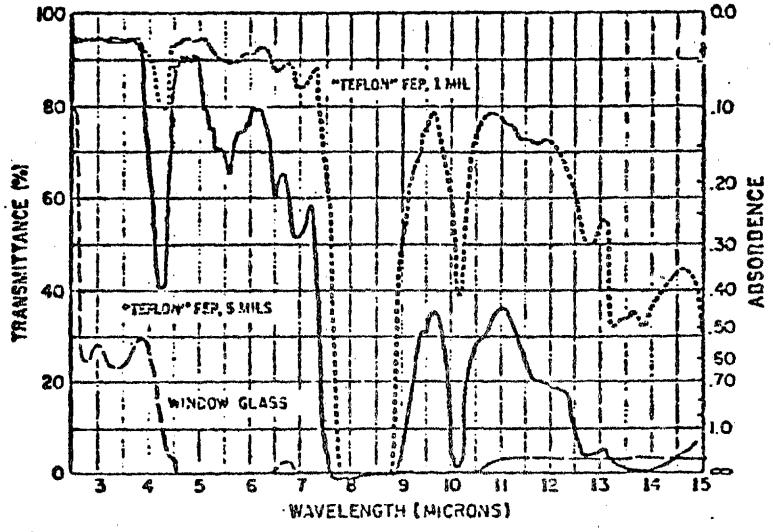


Figure 2. ABSORPTION SPECTRUM FOR "TEFLON" FEP FILM



REFRACTIVE INDEX

The refractive index of "Teflon" FEP film is between 1.341 and 1.347.

*Reg. U.S. Pat. Off.

**1 Micron = 10,000 Angstroms = 0.001 mm

Figure 3. LIGHT TRANSMISSION VS. THICKNESS—"TEFLON" FEP FILM

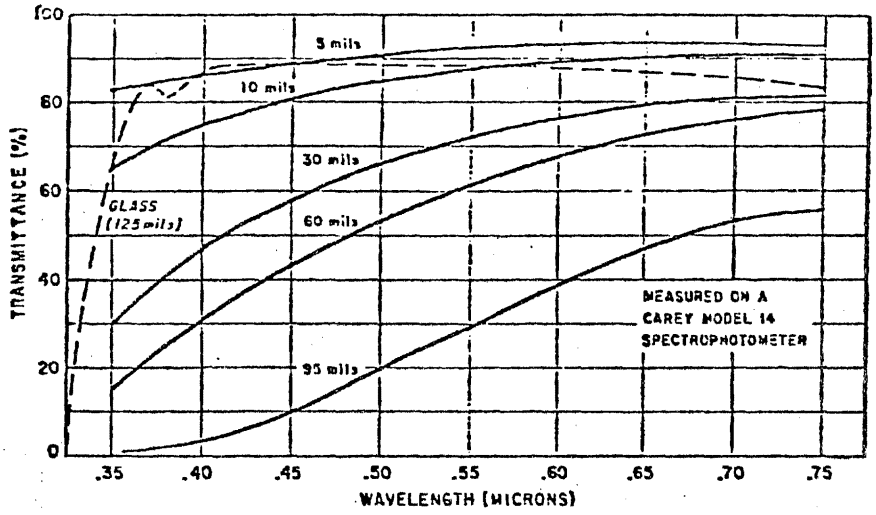


Figure 4. LIGHT TRANSMISSION VS. THICKNESS—"TEFLON" FEP FILM

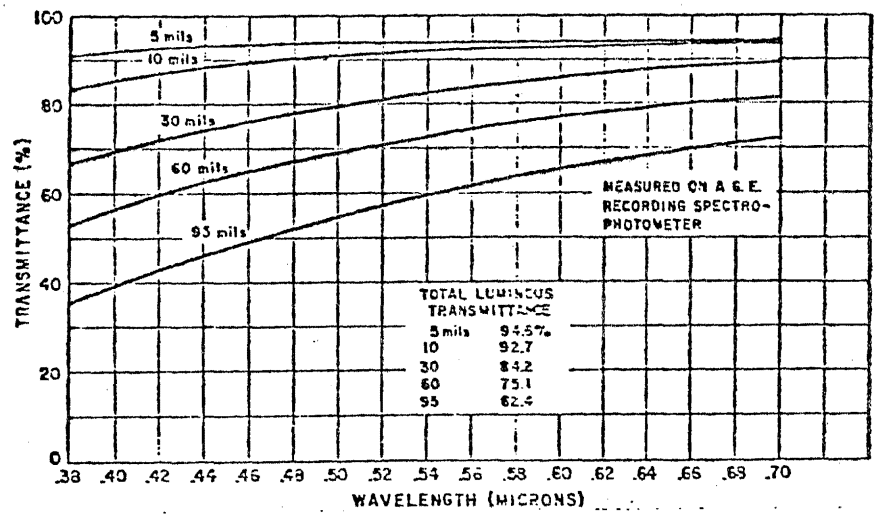


Figure 5. Comparison of PAR Curve for Chamber 3 With the Ambient Curve. Data taken August 20, 1977.

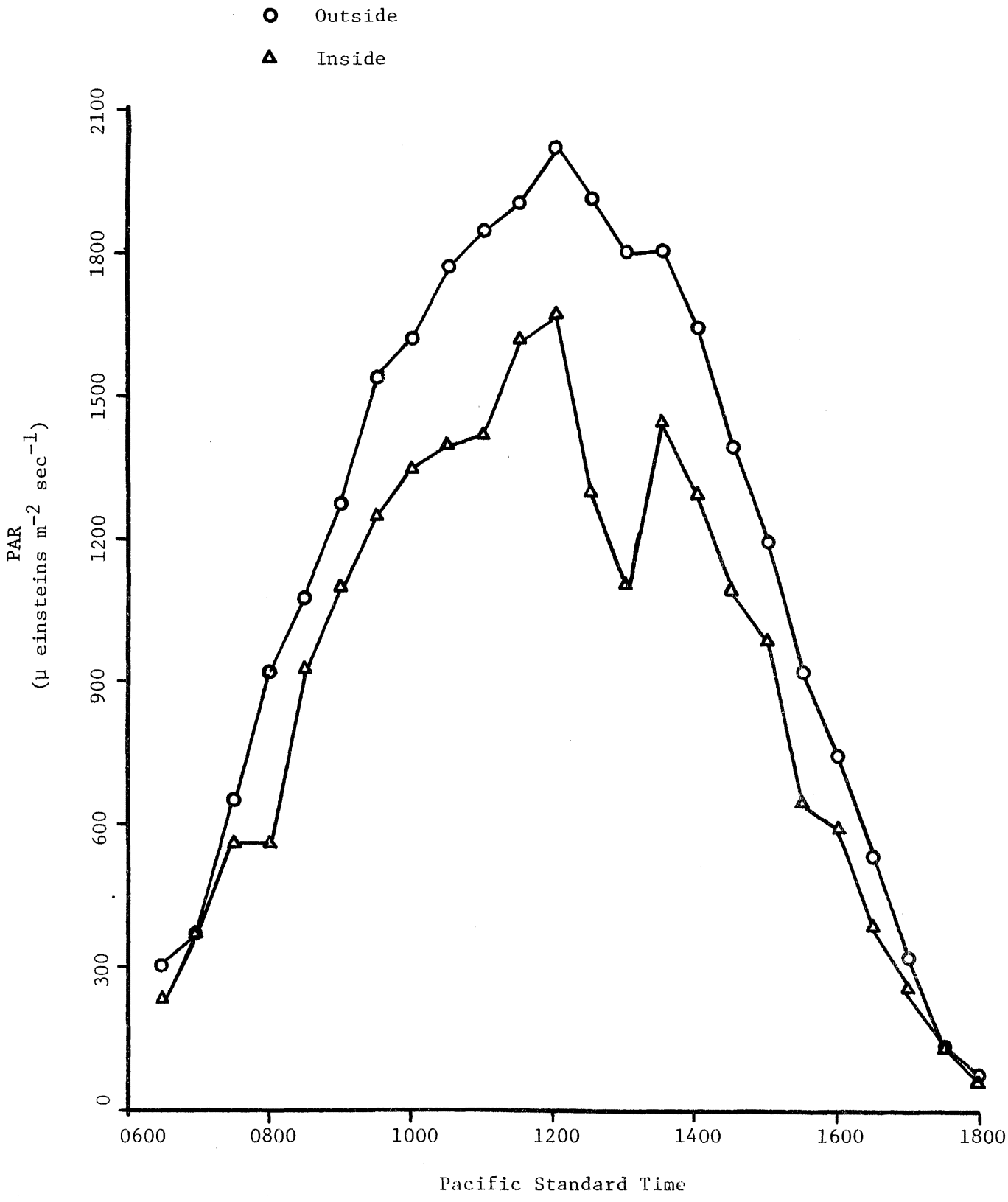


Figure 6. Comparison of PAR Curve for Chamber 3 with the Ambient Curve. Data taken August 24, 1977.

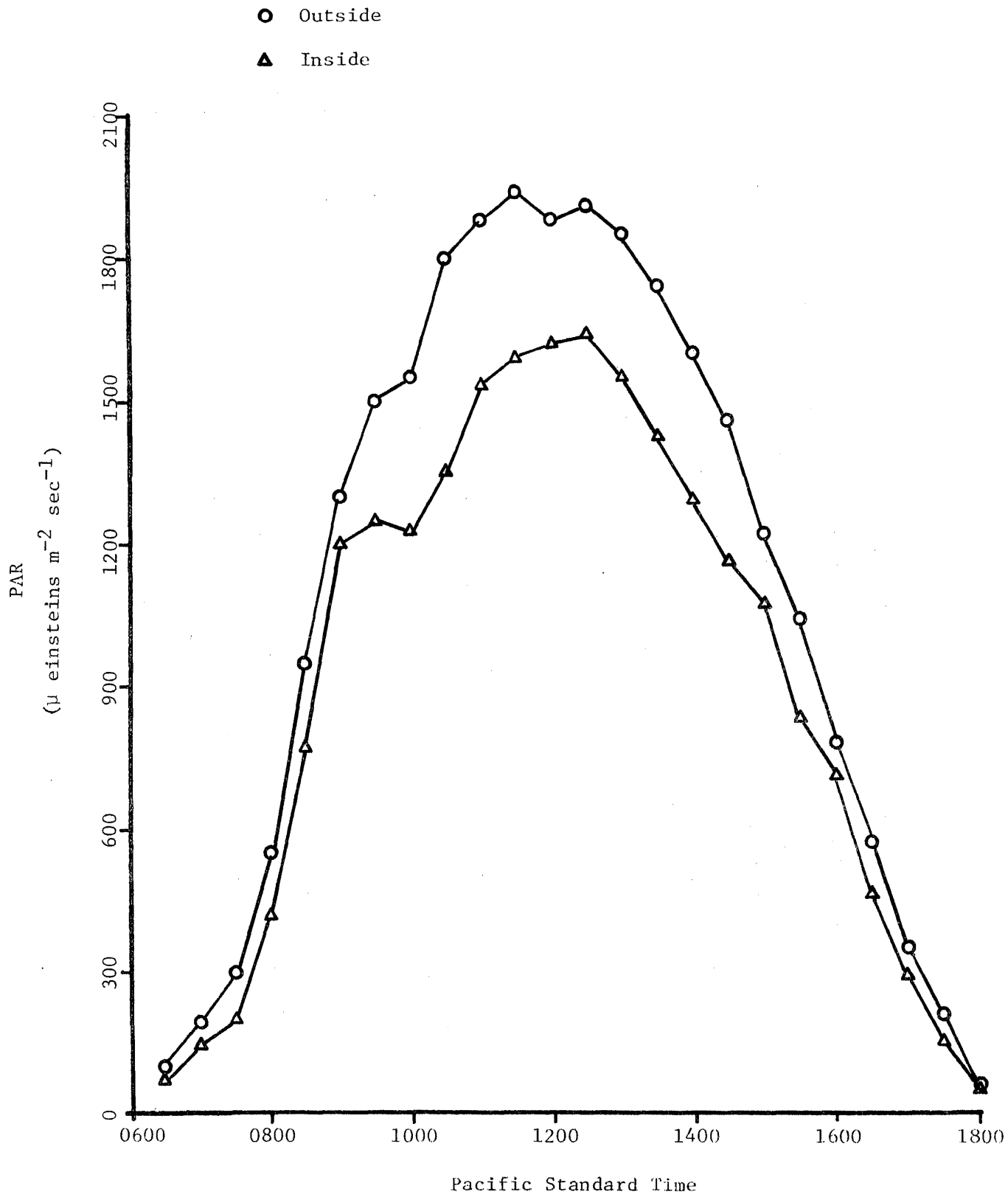


Figure 7. Comparison of PAR Curve for Chamber 3 with the Ambient Curve. Data taken August 25, 1977.

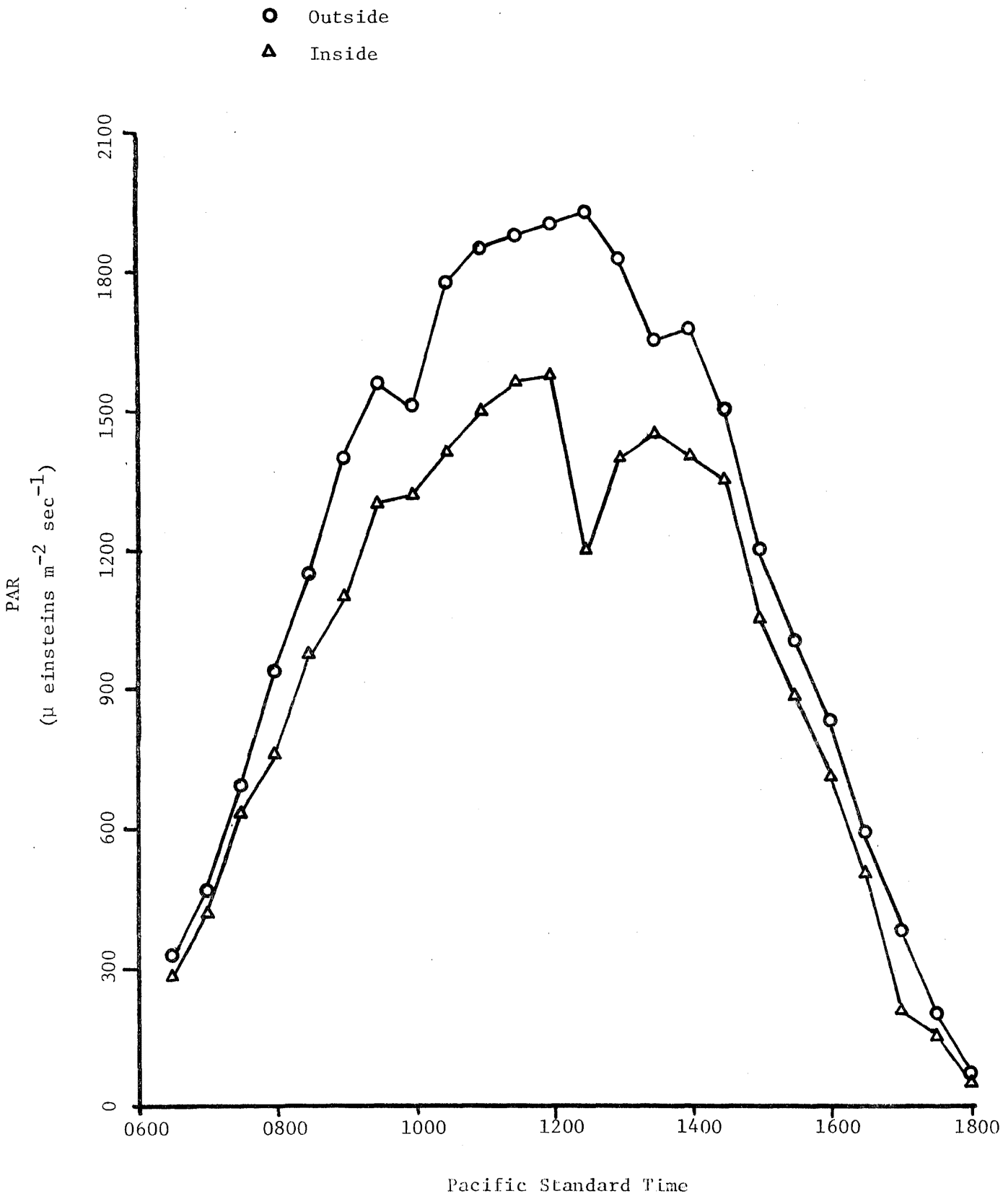


Figure 8. Comparison of PAR Curve for Chamber 3 with Ambient Curve. Data taken August 26, 1977.

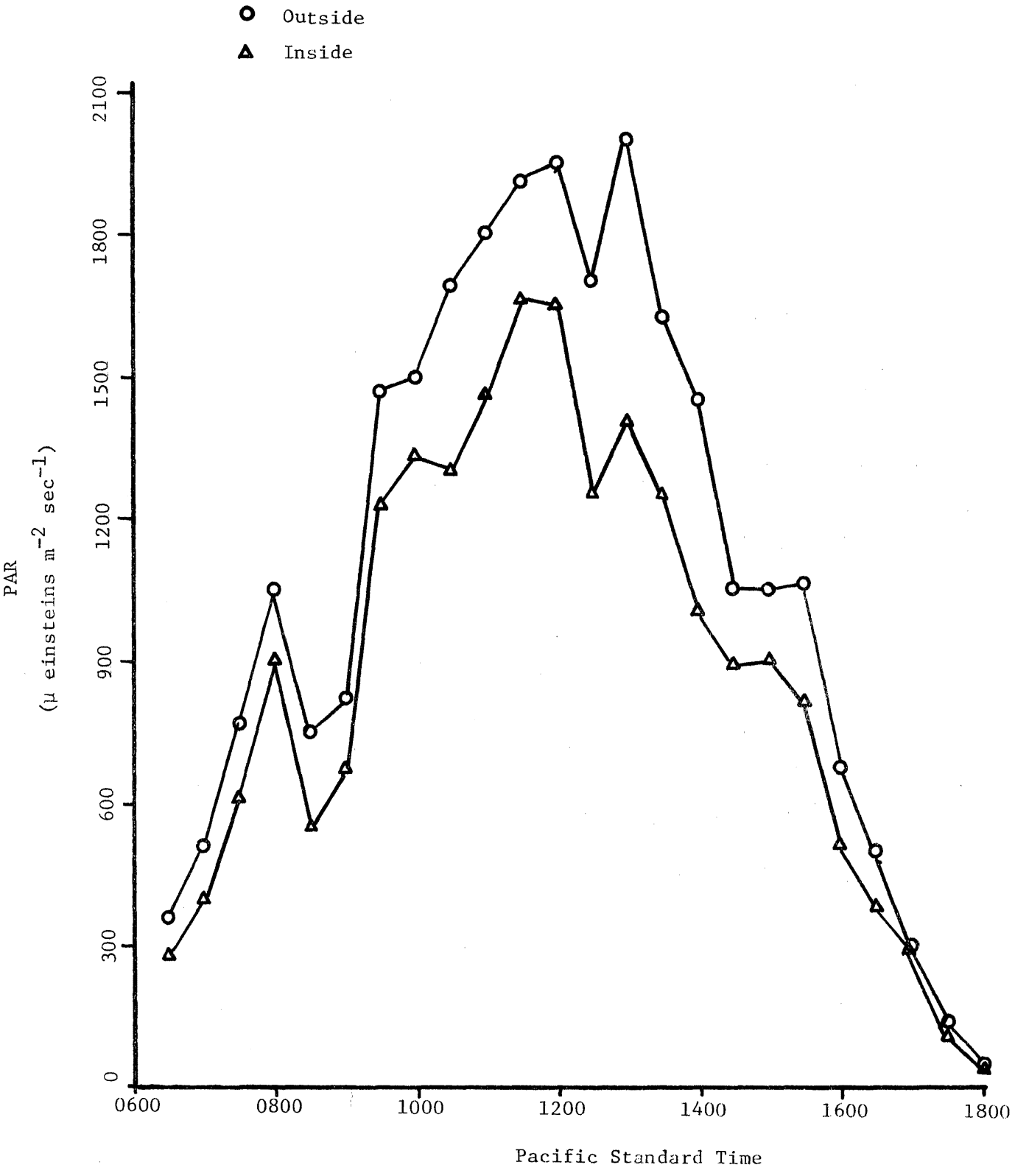


Figure 9. Comparison of PAR Curve for Chamber 3 with the Ambient Curve. Data taken September 10, 1977.

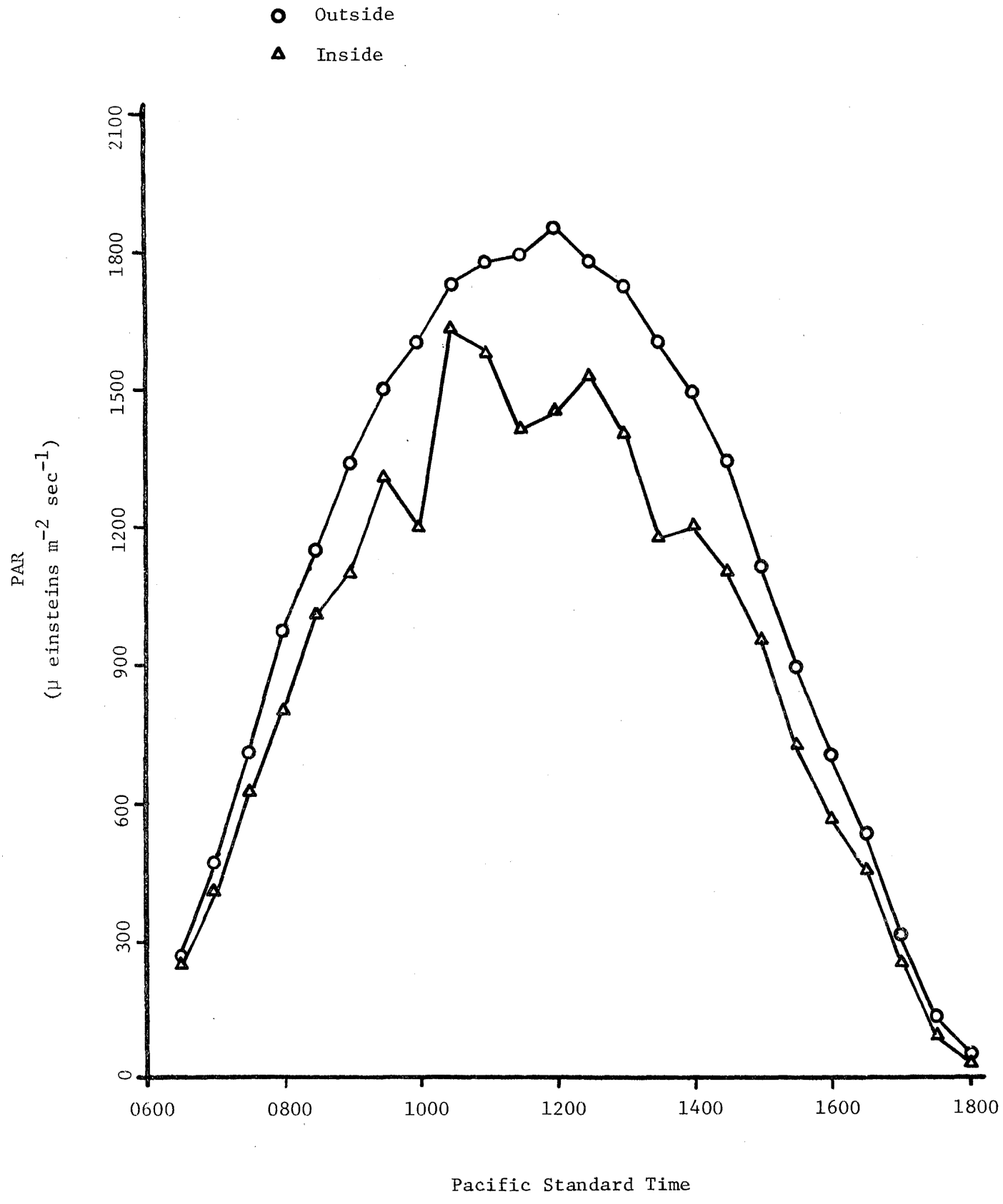


Figure 10. Sample point locations for sulfur dioxide spacial gradient test.

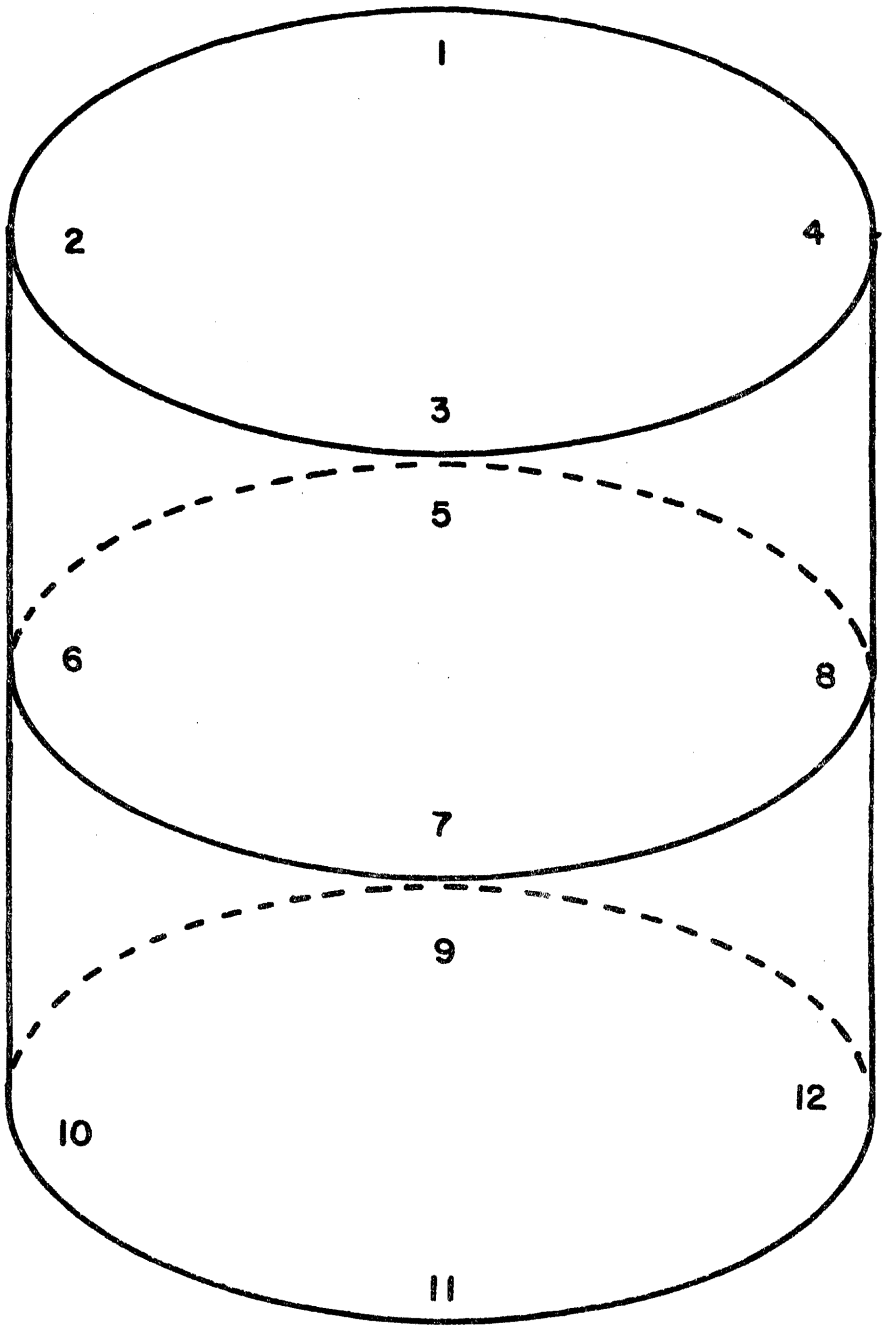


Figure 11. Comparison of ambient ozone concentration with two 0% filtered chambers.

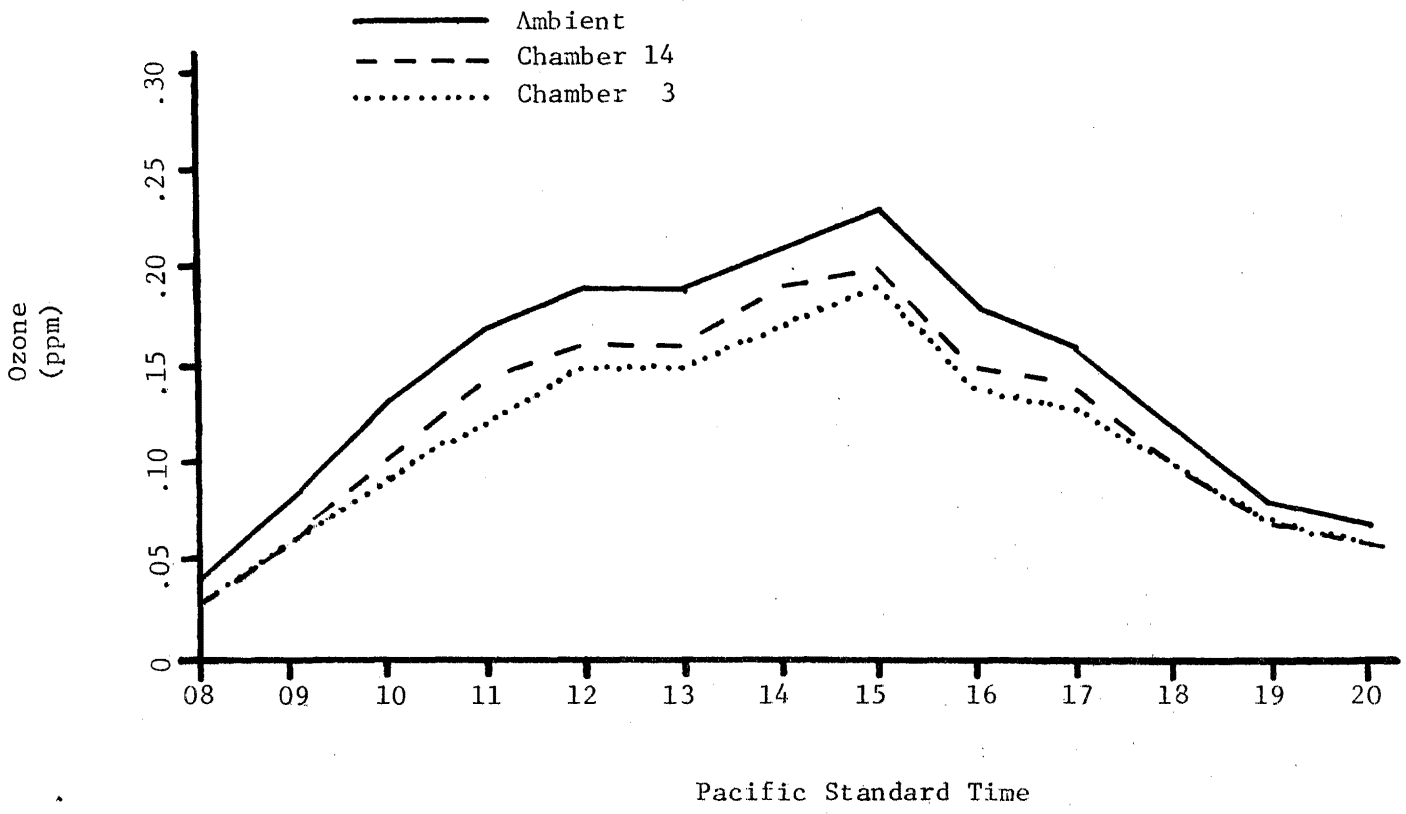


Figure 12. Sample point locations for spacial temperature gradient tests.

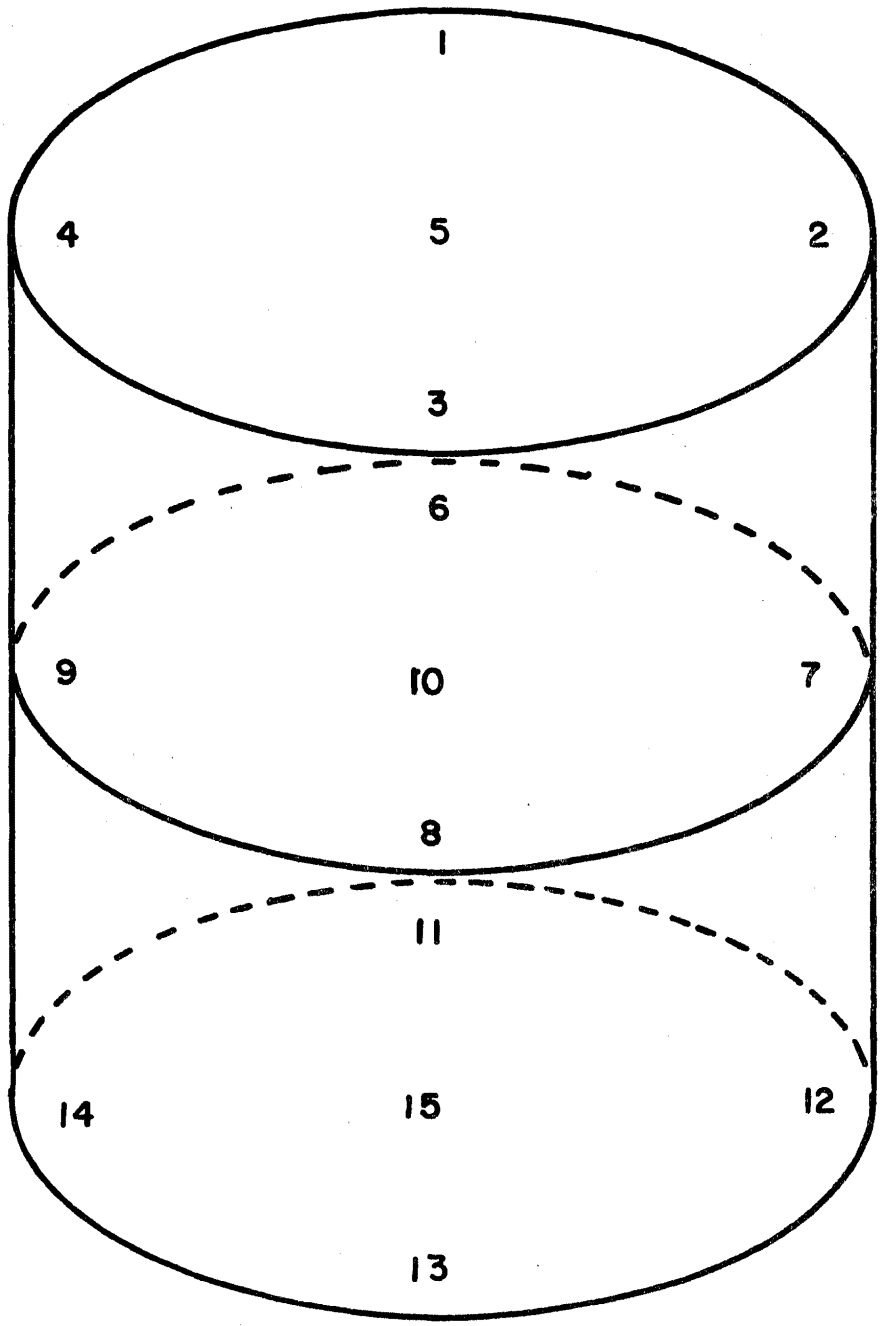


Table 1. Percent of outside PAR transmission through Chamber 3.

Date	Mean Daily Transmission (percent)
8-20-77	79.6 ± 9.4 a[1]
8-24-77	80.3 ± 6.2 a
8-25-77	81.5 ± 8.6 a
8-26-77	79.6 ± 6.7 a

[1]Entries followed by the same letter are not significantly different at the .05 level.

Table 2. Total PAR measured through four chambers at noon.

Chamber Number	PAR (μ einsteins m-2 sec -1)
4	1357 a[1]
7	1342 a
17	1252 a
14	1267 a

[1]Entries followed by the same letter are not significnatly different at the .05 level.

Table 3. Comparison of sulfur dioxide concentrations spacially within chambers.

Sample Point	SO_2 (ppm)[1]		
	Chamber 4	Chamber 6	Chamber 15
1	0.141 a[2]	0.117 a	0.102 a
2	0.141 a	0.117 a	0.102 a
3	0.141 a	0.120 a	0.101 a
4	0.141 a	0.120 a	0.101 a
5	0.139 a	0.116 a	0.101 a
6	0.137 a b	0.112 a	0.102 a
7	0.139 a	0.111 a	0.106 a
8	0.140 a	0.114 a	0.106 a
9	0.137 a b	0.114 a	0.109 a
10	0.132 c	0.111 a	0.107 a
11	0.135 b c	0.114 a	0.102 a
12	0.140 a	0.117 a	0.102 a

[1]All values are the mean of three replicates.

[2]Entries followed by the same letter are not significantly different at the .05 level.

Table 4. Sample line efficiency for sulfur dioxide.

Instrument	Sample point	SO2 (ppm) Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6
Teco I	Chamber 6	.120	.120	.125	.130	.130	.130
Teco II	Chamber 6	.120	.120	.125	.130	.130	.130
Difference[1]	---	0	0	0	0	0	0
Teco I	Chamber 6	.110	.115	.115	.120	.120	.120
Teco II	Chamber 6	.115	.115	.115	.120	.120	.125
Difference[2]	---	.005	0	0	0	0	.005

[1]Both instruments sampling the chamber directly to verify both are calibrated the same.

[2]Teco I sampling through 70 foot sample line to instrument shed; Teco II sampling directly.

Table 5. Chamber exhaust samples for sulfur dioxide.

Distance from source (feet)	SO2 (ppm)[1] Vertical	Upwind	Down wind
0	.111	.111	.111
1	.086	0	0
2	.045	0	0
3	.023	0	0
4	.006	0	0

[1]All values are the mean of 3 replications.

Table 6. Comparison of replicate chambers at moderate ozone levels.

Percent Filtered	Ozone (ppm)		SO_2 (ppm)
	Replicate 1	Replicate 2	
100	0.007[1]	0.007	0
75	0.023	0.022	0
50	0.049	0.047	0
25	0.081	0.081	0
0	0.105	0.105	0
100	0.012	0.008	0.10
75	0.033	0.031	0.10
50	0.071	0.062	0.10
25	0.103	0.099	0.10
0	0.130	0.135	0.10

[1]Values are the mean of 10 replications.

Table 7. Comparison of replicate chambers at high ozone levels.

Percent Filtered	Ozone (ppm)		SO_2 (ppm)
	Replicate 1	Replicate 2	
100	0.025[1]	0.017	0
75	0.062	0.067	0
50	0.125	0.115	0
25	0.180	0.175	0
0	0.205	0.215	0
100	0.025	0.017	0.10
75	0.070	0.060	0.10
50	0.135	0.120	0.10
25	0.170	0.180	0.10
0	0.205	0.225	0.10

[1]Values are hourly averages.

Table 8. Sample line efficiency for ozone.

% filtered	Sulfur dioxide	Ozone[1] chamber (ppm)	Ozone[2] Inst. Shed (ppm)	Difference (ppm)	Sample line efficiency (%)
0	yes	.135	.130	.005	96
25	yes	.070	.070	0	100
50	yes	.050	.050	0	100
75	yes	.030	.030	0	100
100	yes	.015	.015	0	100
0	no	.120	.120	0	100
25	no	.080	.080	0	100
50	no	.050	.050	0	100
75	no	.020	.020	0	100
100	no	.010	.010	0	100

[1]Measured at chamber.

[2]Measured after passage through 70 feet of 1/4 inch O.D. Teflon sampling line.

Table 9. Comparison of aerosol mass loading inside and outside of a chamber.

Date	Sampling Rate (SCFM)[1]	Stage Number	Sampling Time (Min)	Size Range ( )	Mass Collected (g)	TSP[2] (g/m^3)	Sample point
7-27-77	40	THV[3]	1441.5	0-00	0.1436	88.0	Chamber
7-27-77	40	THV	1440.0	0-00	0.2202	135.1	Ambient
7-29-77	40	THV	1435.3	0-00	0.1166	71.8	Chamber
7-29-77	40	THV	1440.0	0-00	0.2386	146.4	Ambient
7-31-77	40	After filter	1464.8	0-0.5	0.0491		Chamber
7-31-77	40	5	1464.8	0.5-1.0	0.0074		Chamber
7-31-77	40	4	1464.8	1.0-2.1	0.0043		Chamber
7-31-77	40	3	1464.8	2.1-3.5	0.0024		Chamber
7-31-77	40	2	1464.8	3.5-8.2	0.0018		Chamber
7-31-77	40	1	1464.8	8.2-00	0.0026		Chamber
7-31-77	40	Total	----	----	0.0676[4]		Chamber
7-31-77	40	THV	1440	0-00	0.1882	115.5	Ambient

[1]Standard cubic feet per minute.

[2]Total suspended particulates.

[3]Total Hi-Vol sampler.

[4]Total of stages is usually about 70% of THV mass.

Table 10. Comparison of chamber and ambient relative humidity.

Sample Point	% Relative Humidity		Difference (%)
	Ambient	Sample Point	
West Air Duct	68	64	4
East Air Duct	68	61	7
Chamber 13	62	62	0
Chamber 14	65	65	0

Table 11. Comparison of spacial temperatures within chambers.

Sample Point	Temperature (°F)/Chamber Number					
	1	3	6	11	16	20
1	96.2 a[1]	101.0 d	105.5 abc	99.2 a	102.0 a	97.7 a
2	96.3 a	101.2 bc	105.7 ab	99.3 a	102.3 a	97.7 a
3	96.5 a	101.5 c	105.8 a	99.3 a	102.5 a	97.5 a
4	96.7 a	102.2 ab	105.8 a	99.3 a	102.7 a	97.5 a
5	96.3 a	101.7 bc	105.7 ab	99.3 a	102.2 a	97.2 a
6	96.3 a	102.0 abc	105.2 bcd	98.2 a	101.0 a	96.7 a
7	96.3 a	102.0 abc	105.3 abcd	98.0 a	101.0 a	96.5 a
8	96.2 a	102.0 abc	105.5 abc	98.2 a	101.0 a	96.5 a
9	96.2 a	102.5 a	105.5 abc	98.3 a	101.2 a	96.7 a
10	96.2 a	101.8 bc	105.3 abcd	98.3 a	101.3 a	96.5 a
11	96.8 a	102.2 ab	105.0 cd	98.5 a	101.3 a	96.3 a
12	96.7 a	102.0 abc	105.0 cd	97.8 a	101.2 a	96.3 a
13	96.3 a	102.2 ab	104.8 d	97.8 a	101.8 a	96.3 a
14	96.2 a	102.5 a	105.0 cd	97.8 a	102.2 a	96.8 a
15	96.2 a	102.2 ab	105.0 cd	97.3 a	102.2 a	96.3 a

[1]Entries followed by the same letter are not significantly different at the .05 level.

Table 12. Chamber temperature data for August 14, 1977.

CHAMBER NUMBER	Clock Hour (PST)																								Daily Peak	
	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Temp	Time
1	70	69	68	67	67	65	72	78	85	91	96	99	103	104	103	101	101	96	89	82	79	77	75	74		
2	70	69	68	67	67	65	71	76	81	86	91	94	98	99	100	100	98	96	89	82	79	77	75	74		
3	70	69	68	67	67	65	72	78	84	90	96	100	101	104	103	102	101	96	89	82	79	77	75	74		
4	70	69	68	67	67	65	71	77	84	87	94	98	101	104	105	102	101	96	89	82	79	77	75	74		
5	70	69	68	67	67	65	72	78	84	90	96	99	101	105	105	103	101	96	89	82	79	77	75	74		
6	70	69	68	67	67	65	72	78	84	90	96	99	101	104	105	104	101	96	89	82	79	77	75	74		
7	70	69	68	67	67	65	73	79	88	94	97	100	104	105	105	103	101	96	89	82	79	77	75	74		
8	70	69	68	67	67	65	70	76	83	88	94	99	102	104	104	104	100	96	89	82	79	77	75	74		
9	70	69	68	67	67	66	72	79	87	91	99	103	106	107	106	103	101	96	89	82	79	77	75	74		
10	70	69	68	67	67	65	72	77	85	91	97	101	105	106	105	102	101	96	89	82	79	77	75	74		
11	70	69	68	67	67	65	72	77	84	91	91	100	103	103	104	99	101	96	89	82	79	77	75	74		
12	70	69	68	67	67	66	72	77	86	87	95	94	97	100	100	99	97	96	89	82	79	77	75	74		
13	70	69	68	67	67	66	76	79	88	89	95	99	101	104	104	103	101	96	89	82	79	77	75	74		
14	70	69	68	67	67	65	74	79	85	91	95	99	102	101	100	99	97	96	89	82	79	77	75	74		
15	70	69	68	67	67	65	73	81	85	91	95	100	102	104	105	104	101	96	89	82	79	77	75	74		
16	70	69	68	67	67	65	76	79	85	91	95	98	102	102	102	102	101	96	89	82	79	77	75	74		
17	70	69	68	67	67	65	73	76	84	91	95	101	104	105	105	104	101	96	89	82	79	77	75	74		
18	70	69	68	67	67	65	70	81	82	91	95	99	103	105	105	104	101	96	89	82	79	77	75	74		
19	70	69	68	67	67	65	72	77	87	93	99	103	108	107	105	104	101	96	89	82	79	77	75	74		
20	70	69	68	67	67	65	71	77	82	89	94	99	103	105	105	104	101	96	89	82	79	77	75	74		
AMBIENT	67	66	65	65	64	63	71	79	86	93	100	103	106	105	104	103	101	96	89	82	79	74	71	72		
22																										
23																										
24																										
25																										
26																										
27																										
28																										
29																										
30																										
31																										

Table 13. Chamber temperature data for August 15, 1977.

AMBER MBER	Clock Hour (PST)																								Daily Peak	
	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Temp	Tim
1	72	72	71	70	71	71	77	85	90	97	103	104	107	96	105	105	98	94	87	85	84	82	81	82		
2	72	72	71	70	71	71	77	82	88	93	99	101	104	96	102	103	98	94	87	85	84	82	81	82		
3	72	72	71	70	71	71	77	84	90	96	103	105	107	96	105	105	98	94	87	85	84	82	81	82		
4	72	72	71	70	71	71	77	83	89	95	101	105	107	96	105	105	98	94	87	85	84	82	81	82		
5	72	72	71	70	71	71	77	83	90	96	103	106	107	96	106	107	98	94	87	85	84	82	81	82		
6	72	72	71	70	71	71	77	83	90	97	103	106	107	96	104	105	98	94	87	85	84	82	81	82		
7	72	72	71	70	71	71	77	83	94	100	105	107	108	96	106	107	98	94	87	85	84	82	81	82		
8	72	72	71	70	71	71	77	83	89	96	102	106	107	96	105	105	98	94	87	85	84	82	81	82		
9	72	72	71	70	71	71	77	85	93	99	106	111	109	96	108	107	98	94	87	85	84	82	81	82		
10	72	72	71	70	71	71	77	84	91	99	104	109	108	96	107	106	98	94	87	85	84	82	81	82		
11	72	72	71	70	71	71	77	84	90	97	103	106	104	96	104	104	98	94	87	85	84	82	81	82		
12	72	72	71	70	71	71	77	82	87	92	97	100	101	96	101	102	95	94	87	85	84	82	81	82		
13	72	72	71	70	71	71	77	85	93	97	102	106	105	96	105	105	96	94	87	85	84	82	81	82		
14	72	72	71	70	71	71	77	85	90	97	101	104	104	96	102	103	95	94	87	85	84	82	81	82		
15	72	72	71	70	71	71	80	84	91	95	101	107	106	96	106	105	96	94	87	85	84	82	81	82		
16	72	72	71	70	71	71	80	87	92	97	102	105	105	96	105	105	98	94	87	85	84	82	81	82		
17	72	72	71	70	71	71	77	85	90	97	102	109	107	96	107	106	98	94	87	85	84	82	81	82		
18	72	72	71	70	71	71	77	83	89	97	102	105	106	96	107	106	98	94	87	85	84	82	81	82		
19	72	72	71	70	71	71	77	88	94	100	106	111	111	96	107	107	98	94	87	85	84	82	81	82		
20	72	72	71	70	71	71	77	83	88	96	98	105	106	96	105	105	96	94	87	85	84	82	81	82		
AMBIENT	69	69	68	68	69	70	78	85	96	103	108	109	109	94	103	102	92	90	84	83	84	79	81	82		
22																										
23																										
24																										
25																										
26																										
27																										
28																										
29																										
30																										
31																										

Table 14. Chamber temperature data for August 27, 1977.

CHAMBER NUMBER	Clock Hour (PST)																							Daily	Pea
	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Temp	T
1	68	67	67	68	67	67	67	70	75	85	88	89	90	93	93	91	87	81	76	73	71	70	69	68		
2	68	67	67	68	67	67	67	70	76	80	83	84	87	88	89	88	85	81	76	73	71	70	69	68		
3	68	67	67	68	67	67	67	70	77	83	87	89	91	92	93	90	87	81	76	73	71	70	69	65		
4	68	67	67	68	67	67	67	70	78	80	84	87	86	88	89	87	85	81	76	73	71	70	69	68		
5	68	67	67	68	67	67	67	70	76	82	86	86	90	90	92	89	87	81	76	73	71	70	69	68		
6	68	67	67	68	67	67	67	70	75	81	87	86	88	91	91	89	87	81	76	73	71	70	69	68		
7	68	67	67	68	67	67	67	70	74	85	85	87	90	89	91	89	87	81	76	73	71	70	69	68		
8	68	67	67	68	67	67	67	70	77	79	87	85	88	93	91	89	87	81	76	73	71	70	69	68		
9	68	67	67	68	67	67	67	70	76	84	86	88	90	91	92	89	87	81	76	73	71	70	69	68		
10	68	67	67	68	67	67	67	70	75	82	85	88	90	90	91	89	87	81	76	73	71	70	69	68		
11	68	67	67	68	67	67	67	70	75	80	82	86	87	88	91	89	87	81	76	73	71	70	69	68		
12	68	67	67	68	67	67	67	70	76	79	86	84	87	91	88	89	87	81	76	73	71	70	69	68		
13	68	67	67	68	67	67	67	70	78	84	88	87	88	95	91	89	87	81	76	73	71	70	69	68		
14	68	67	67	68	67	67	67	70	75	89	84	90	91	90	93	89	87	81	76	73	71	70	69	68		90
15	68	67	67	68	67	67	67	70	76	81	85	85	88	91	91	89	87	81	76	73	71	70	69	68		
16	68	67	67	68	67	67	67	70	75	83	86	86	89	92	90	89	87	81	76	73	71	70	69	68		
17	68	67	67	68	67	67	67	70	75	82	85	86	90	92	92	89	87	81	76	73	71	70	69	68		
18	68	67	67	68	67	67	67	70	78	82	85	88	91	93	92	89	87	81	76	73	71	70	69	68		
19	68	67	67	68	67	67	67	70	78	86	89	91	92	89	93	91	87	81	76	73	71	70	69	68		
20	68	67	67	68	67	67	67	70	74	79	82	84	88	90	89	89	85	80	76	73	71	70	69	68		
AMBIENT	66	66	66	66	66	66	66	68	75	80	86	84	90	91	88	87	84	78	74	71	69	68	67	65		
22																										
23																										
24																										
25																										
26																										
27																										
28																										
29																										
30																										
31																										

Table 15. Chamber temperature data for August 28, 1977.

CHAMBER NUMBER	Clock Hour (PST)																								Daily Peak	
	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Temp	Time
1	67	66	66	65	64	64	65	68	77	83	88	90	93	95	96	95	92	87	81	77	75	73	71	70		
2	67	66	66	65	64	64	65	68	74	79	83	85	90	90	93	91	89	86	81	77	75	73	71	70		
3	67	66	66	65	64	64	65	68	76	82	84	90	93	95	97	95	92	87	81	77	75	73	71	70		
4	67	66	66	65	64	64	65	68	74	78	87	86	89	90	93	91	89	86	81	77	75	73	71	70		
5	67	66	66	65	64	64	65	68	74	80	85	87	93	94	95	94	92	87	81	77	75	73	71	70		
6	67	66	66	65	64	64	65	68	74	79	89	87	91	93	95	94	92	87	81	77	75	73	71	70		
7	67	66	66	65	64	64	65	68	78	84	84	90	92	94	95	94	92	87	81	77	75	73	71	70		
8	67	66	66	65	64	64	65	68	73	88	87	87	91	92	94	94	92	87	81	77	75	73	71	70		
9	67	66	66	65	64	64	65	68	77	82	87	91	94	95	96	94	92	87	81	77	75	73	71	70		
10	67	66	66	65	64	64	65	68	75	81	87	91	93	94	96	94	92	87	81	77	75	73	71	70		
11	67	66	66	65	64	64	65	68	77	82	86	90	92	93	94	94	92	87	81	77	75	73	71	70		
12	67	66	66	65	64	64	65	68	73	78	82	85	89	91	92	91	89	87	81	77	75	73	71	70		
13	67	66	66	65	64	64	65	68	80	83	87	89	91	92	94	94	92	87	81	77	75	73	71	70		
14	67	66	66	65	64	64	65	68	82	88	89	93	94	98	97	94	92	87	81	77	75	73	71	70		
15	67	66	66	65	64	64	65	68	75	80	85	88	91	92	93	93	92	87	81	77	75	73	71	70		
16	67	66	66	65	64	64	65	68	78	82	85	87	93	94	95	94	92	87	81	77	75	73	71	70		
17	67	66	66	65	64	64	65	68	75	81	86	89	93	94	96	94	92	87	81	77	75	73	71	70		
18	67	66	66	65	64	64	65	68	75	81	87	88	93	96	96	94	92	87	81	77	75	73	71	70		
19	67	66	66	65	64	64	65	68	78	85	91	94	96	98	95	94	92	87	81	77	75	73	71	70		
20	67	66	66	65	64	64	65	68	73	78	83	86	90	92	93	94	92	87	81	77	75	73	71	70		
AMBIENT	65	64	63	63	62	61	64	66	75	80	85	86	93	93	93	92	90	86	80	76	73	72	70	68		
22																										
23																										
24																										
25																										
26																										
27																										
28																										
29																										
30																										
31																										