WIND TUNNEL STUDY OF STACK GAS DISPERSAL AT HARRINGTON POWER STATION PART II: Unit III

by

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ABSTRACT

Tests were conducted in the Colorado State University Environmental Wind Tunnel facility, to study the gaseous plumes released from stacks associated with the Harrington Power Station of the Southwestern Public Service Company. The tests were conducted as a supplement to an earlier study. The effects of an additional stack and buildings associated with a third unit were observed.

The tests were conducted over a model power plant to a scale of 1/250 which included all significant structures, topography, and roughness elements in the vicinity. Effects of wind orientation were established. Data obtained included photographs and color motion pictures of smoke plume trajectories and contaminant concentration downwind of the power plant at ground level sampling positions.

ACKNOWLEDGMENTS

The support of Southwestern Public Service Company in carrying out this study is gratefully acknowledged. Construction of the building model was accomplished by personnel of the Engineering Research Center Machine Shop. Mr. James A. Garrison supervised motion picture and photographic records of flow visualization. Mr. James Maxton supervised operation of concentration measuring equipment. Mr. Robert Hatcher and Mr. Ronald Petersen were responsible for concentration and visualization measurements.

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LIST OF SYMBOLS

Symbol	Definition	
D	Stack diameter	(L)
Fr	Froude number $\frac{V^2}{g\frac{\Delta\rho}{\rho_a}D}$	(-)
g	Gravitational constant	(L/T^2)
H	Stack height	(L)
ΔH	Plume rise	(L)
Q	Source strength	(M/T)
R	Exhaust velocity ratio V_s/V_a	(-)
T	Temperature	(θ)
V	Mean velocity	(L/T)
x,y,z	General coordinates--downwind, lateral, upwind	(L)
z_o	Surface roughness parameter	(L)

Greek symbols

χ	Local concentration	$(M/L^3$ or ppm)
ρ	Density	(M/L^3)

Subscripts

a	Free stream
s	Stack
m	Model
p	Prototype
max	Maximum

1.0 INTRODUCTION

A wind tunnel study of the Harrington Power Station, Southwestern Public Service Company (SWPSC), near Amarillo, Texas, was performed in April 1976 (Meroney and Cermak, 1976) to determine the optimum stack height which would eliminate plume downwash and reduce the concentration of sulfur dioxide at ground level such that the plant can meet state and federal ambient air quality standards, for Units I and II.

The purpose of this study is to determine the behavior of plumes created by gases discharged by the existing Unit I stack and the two proposed stacks Units II and III. Since the previous wind tunnel study was made for emissions from Units I and II only, the concentrations caused by emissions from Unit III constitute an entirely new set of measurements.

The general scope includes determination of how plume behavior is affected by the existence of Unit III for a wide range of wind directions, holding the wind speed and percent load constant.

The modeling criteria necessary to simulate atmospheric motions over such a site are discussed in the earlier report (Meroney and Cermak, 1976) which will hereafter be referred to as Report 1. Details of the model construction and the experimental equipment along with complete references are also described in Report 1.

The test apparatus is discussed in section 2. Sections 3, 4 and 5 discuss the results obtained for Units I, II, and III, respectively, and their significance.

This report is supplemented by a motion picture (in color) which shows the plume behavior for all stacks for all operating levels, wind directions and meteorological conditions investigated during the course of this study. A set of black-and-white photographs and color slides of each plume visualization further supplements the material presented in this report.

2.0 TEST APPARATUS

2.1 Wind Tunnel

The Environmental Wind Tunnel (EWT), Fig. 2.1, was used for this study. The EWT incorporates a test section 12 ft wide and 57 ft long with a flexible ceiling which can be raised from 7 to 9 ft high to insure a zero longitudinal pressure gradient. A mean velocity of 1 to 60 ft/sec (0.68 to 41 mi/hr) can be obtained with a turbulence level of about one percent. This tunnel was employed because of the wider model and corresponding wider test section in the EWT.

Vortex generators were installed at the tunnel entrance together with an initial roughness to accelerate the preliminary growth of the modeled boundary layer.

The Harrington Power Station model (see section 2.2) was constructed to represent a swath 1000 ft centered on the wind orientation chosen. The floor of the tunnel was equipped with 23 taps arranged in sampling arrays to measure ground level concentrations (see Fig. 2.3).

2.2 Model

The model consisted of the power station, the stacks, and the auxiliary buildings constructed from lucite to a linear scale of 1:250 (see Fig. 2-2).

A model was built to a 1:250 scale from drawings supplied by SWPSC. A 250 ft high 27 ft diameter stack was used for Unit I in this study. For Units II and III models of 300 ft high 19.2 ft diameter stacks were used. All connections to the stacks were made by the addition of fittings at the base of each stack.

2.3 Gas Tracer Techniques

Metered quantities of gas were allowed to flow from each stack to simulate the exit velocity and also account for buoyancy effects due to the temperature difference between the stack gas and the ambient atmosphere. Helium and compressed air were mixed in metered amounts to adjust the specific weight as proposed in section 2. Fischer-Porter flow rator settings were adjusted for pressure, temperature, and molecular weight effects as necessary. When a visible plume was required the gas was bubbled through titanium tetrachloride before emission. When a traceable plume was required a high pressure mixture of propane, helium and air was used in place of the compressed air. The concentrations of the tracer gas (propane) were measured using gas chromotography techniques. Flow visualization and gas tracer techniques were identical to the original study as was the data analysis.

2.4 Error in Concentration Measurements

The cumulative confidence in the measured values of concentration, as determined in Report 1, was found to be ± 11% and under the worst cumulative scenario no more than ± 20%. These error values did not change for this series of tests.

However, these tests were performed in the Environmental Wind Tunnel (EWT) whereas the first tests (Report 1) were carried out in the Meteorological Wind Tunnel (MWT). Because each tunnel has slightly different physical characteristics and the model blockage was reduced in the EWT the two sets of data may show some differences. To test the reproducibility of similar data collected in two different tunnels, select test conditions from Report 1 were re-run in the EWT. Table 2-1 shows the maximum concentrations for the corresponding runs and the percent deviation from a mean value. As can be seen the mean percent deviation is 41%. This deviation is believed to result from two effects. First the ground-level concentration distribution is exponential and a finite sampling grid was employed. Small changes in the location of the maximum impact may result in large changes in the measured maximum concentration.

In addition, the model blockage varied between the two tunnels. The blockage associated with Unit I and II in the MWT was 4.2% overall or 13% in the bottom 1/3 of the tunnel. The blockage associated with Units I, II in the EWT was 1.6% overall or 6.3% in the bottom 1/3 of the tunnel. For some wind approach angles the model as placed in the MWT appeared as a fence to the approach flow permitting full passage at ground level only to one side of the complex. It is believed that this resulted is skewed ground concentration profiles and a portion of the noted deviation between the two wind tunnel experiments.

3.0 TEST PROGRAM AND RESULTS: UNIT I

3.1 Test Program

The test program consisted of (1) a qualitative study of the flow field around the power plant by visual observation of the smoke plume trajectory released from the stacks; and (2) a quantitative study of gas concentrations produced by the release of a propane tracer from the stacks. The model and prototype test conditions are summarized in Table 3-1. Angular locations of the approach winds are referred to in terms of angles from a nominal north. Downwind distances refer to lengths as measured from the center of the complex as marked in Fig. 2-3. Unless otherwise noted, the term wind velocity refers to the velocity in the undisturbed free stream at an equivalent height of 250 feet; however, a velocity at any reference height is available by referring to the velocity profiles (Fig. 2-4).

3.2 Test Results: Characteristics of Flow

All the experiments were carried out in the EWT over the range of conditions shown in Table 3-1. The atmospheric boundary layer was modeled to produce a velocity profile equivalent to flow typical of irregular terrain. Figure 2-4 shows the development of the velocity profile over the model for a neutral situation. No comparison of model velocity data with that in the prototype is possible because the latter is not available over a range of height. However, as the model velocity profiles were carefully produced over roughness tailored to reflect the characteristics of the site, it is expected that the prototype flow is adequately represented in the model. The power law exponent for the upstream velocity profile was 0.19.

3.3 Test Results: Visualization

The test results consist of photographs and movies showing the general nature of airflow and diffusion in the vicinity of the power station (Figs. 3-1 to 3-2). A general understanding of wake and cavity flows is necessary for an interpretation of the plume behavior (see Halitsky, 1963).

Entrainment, as utilized herein, will be understood as the presence of any of the gas released from the stack in the power station cavity. A small amount of entrainment usually first occurs under conditions where the gas plume follows the cavity separation streamline to the downstream cavity stagnation point from which it diffuses upstream into the cavity proper. Downwash will be understood as severe entrainments where the plume does not penetrate the separation streamline but rather ventilates directly into the cavity region. A decrease in load from full to one-half has the same effect on the plume behavior as an increase in wind speed. In general lower load aggravates plume behavior; however, one must consider the reduced pollutant burden in any assessment of the net significance.

The sequence of photographs shown in Figs. 3-1 and 3-2 show side views of the behavior of a smoke plume released from Unit 1 for 50 percent load at 30 mph for the cardinal wind directions (i.e., N, NE, E, etc.). Observations of plume behavior suggest that SE and SW wind approach angles develop flow fields about the plant buildings which encourage plume downwash. These orientations of the wind to the plant offer the greatest effective building width and consequently greatest cavity length and width. Additionally the stack is located in the cavity region for these orientations. As a result of the insuing low pressure region, the plume from Unit I is swept to the surface very near the plant.

The observed "touchdown" distances evaluated from the flow visualization tests are summarized in Table 3-2. Touchdown is defined during observation as that point where the plume encounters the ground more than 10 percent of the time. Such an interpretation is necessarily qualitative but different observers do not vary by more than 500 ft. Smoke photographs tend to confirm the initial opinion. Complete sets of still photographs supplement this report. Color motion pictures have been arranged into titled sequences and the sets available are summarized in Table 3-2.

3.4 Test Results: Concentration Measurements

Turbulent diffusion of gaseous effluent released for one stack height was studied. Propane concentrations at ground level were measured at prototype distances from 915 ft. to 5355 ft downwind.

Twenty-three samples were taken over the model distributed at ground level over the topography in the matrix shown in Fig. 2-3. The stack for Unit I was sometimes displaced to the right or left of the concentration grid centerline, the zero coordinate rests due west of Unit I stack centered between Units I and II boilers. All concentration data have been converted to the prototype scale levels as explained in section 3.5.1 of the original report. The data is recorded herein in dimensional form as $\chi(\mu g/m^3)$ and $\chi V_a/Q$ where χ is the concentration over the assumed equivalent averaging time for laboratory measurements, Q is the source strength, and V_a is the mean wind velocity at stack height (250 ft). The source flow rate and thermal conditions assumed for each stack and load condition are summarized in Table 3-1. Data in Table 3-1 were provided by SWPSC.

The results for various loads, wind directions, and a 30 mph wind velocity are presented in Table 3-4. Sample positions shown in the tables are located on the definition sketch (Fig. 2-3). The maximum concentration measured and its respective downwind location for each situation has been gathered together in Table 3-3.

A series of figures have been prepared from the bulk data to enable some general conclusions to be made concerning the background SO_2 concentrations from Unit I. Figure 3-3 shows the maximum ground level SO_2 concentration ($\mu g/m^3$) versus distance from the center of the plant site for the two wind directions of highest impact. The maximum ground level concentrations were 994 $\mu g/m^3$ at 915 ft for the SE wind direction and 832 $\mu g/m^3$ at 915 ft for the SW wind direction. The plume visualizations showed these directions to have the closest touchdown and most noticeable downwash.

Figures 3-4 through 3-7 show the ground level isopleth patterns of SO_2 concentration for the eight cardinal wind directions. The figures show the expected tendency for the maximum concentration to occur near the center of the sampling grid and also the fairly uniform concentration distribution. The isopleth pattern for the SW and SE wind directions indicates that the maximum concentration was within 915 ft from the center of the plant. A building wake influence was shown by all of the isopleth patterns, but was a minimum for the NE and E wind directions.

4.0 TEST PROGRAM AND RESULTS: UNIT II

4.1 Test Program

The test program consists of (1) a qualitative study of the flow field around the power plant by visual observation of the smoke plume trajectory released from the stacks, and (2) a quantitative study of gas concentrations produced by the release of a propane tracer from the stacks. The model and prototype test conditions are summarized in Table 4-1. Angular locations of the approach winds are referred to in terms of angles from a nominal north. Downwind distances refer to lengths as measured from the center of the complex as marked in Fig. 2-3. Unless otherwise noted, the term wind velocity refers to the velocity in the undisturbed free stream at an equivalent height of 250 feet; however, a velocity at any reference height is available by referring to the velocity profiles (Fig. 2-4).

4.2 Test Results: Characteristics of Flow

All the experiments were carried out in the EWT over the range of conditions shown in Table 4-1. The atmospheric boundary layer was modeled to produce a velocity profile equivalent to flow typical of irregular terrain. Figure 2-4 shows the development of the velocity profile over the model for a neutral situation. No comparison of model velocity data with that in the prototype is possible because the latter is not available over a range of height. However, as the model velocity profiles were carefully produced over roughness tailored to reflect the characteristics of the site, it is expected that the prototype flow is adequately represented in the model. The power law exponent for the upstream velocity profile was 0.19.

4.3 Test Results: Visualization

The test results consist of photographs and sketches showing the general nature of airflow and diffusion in the vicinity of the power station (Figs. 4-1 to 4-2). A general understanding of wake and cavity flows is necessary for an interpretation of the plume behavior (see Halitsky, 1963).

Entrainment, as utilized herein, will be understood as the presence of any of the gas released from the stack in the power station cavity. A small amount of entrainment usually first occurs under conditions where the gas plume follows the cavity separation streamline to the downstream cavity stagnation point from which it diffuses upstream into the cavity proper. Downwash will be understood as severe entrainment where the plume does not penetrate the separation streamline but rather ventilates directly into the cavity region.

The sequences of photographs shown in Figs. 4-1 and 4-2 show side views of the behavior of a smoke plume released from Unit II for 50 percent load at 30 mph for various wind angles. Since Unit II stack sets some distance from the tall boiler units of the complex the plume is not strongly influenced by the immediate cavity and wake of these buildings. Nevertheless it was the opinion of those observing the visualization experiments that plumes spread more rapidly downward to the surface for wind approach angles from the W, NW, and SW. In no case did the plume appear to travel upwind on the ground surface or become directly entrained into the building complex wake cavity.

The observed "touchdown" distances evaluated from the flow visualization tests are summarized in Table 4-2. Touchdown is defined during observation as that point where the plume encounters the ground more than 10 percent of the time. Such an interpretation is necessarily qualitative but different observers do not vary by more than 500 ft. Smoke photographs tend to confirm the initial opinion. Complete sets of still photographs supplement this report. Color motion pictures have been arranged into titled sequences and the sets available are summarized in Table 4-2.

4.4 Test Results: Concentration Measurements

Turbulent diffusion of gaseous effluent released for one stack height was studied. Propane concentrations at ground level were measured at distances equivalent to 915 ft to 5355 ft downwind.

Twenty-three samples were taken over the model distributed at ground level over the topography in the matrix shown in Fig. 2-3. Since the stack for Unit II was sometimes displaced to the right or left of the concentration grid centerline, the zero coordinate rests due west of Unit I stack centered between Units I and II boilers. All concentration data have been converted to the prototype scale levels as explained in section 3.5.1 of Report 1. The data is recorded herein in dimensional form as $\chi(\mu g/m^3)$ and $\chi V_a/Q$ where χ is the concentration over the assumed equivalent averaging time for laboratory measurements, Q is the source strength, and V_a is the mean wind velocity at stack height (250 ft). The source flow rate and thermal condition assumed for this stack at 50 percent load are summarized in Table 4-1. Data in Table 4-1 were provided by SWPSC.

The results for the eight cardinal wind directions, 50 percent load and 30 mph wind velocity are presented in Table 4-4. Sample positions shown in the tables are explained in the definition sketch in Fig. 2-3. The maximum concentration measured and its respective downwind location for each situation have been gathered together in Table 4-3.

A series of figures have been prepared from the bulk data to enable some general conclusions to be made concerning the influence of wind approach angle on plume behavior. Figure 4-3 gives the maximum ground level concentration ($\mu g/m^3$) versus distance for the two wind directions giving the highest impact (SW and W). The maximum ground level concentration for the SW direction was 255 $\mu g/m^3$ and occurred approximately 4500 ft from the plant center. For the West wind direction the maximum value was 218 $\mu g/m^3$ at 4500 ft.

Figures 4-4 through 4-7 show the ground level isopleth patterns of SO_2 concentration for seven of the eight cardinal wind directions (isopleths were not plotted for the east direction because of the low concentrations). The figures (in comparison with those for Unit 1) clearly show the minimal building influence upon the concentration patterns. The maximum concentrations occurred at or beyond 4500 ft for all directions.

5.0 TEST PROGRAM AND RESULTS: UNIT III AND UNITS II AND III COMBINED

5.1 Test Program

The test program consisted of (1) a qualitative study of the flow field around the power plant by visual observation of the smoke plume trajectory released from the stacks; and (2) a quantitative study of gas concentrations produced by the release of a propane tracer from the stacks. The model and prototype test conditions are summarized in Table 5-1. Angular locations of the approach winds are referred to in terms of angles from a nominal north. Downwind distances refer to lengths as measured from the center of the complex as marked in Fig. 2-3. Unless otherwise noted, the term wind velocity refers to the velocity in the undisturbed free stream at an equivalent height of 250 feet; however, a velocity at any reference height is available by referring to the velocity profiles (Fig. 2-4).

5.2 Test Results: Characteristics of Flow

All the experiments were carried out in the EWT over the range of conditions shown in Table 5-1. The atmospheric boundary layer was modeled to produce a velocity profile equivalent to flow typical of irregular terrain. Figure 2-4 shows the development of the velocity profile over the model for a neutral situation. No comparison of model velocity data with that in the prototype is possible because the latter is not available over a range of height. However, as the model velocity profiles were carefully produced over roughness tailored to reflect the characteristics of the site, it is expected that the prototype flow is adequately represented in the model. The power law exponent for the upstream velocity profile was 0.19.

5.3 Test Results: Visualization

The test results consist of photographs and movies showing the general nature of airflow and diffusion in the vicinity of the power station (Fig. 5-1). A general understanding of wake and cavity flows is necessary for an interpretation of the plume behavior (see Halitsky, 1963).

Entrainment as utilized herein, will be understood as the presence of any of the gas released in the power station cavity. A small amount of entrainment usually first occurs under conditions where the gas plume follows the cavity seperation streamline to the downstream cavity stagnation point from which it diffuses upstream into the cavity proper. Downwash will be understood as severe entrainment where the plume does not penetrate the seperation streamline but rather ventilates directly into the cavity region.

The sequence of photographs shown in Fig. 5-1 show side views of the behavior of a smoke plume released from Unit III for 50 percent load at 30 mph for the SE and SW wind angles. Since Unit III stack sets some distance from the tall boiler units of the complex, the plume is not strongly influenced by the immediate cavity and wake of these buildings for most wind directions. Nevertheless, it was the opinion of those observing the visualization experiment when the model was rotated slowly through 360° (recorded on motion picture) that the plume spread more rapidly downwind to the surface for the SW wind direction. In no case did the plume appear to travel upwind on the ground surface or become directly entrained into the building complex wake cavity.

The observed "touchdown" distances evaluated from the flow visualization tests are summarized in Table 5-2. Touchdown is defined during observation as that point where the plume encounters the ground more than 10 percent of the time. Such an interpretation is necessarily qualitative but different observers do not vary by more than 500 ft. Smoke photographs tend to confirm the initial opinion. Complete sets of still photographs supplement this report. Color motion pictures have been arranged into titled sequences and the set available summarized in Table 5-2.

5.4 Test Results: Concentration Measurements

Turbulent diffusion of gaseous effluent released for one stack height was studied. Propane concentrations at ground level were measured at distances equivalent to 915 ft to 5355 ft downwind.

Twenty-three samples were taken over the model distributed at ground level over the topography in the matrix shown in Fig. 2-3. The stack for Unit III was sometimes displaced to the right or left of the concentration grid centerline, the zero coordinate rests due west of Unit I stack centered between Unit I and II boilers. All concentration data have been converted to the prototype scale levels as explained in section 3.5.1 of Report 1. The data is recorded herein in dimensional form as $\chi(\mu g/m^3)$ and $\frac{\chi V_a}{Q}$ where χ is the concentration over the assumed equivalent averaging time for laboratory measurements, Q is the source strength, and V_a is the mean wind velocity at stack height (250 ft). The source flow rate and thermal condition assumed for each stack and load condition are summarized in Table 5-1. Data in Table 5-1 were provided by SWPSC.

The results for the SE and SW wind directions, 50 percent load and 30 mph velocity, are presented in Table 5-4. Sample positions shown in the tables are located on the definition sketch (Fig. 2-3). The maximum concentration measured and its respective downwind location for each situation has been gathered together in Table 5-3.

A series of figures have been prepared from the bulk data to enable some general conclusions to be made concerning the influence of wind approach angle on plume behavior. Figure 5-2 gives the maximum ground level concentrations ($\mu g/m^3$) versus distance for Unit III and Units II and III combined for the SW wind orientation. The maximum concentration for Unit III is 323 $\mu g/m^3$ and Units II and III combined 566 $\mu g/m^3$. Both maxima occur 2875 ft from the plant center.

Figure 5-3 shows the ground level isopleth patterns of SO_2 concentration from Unit III for the SE and SW wind directions. The figures show that the building effects are minimal but greatest for the SW wind orientation. This is to be expected since the effective building width upwind of the Unit 3 stack is the greatest for this wind orientation.

6.0 CONCLUSIONS

This investigation was undertaken to determine the ground-level concentrations if one additional boiler unit were added to the plant complex. The results presented herein (when scaled to 3-hours) are particularly relevant in comparison with the Federal 3-hour SO_2 air quality standards. New construction, however, must comply with the Federal regulation on significant deterioration. According to this regulation the baseline air quality is that as measured from Unit I. Three hour concentrations from Units 2 and 3 must fall below the Class II allowable increment of 700 $\mu g/m^3$ and additionally the baseline plus the maximum concentrations from Units 2 and 3 must be less than 1300 $\mu g/m^3$.

On the basis of the experimental measurements the following conclusions can be made.

- Unit 1 Stack

1. Plumes from Unit 1 do entrain directly into the building complex for a number of wind angles at 50% load and 30 mph.

2. The plume - building wake influence is a maximum for the SE and SW wind directions and a minimum for the E and NE wind directions.

3. Concentration measurements show a maximum ground-level SO_2 concentration of 994 $\mu g/m^3$ (~ 10 min average) for a SE wind orientation, 50% load and 30 mph wind. The equivalent 3-hour maximum using the power law as given in Turner (1969) is 558 $\mu g/m^3$.

4. The addition of Unit 3 does not affect the concentration patterns from Unit 1 significantly with the exception of the changing wind direction of maximum impact from SW to SE.

- Unit 2 Stack

1. Plumes from Unit 2 do not appear to entrain directly into the building complex for any wind angle at 50% load and with 30 mph winds.

2. The building influence was the greatest for the SW and W wind orientations and least for the E and N wind directions.

3. Concentration measurements show a maximum SO_2 concentration of 255 $\mu g/m^3$ (~ 10 min average) for the SW wind direction with 50% load and 30 mph winds. The equivalent maximum 3-hour SO_2 concentration is 143 $\mu g/m^3$ using the power law in Turner (1969).

4. The addition of Unit 3 does not appear to change the concentration distributions significantly, although the maximum value increased by approximately 30%.

- Unit 3 Stack

1. The plume from Unit 3 did not appear to entrain directly into the building complex for any wind orientation with 50% load and 30 mph winds.

2. The building influence appeared to be the greatest for the SW wind direction.

3. Concentration measurements show a maximum concentration of 323 $\mu g/m^3$ (~ 10 min average) for the SW wind direction, 50% load and 30 mph winds. The corresponding 3-hour average using the power law in Turner (1969) is 181 $\mu g/m^3$.

- Units 2 & 3 Combined

1. The combined maximum SO_2 concentration (~ 10 min average) for Units 2 & 3 is 566 $\mu g/m^3$ for the SW wind direction, 50% load and 30 mph winds.

2. The equivalent 3-hour average SO_2 concentration is 317 $\mu g/m^3$.

In summary the baseline air quality (3 hour average) for the plant and meteorological conditions modeled is 558 $\mu g/m^3$. The incremental concentration due to Units 2 & 3 is 317 $\mu g/m^3$. Thus the concentrations from Units 2 & 3 fall below the Class II increment of 700 $\mu g/m^3$ and the sum of the baseline and the increment from Units 2 & 3 is below 1300 $\mu g/m^3$.

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Turner, P. B., "Workbook of Atmospheric Dispersion Estimates," U.S. Department of Health, Education and Welfare, Public Health Service, Cincinnati, Ohio, 1969.

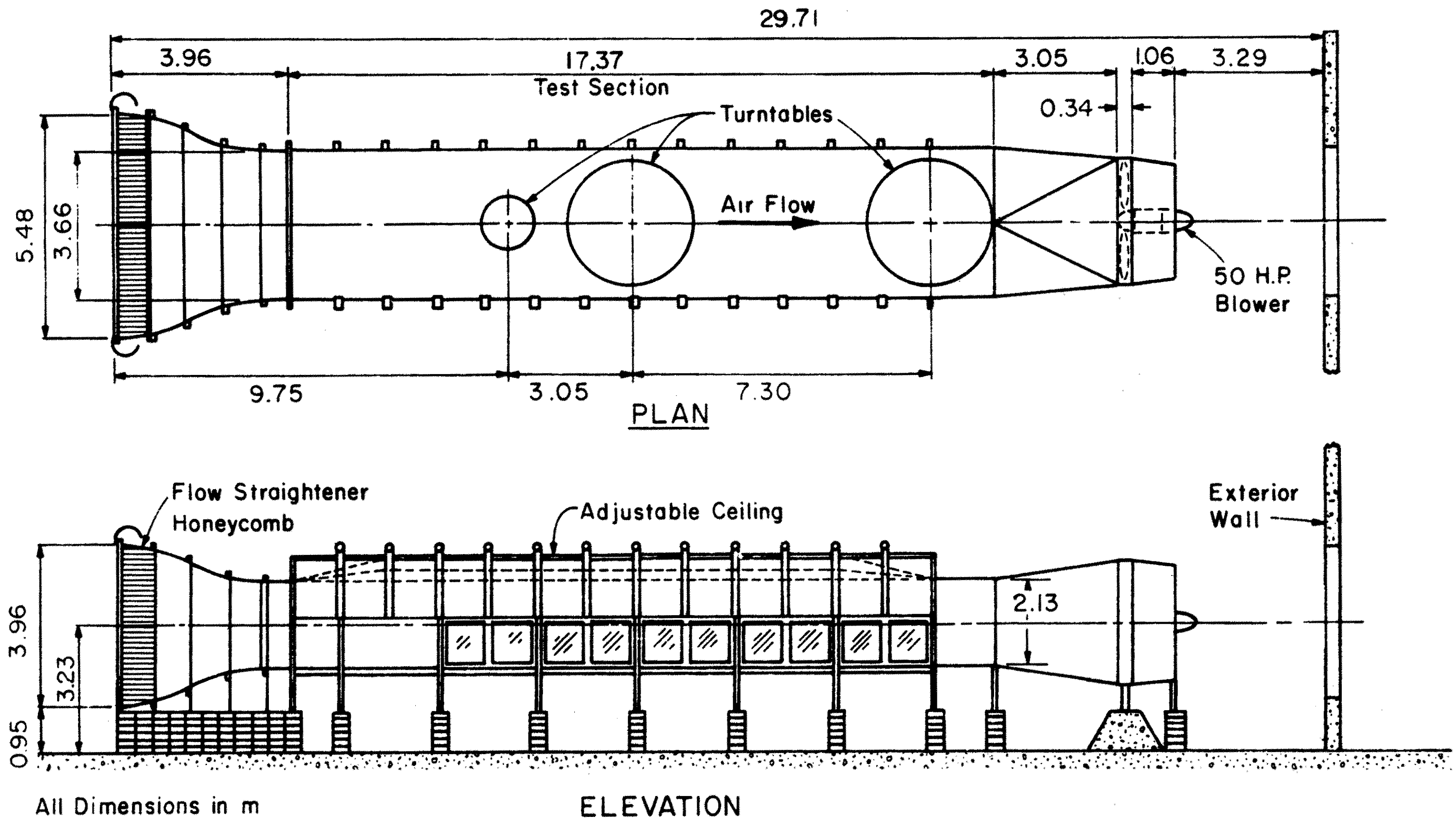
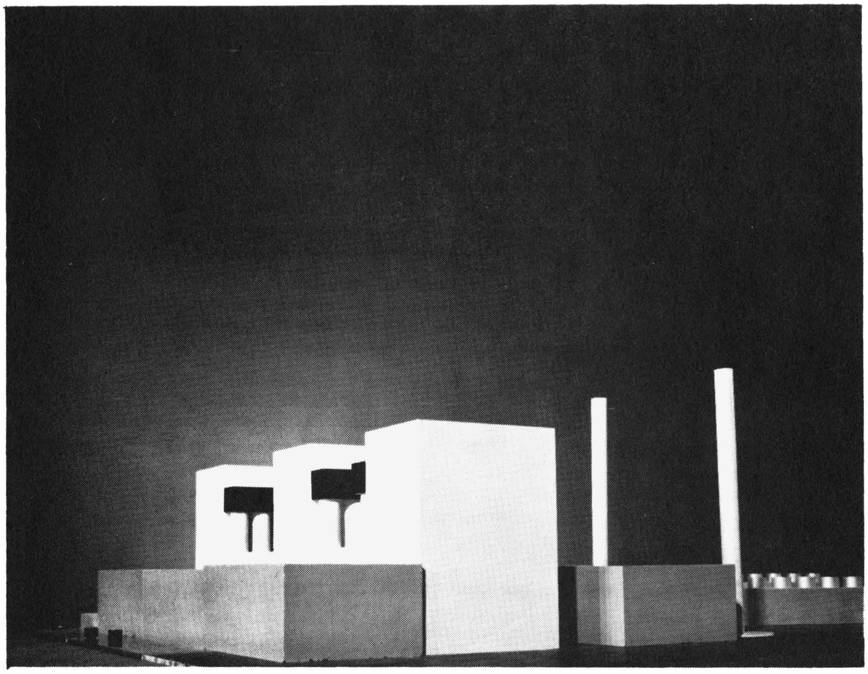


Fig. 2.1

ENVIRONMENTAL WIND TUNNEL
FLUID DYNAMICS & DIFFUSION LABORATORY
COLORADO STATE UNIVERSITY



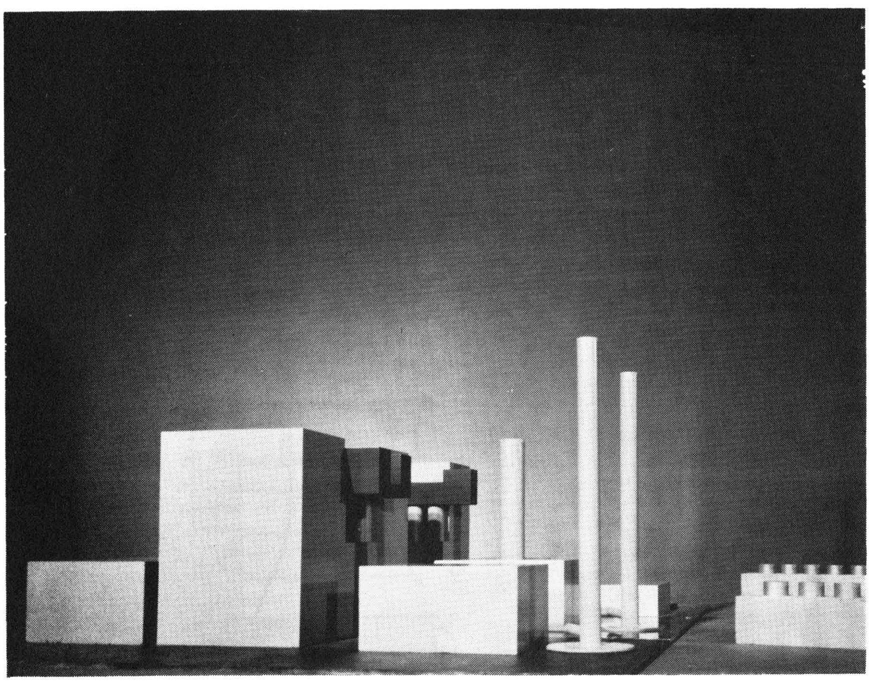


Figure 2-2. Harrington Power Station, Model Scale 1:250

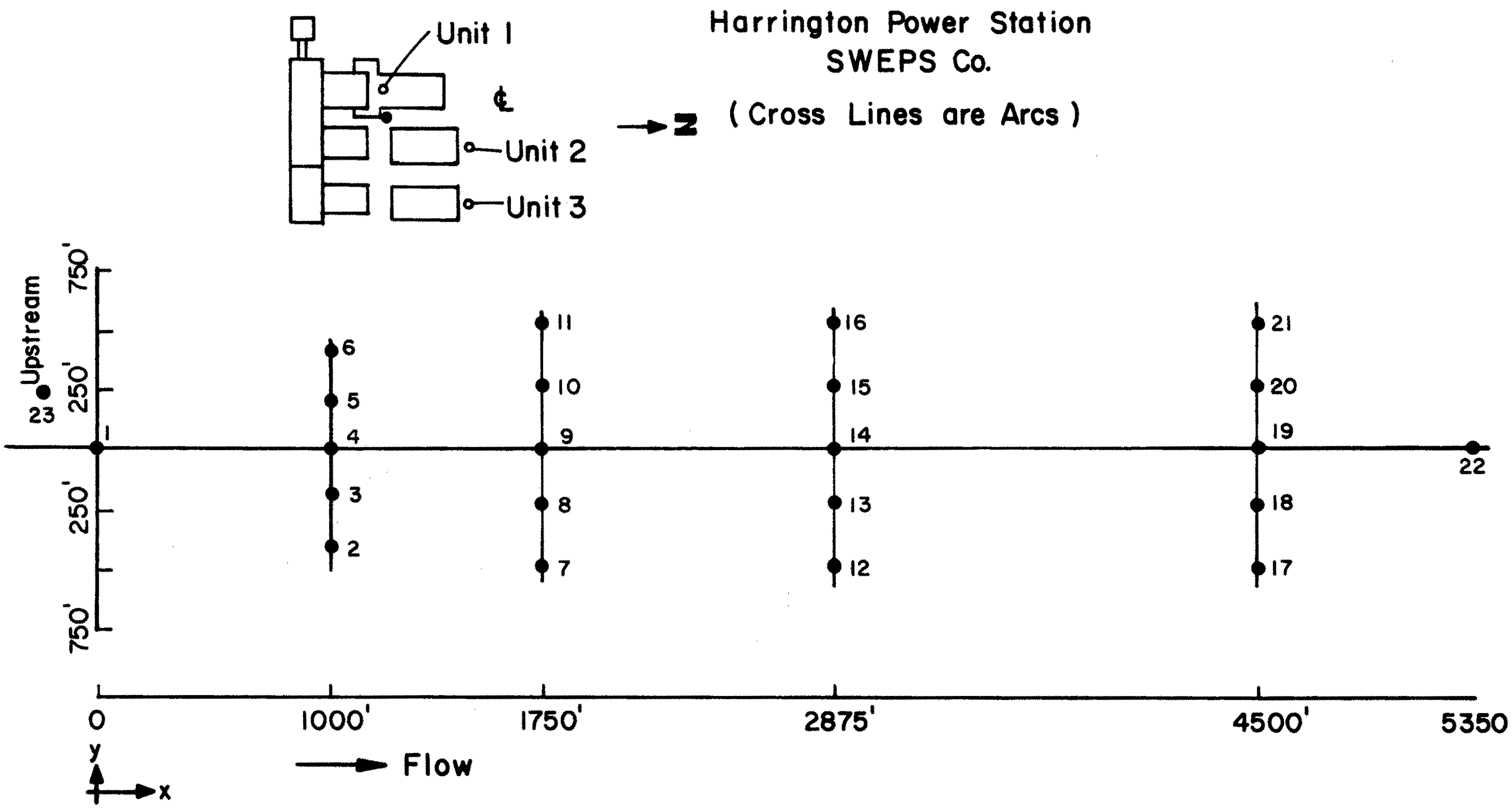


Figure 2-3 Concentration Measuring Locations in Environmental Wind Tunnel.

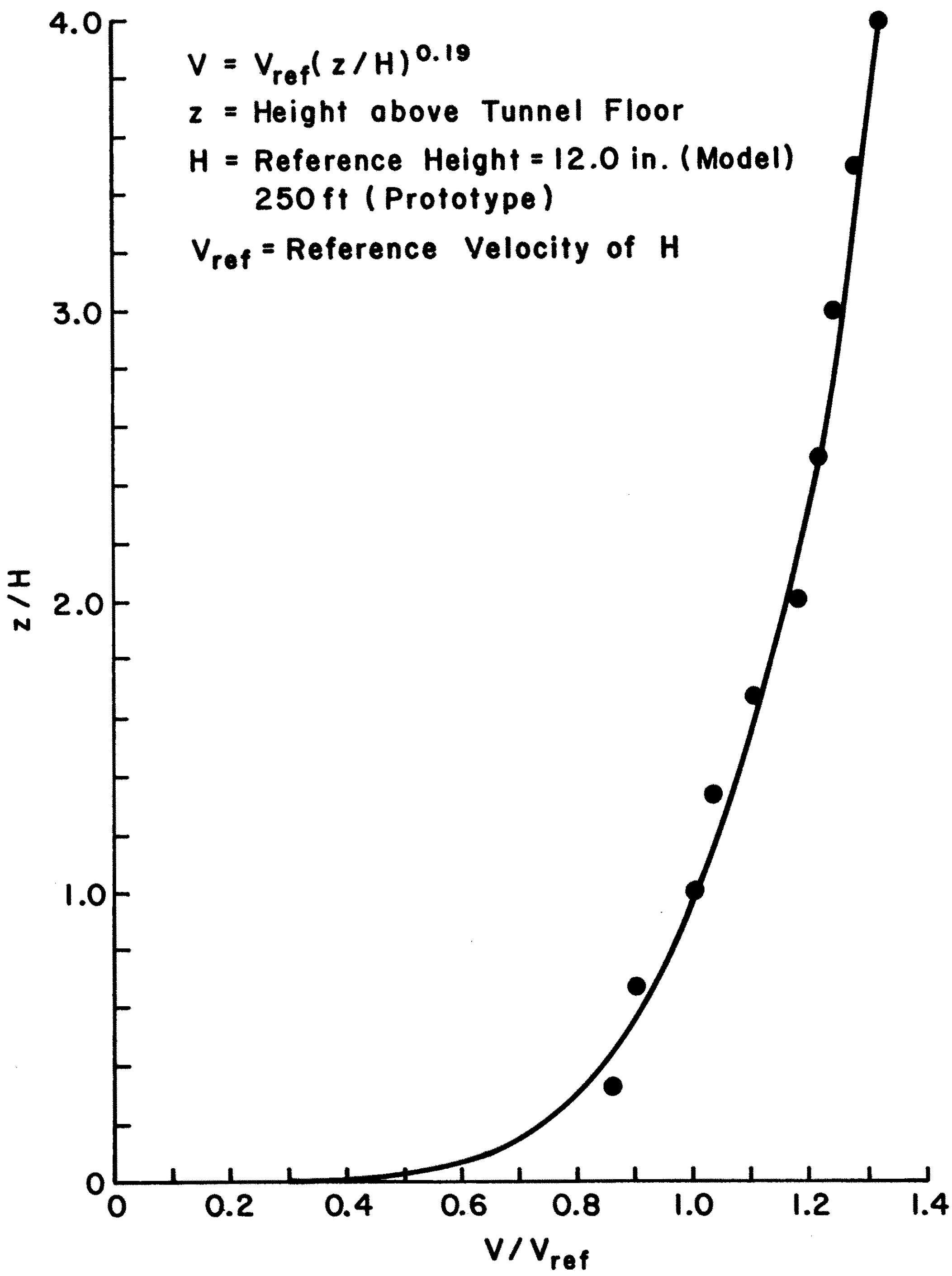


Figure 2.4 Approach Velocity Profile, Neutral Conditions, Environmental Wind Tunnel

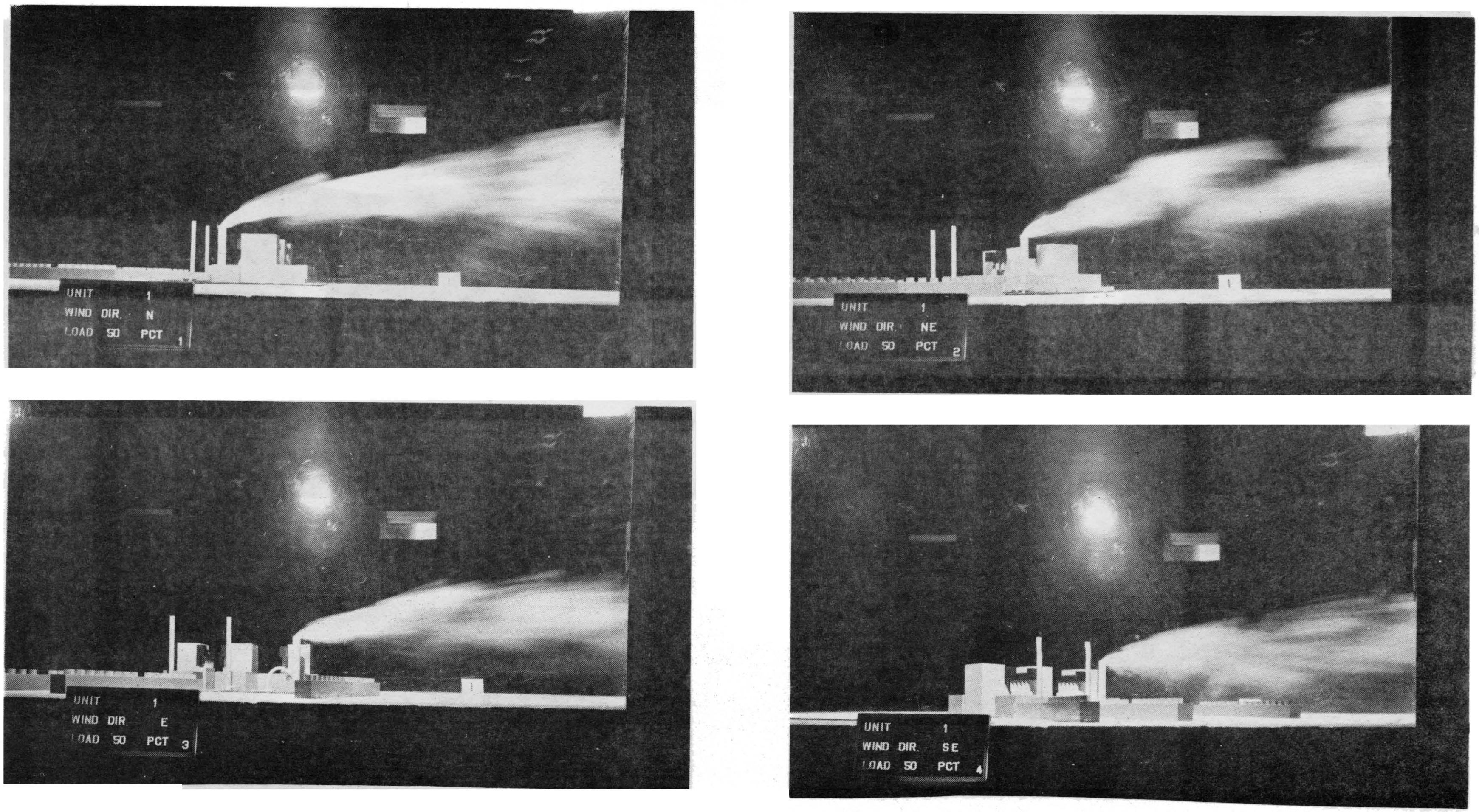


Figure 3-1. Flow Visualization. Unit 1: 250 foot stack, 30 mph, 50% load, N, NE, E, SE Wind Directions

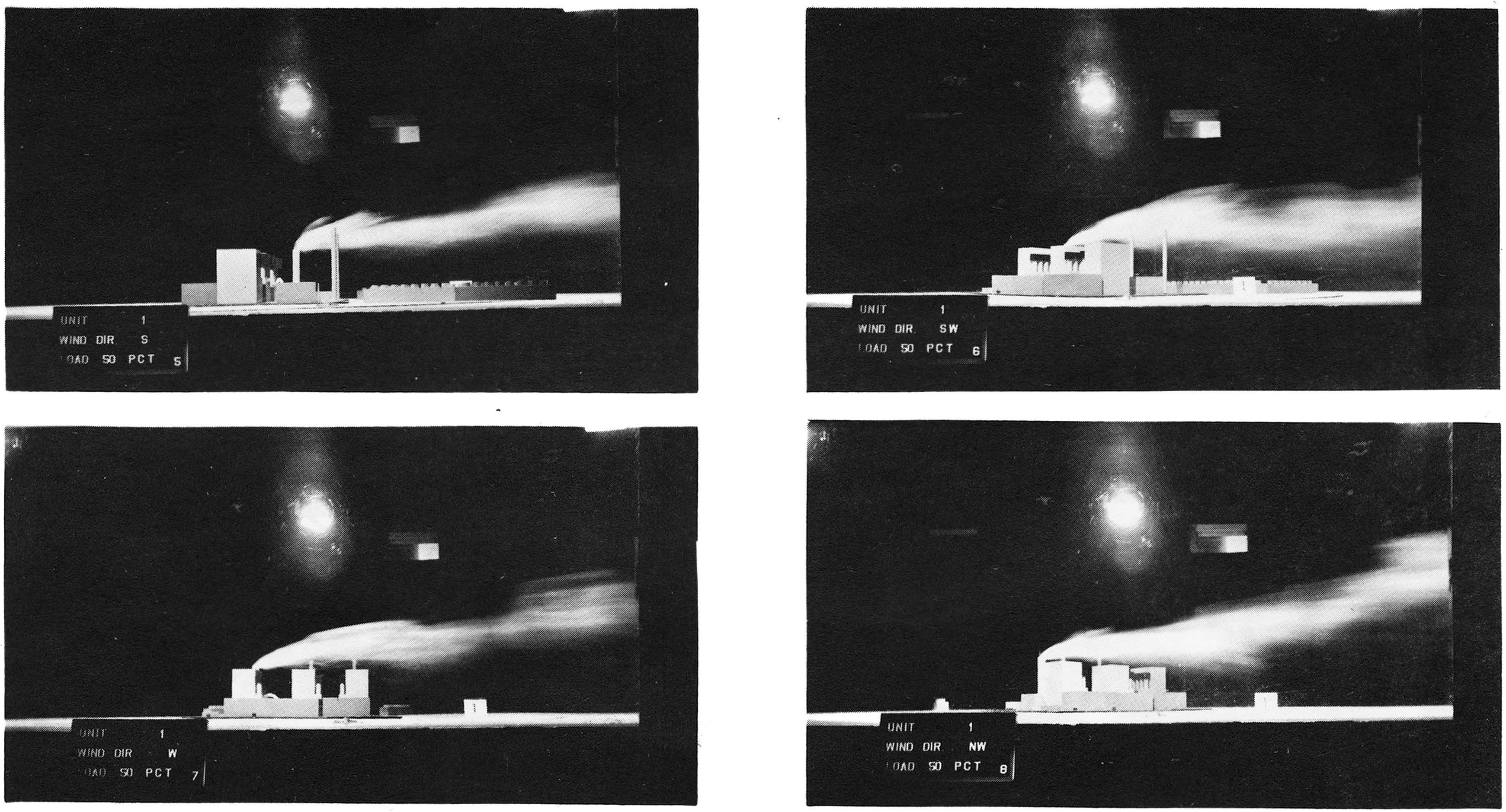


Figure 3-2. Flow Visualization. Unit 1: 250 foot stack, 30 mph, 50% Load, S, SW, W, NW Wind Directions

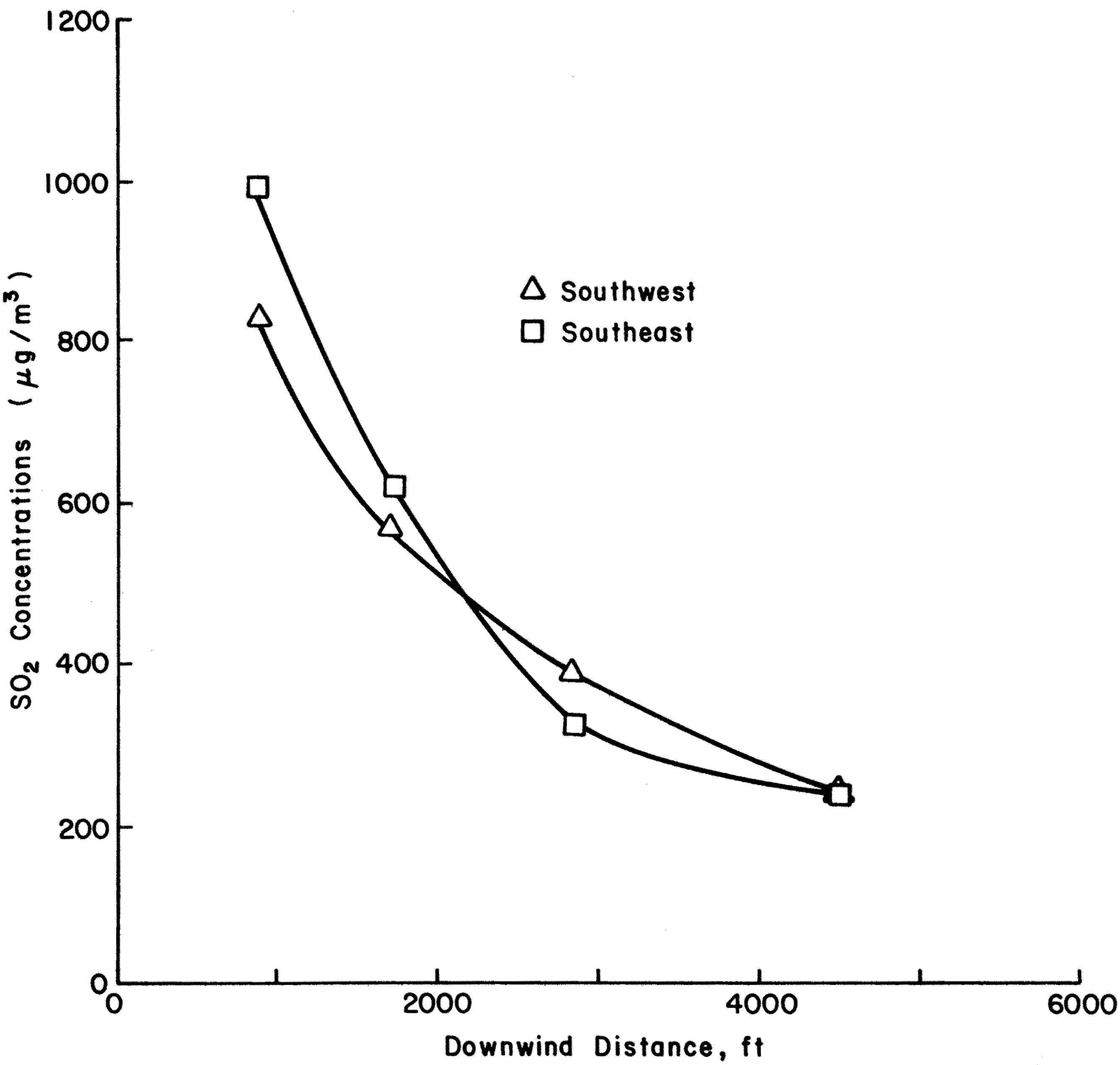
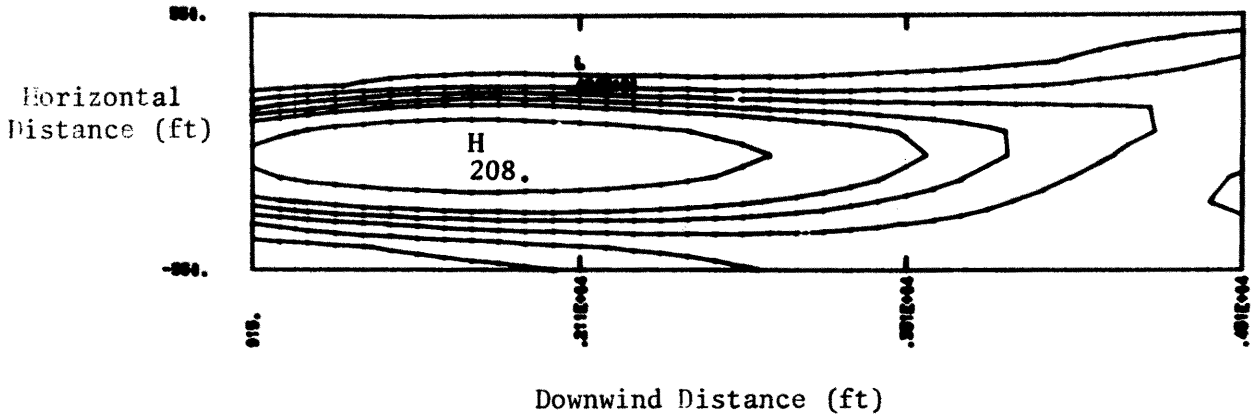


Figure 3-3 Maximum ground-level SO_2 concentrations (~ 10 min average) versus distance for Unit 1, SE and SW wind directions, at 50% load, and 30 mph winds.



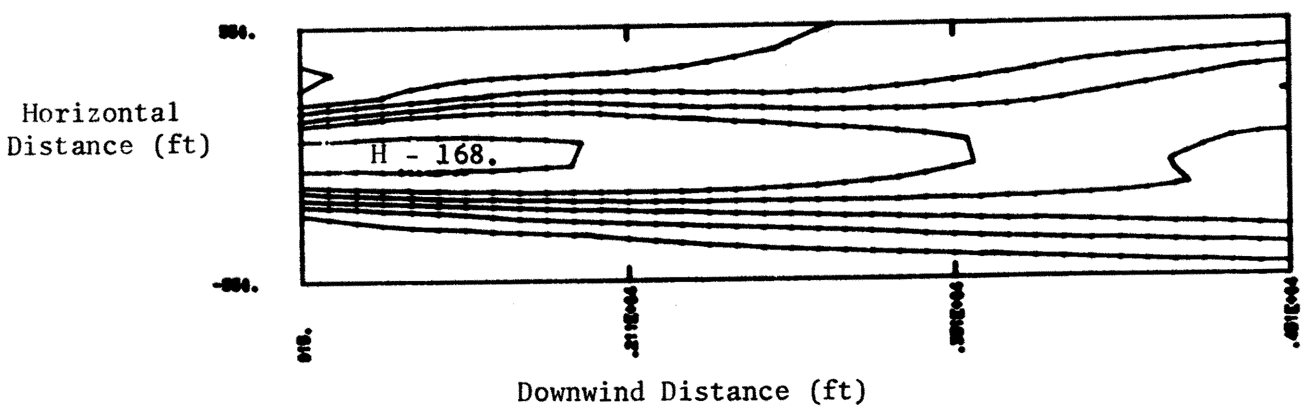
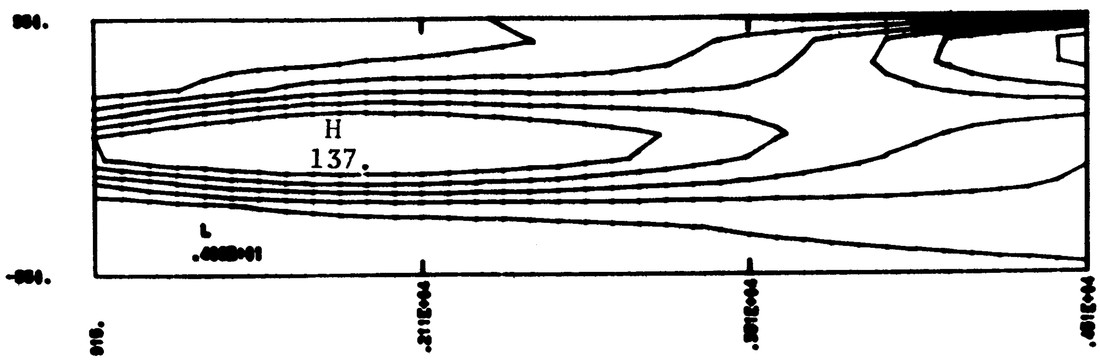


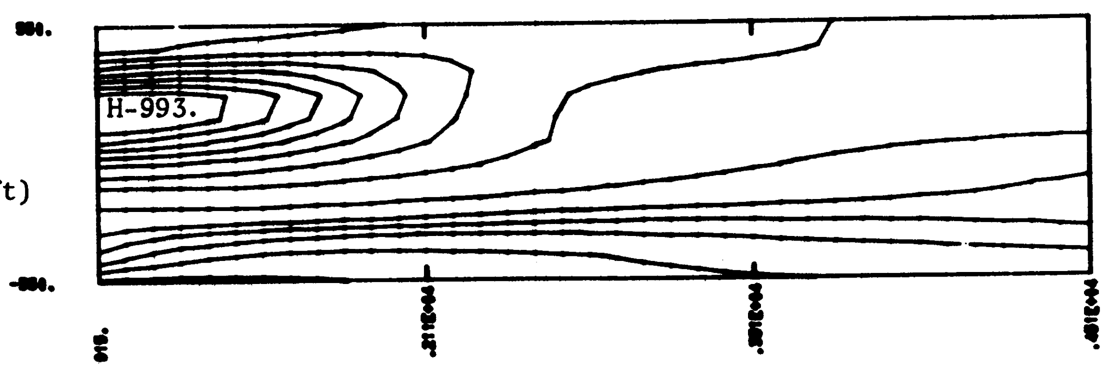
Figure 3-4 Ground Level Isopleph Patterns of SO_2 Concentration ($\mu g/m^3$). Unit 1: 50% Load, 30 MPH, N (top) and NE (bottom) Wind Directions. Contour interval from 20 to 100 $\mu g/m^3$ in 20 $\mu g/m^3$ increments and from 150 $\mu g/m^3$ to 850 $\mu g/m^3$ in 100 $\mu g/m^3$ increments.

Horizontal Distance (ft)



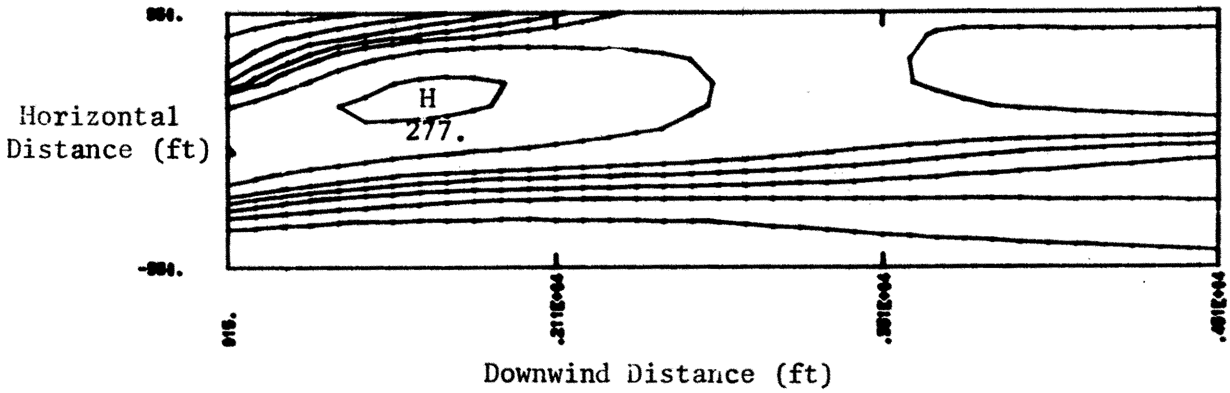
Downwind Distance (ft)

Horizontal Distance (ft)



Downwind Distance (ft)

Figure 3-5 Ground Level Isopleth Patterns of SO_2 Concentration ($\mu g/m^3$). Unit 1: 50% Load, 30 MPH, E (top) and SE (bottom) Wind Direction. Contour interval from 20 to 100 $\mu g/m^3$ in 20 $\mu g/m^3$ increments and from 150 $\mu g/m^3$ to 850 $\mu g/m^3$ in 100 $\mu g/m^3$ increments.



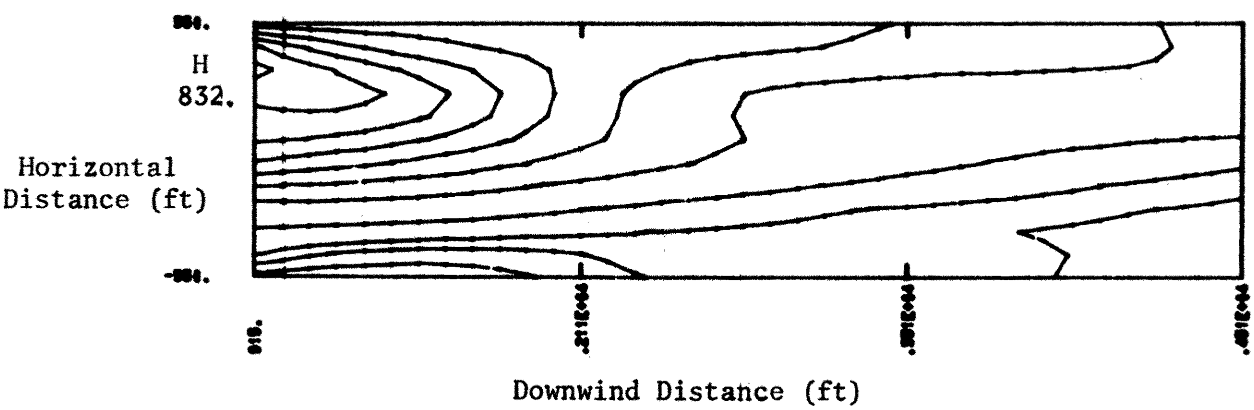
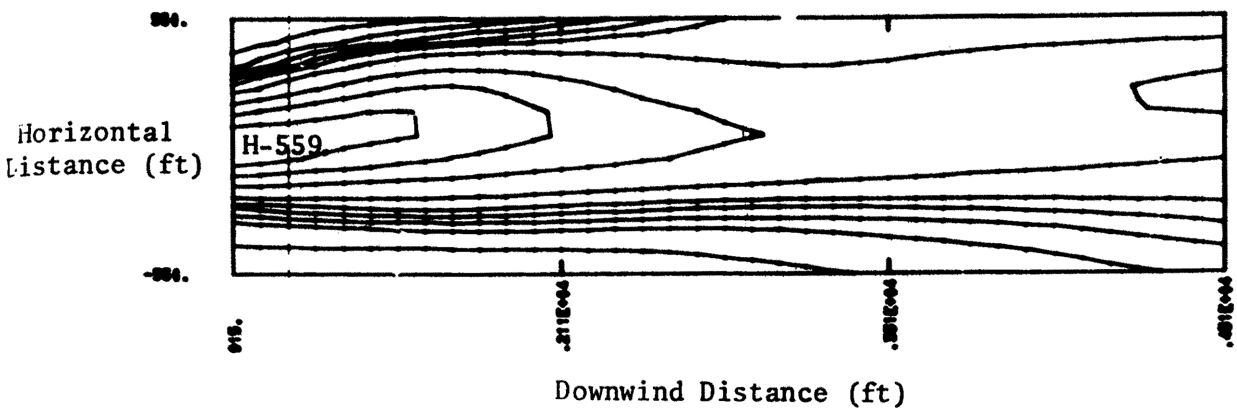


Figure 3-6 Ground Level Isopleth Patterns of SO_2 Concentration ($\mu g/m^3$). Unit 1: 50% Load, 30 MPH, S (top) and SW (bottom) Wind Directions. Contour interval from 20 to 100 $\mu g/m^3$ in 20 $\mu g/m^3$ increments and from 150 $\mu g/m^3$ to 850 $\mu g/m^3$ in 100 $\mu g/m^3$ increments.



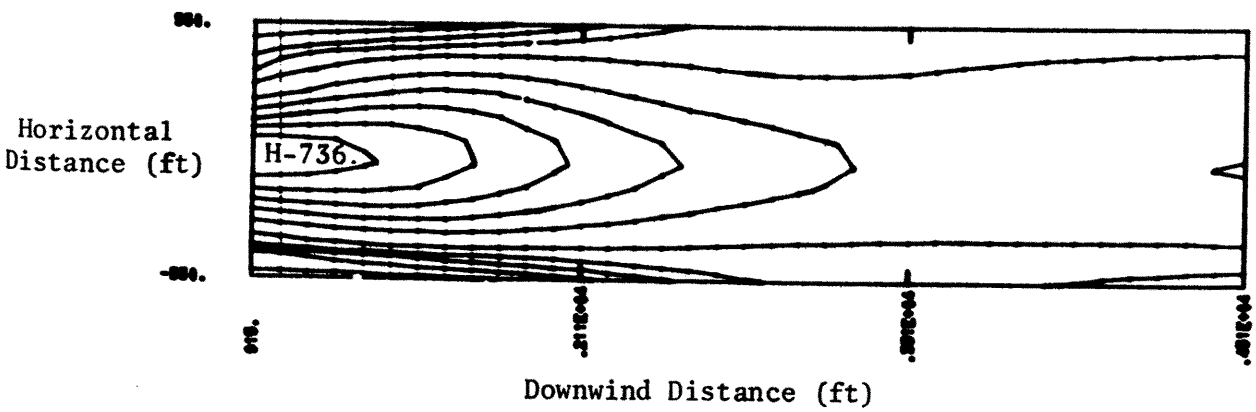


Figure 3-7 Ground Level Isopleth Patterns of SO_2 Concentration ($\mu g/m^3$). Unit 1: 50% Load, 30 MPH, W (top) and NW (bottom) Wind Directions. Contour interval from 20 to 100 $\mu g/m^3$ in 20 $\mu g/m^3$ increments and from 150 $\mu g/m^3$ to 850 $\mu g/m^3$ in 100 $\mu g/m^3$ increments.

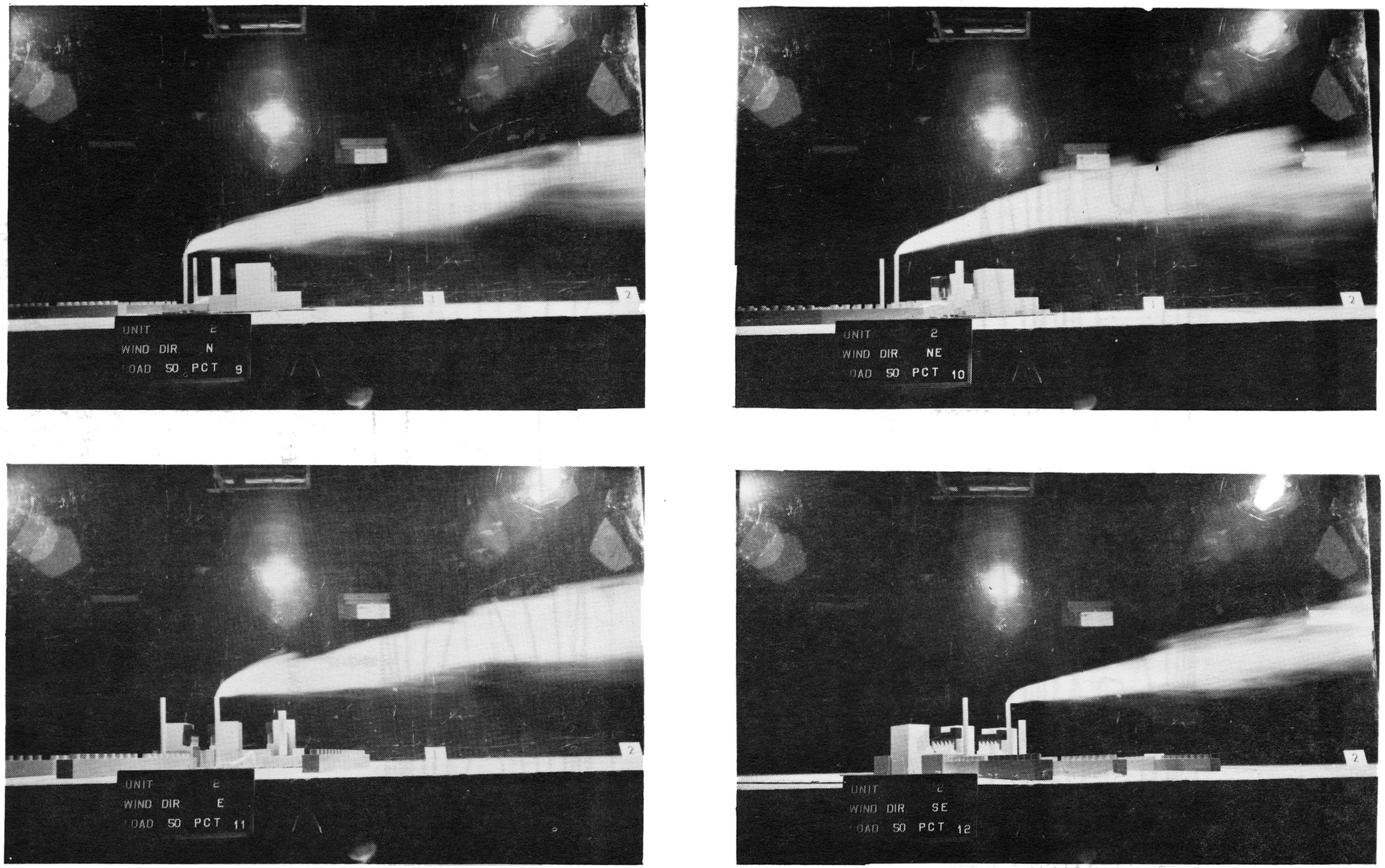


Figure 4-1. Flow Visualization. Unit 2: 300 foot stack, 30 mph, 50% load, N, NE, E, SE Wind Directions

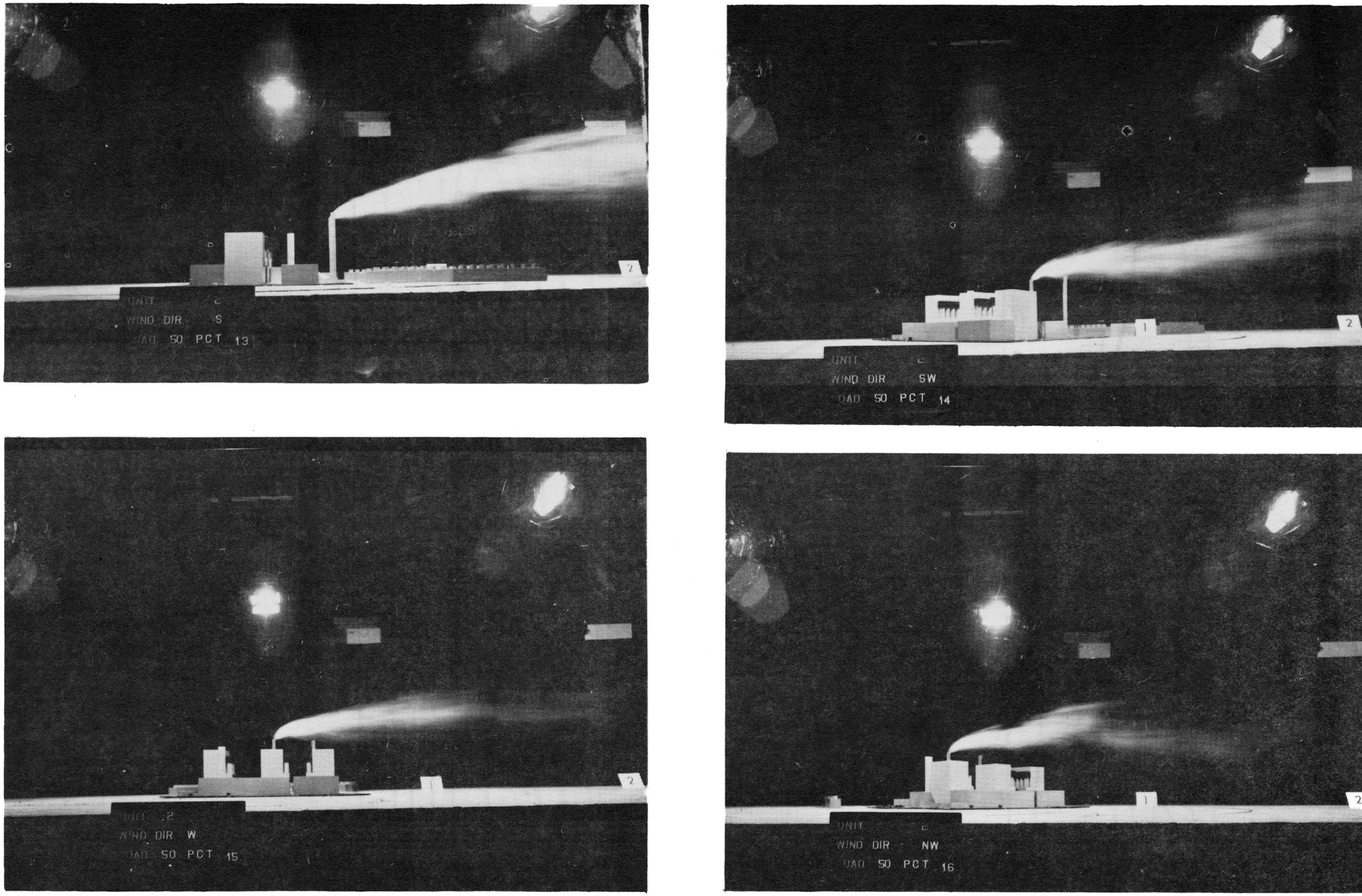


Figure 4-2. Flow Visualization. Unit 2: 300 foot stack, 30 mph, 50% Load, S. SW, W, NW Wind Directions

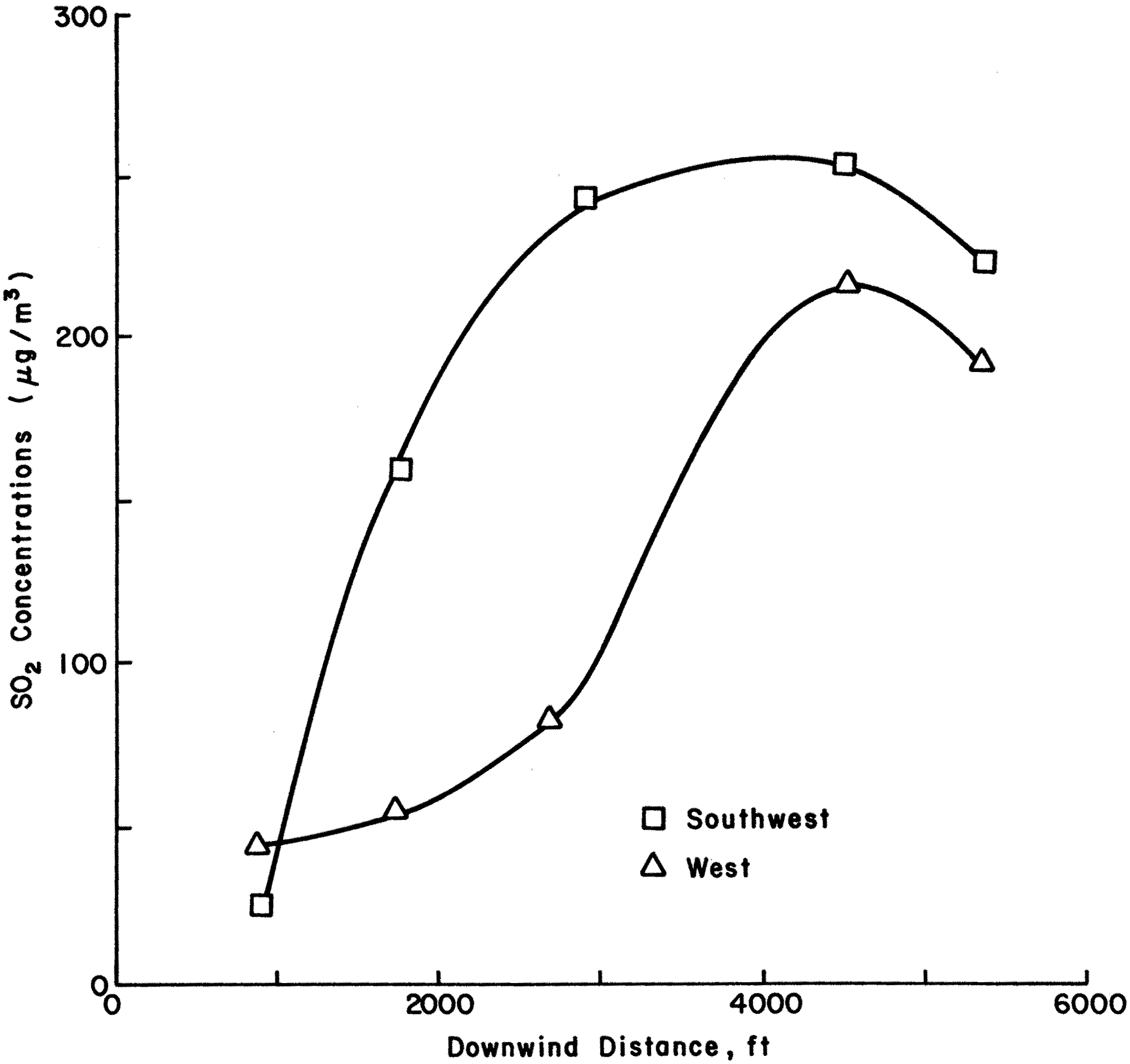
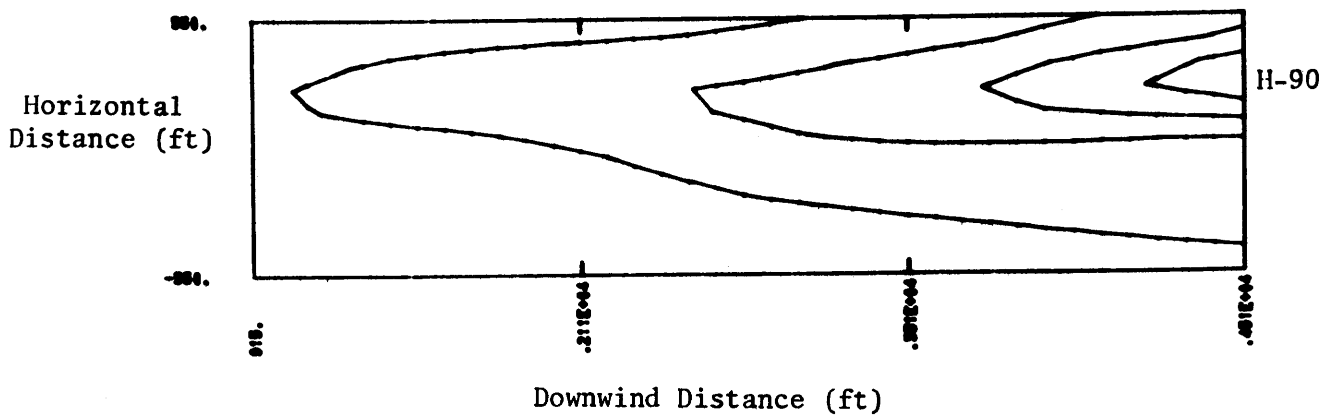


Figure 4-3 Maximum ground-level SO_2 concentrations (~ 10 min average) versus distance for Unit 2, West and South West winds, 50% load and 30 mph.



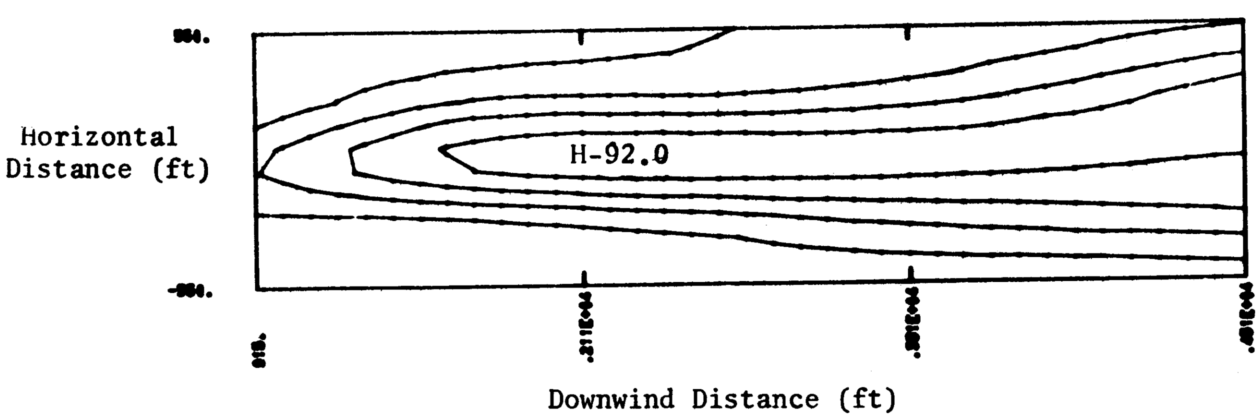
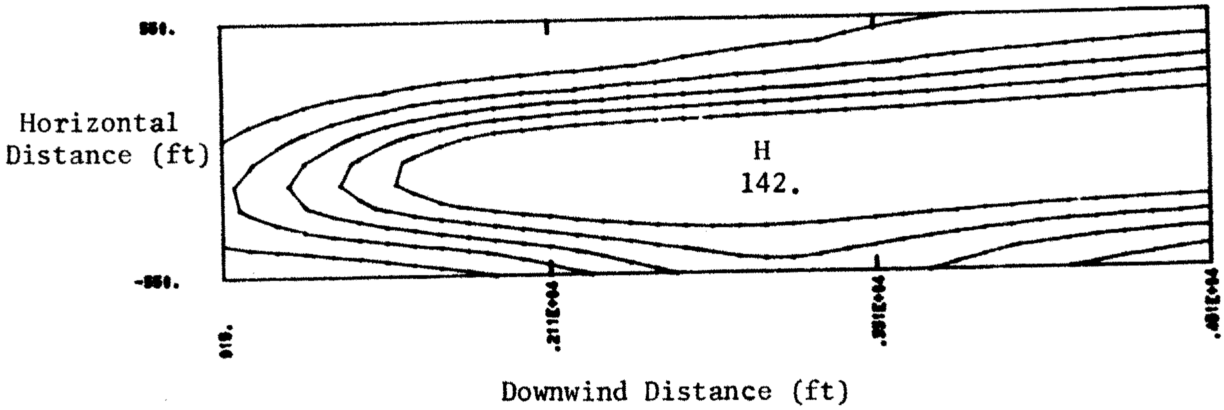


Figure 4-4 Ground Level Isopleph Patterns of SO_2 Concentration ($\mu g/m^3 \simeq$ 10 min. average). Unit 2: 50% Load, 30 MPH, N (top) and NE (bottom) Wind Directions. Contour interval from 20 to 100 $\mu g/m^3$ in 20 $\mu g/m^3$ increments and from 150 $\mu g/m^3$ to 850 $\mu g/m^3$ in 100 $\mu g/m^3$ increments.



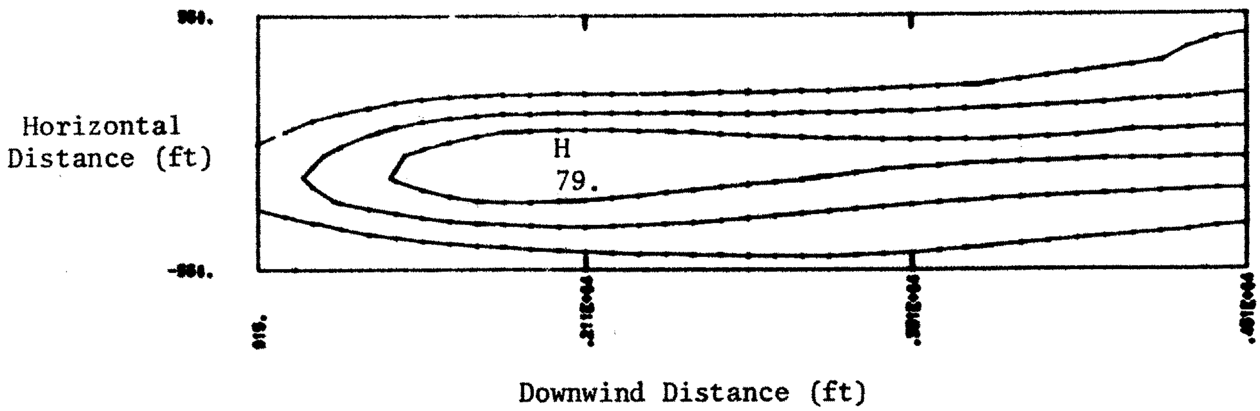
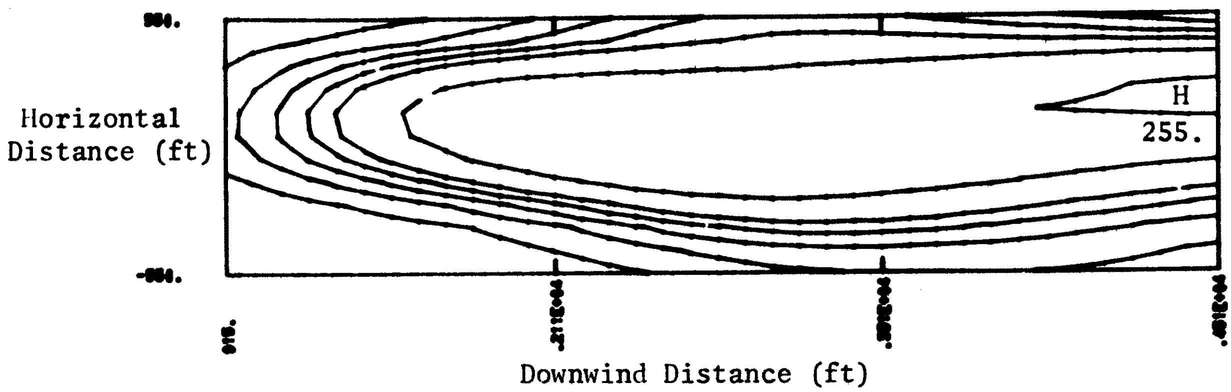


Figure 4-5 Ground Level Isopleph Patterns of SO_2 Concentration ($\mu g/m^3$ ≃ 10 min. average). Unit 2: 50% Load, 30 MPH, SE (top) and S (bottom) Wind Directions. Contour interval from 20 to 100 $\mu g/m^3$ in 20 $\mu g/m^3$ increments and from 150 $\mu g/m^3$ to 850 $\mu g/m^3$ in 100 $\mu g/m^3$ increments.



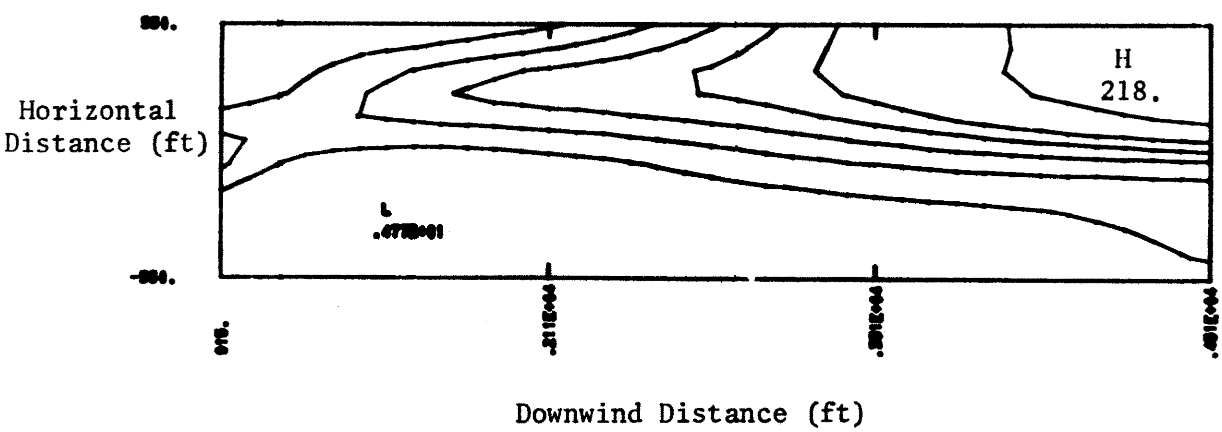


Figure 4-6 Ground Level Isopleph Patterns of SO_2 Concentration ($\mu g/m^3$ ≈ 10 min. average). Unit 2: 50% Load, 30 MPH, SW (top) and W (bottom) Wind Directions. Contour interval from 20 to 100 $\mu g/m^3$ in 20 $\mu g/m^3$ increments and from 150 $\mu g/m^3$ to 850 $\mu g/m^3$ in 100 $\mu g/m^3$ increments.

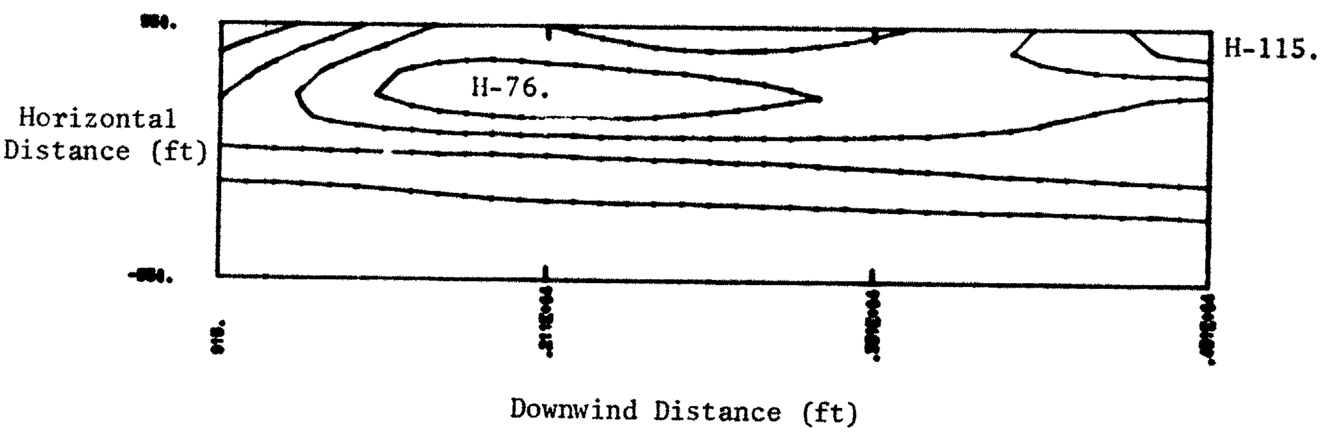


Figure 4-7 Ground Level Isopleph Patterns of SO_2 Concentration ($\mu g/m^3$ ≈ 10 min. average). Unit 2: 50% Load, 30 MPH, NW Wind Direction. Contour interval from 20 to 100 $\mu g/m^3$ in 20 $\mu g/m^3$ increments and from 150 $\mu g/m^3$ to 850 $\mu g/m^3$ in 100 $\mu g/m^3$ increments.

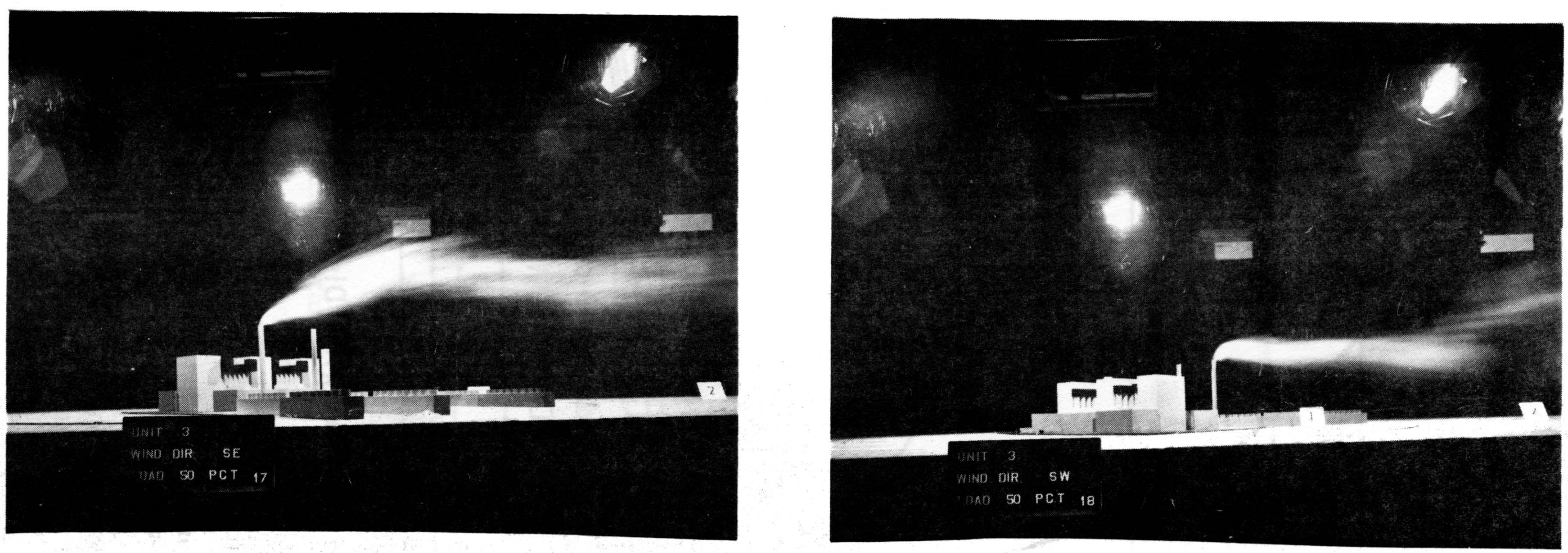


Figure 5-1. Flow Visualization. Unit 3: 300 foot stack, 30 mph, 50% load, SE, SW Wind Direction

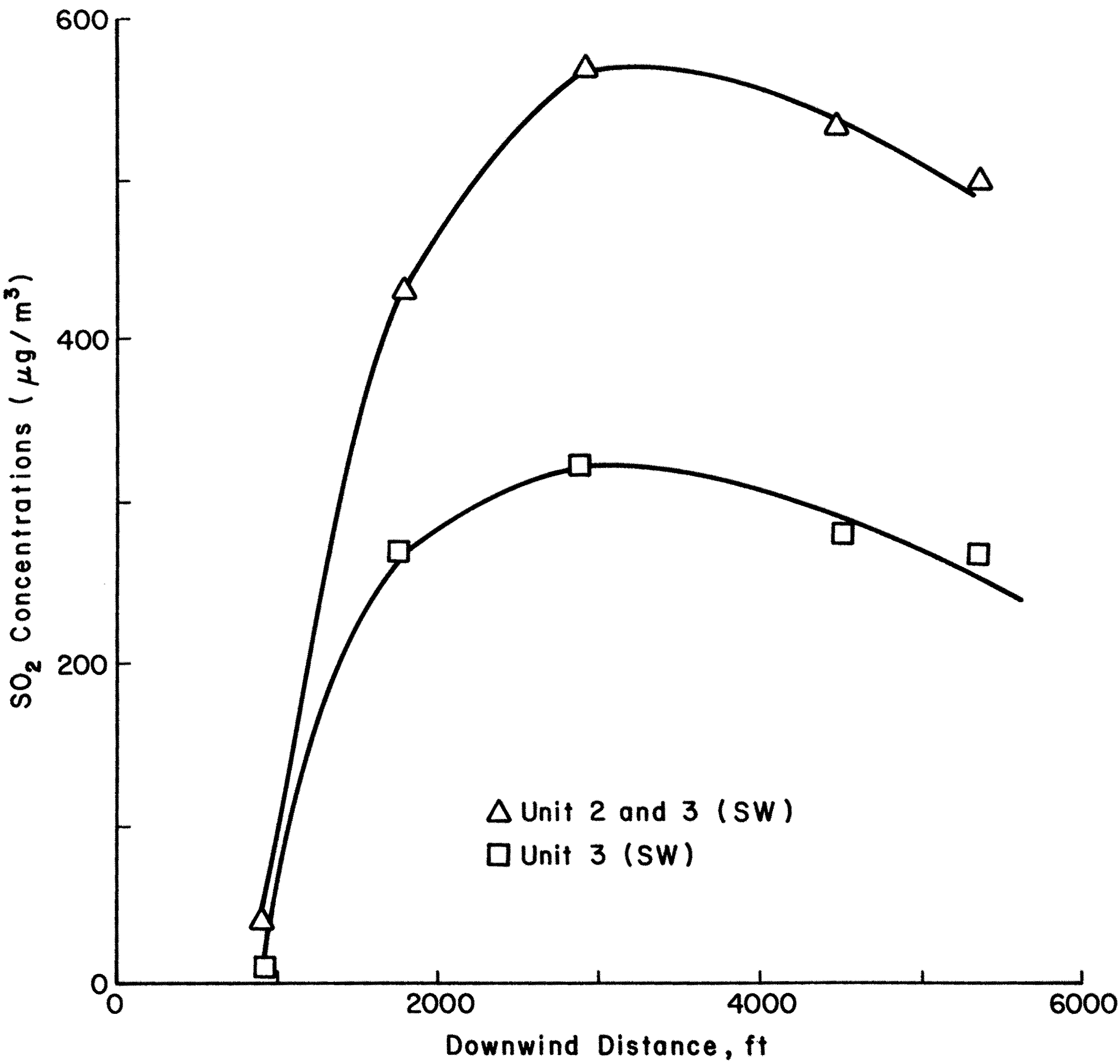
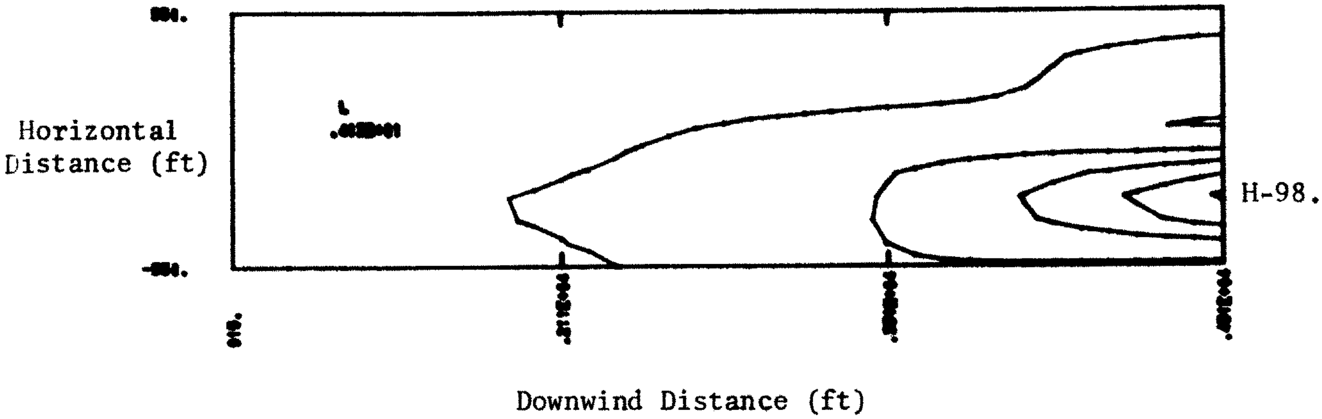


Figure 5-2 Maximum ground-level SO_2 concentration (~ 10 min average) versus distance for Unit 3 and Units 2 and 3 combined for a SW wind direction, 30 mph and 50% load.



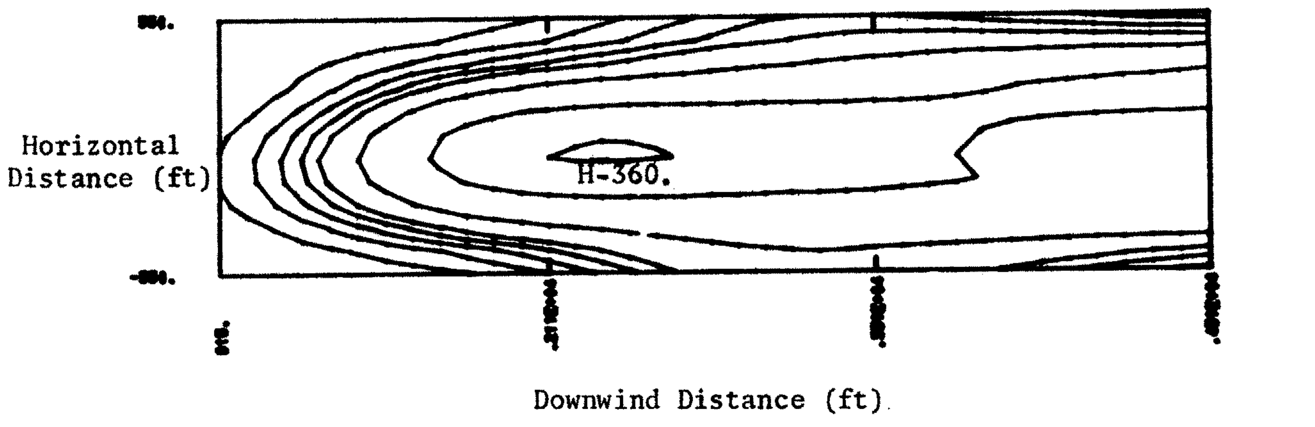


Figure 5-3 Ground Level Isopleph Patterns of SO_2 Concentration ($\mu g/m^3$ ≃ 10 min. average). Unit 2: 50% Load, 30 MPH, SE (top) and SW (bottom) Wind Directions. Contour interval from 20 to 100 $\mu g/m^3$ in 20 $\mu g/m^3$ increments and from 150 $\mu g/m^3$ to 850 $\mu g/m^3$ in 100 $\mu g/m^3$ increments.

Table 2-1 Comparison of Maximum Ground Level Concentration for the Same Conditions in the Environmental and Meteorological Wind Tunnels.

			Maximum Concentration (ppm)		
Run # From Report 1	Wind Direction	Unit Operating	EWT	MWT	% Difference[1]
12	SE	1	.63	.37	52
14	SW	1	.29	.28	4
15	W	1	.19	.20	10
16	NW	1	.14	.40	96
73	W	2	.05	.08	46
79	SW	2	.07	.10	35
				Mean	41

1) % Difference = $2\left(\frac{EWT - MWT}{EWT + MWT}\right)$

Table 3-1 Prototype and Model Source Parameters for Unit 1: Harrington Station

DESCRIPTION	PROTOTYPE	MODEL
Stack Diameter (ft)	27.0	0.11
Stack Area (ft^2)	573.0	0.009
Stack Height (ft)	250.0	1.0
Gas Temperature (^oF) @ (26.57" Hg)	160.0	-
Load (%)	50.0	50.0
Gas Velocity (ft/s)	16.8	1.06
Source Strength - SO_2 (g/s)	78.0	-
Free Stream Velocity (ft/sec)	44.0	2.79
R	.38	.38
$\Delta\rho/\rho_a = \left(\frac{T_s - T_a}{T_a}\right)$	.15	.15
$Fr_s = \dfrac{V^2}{g \frac{\Delta\rho}{\rho_a} D}$	2.19	2.19
Q_s (cfm)	577136	.59
Mol Wts = $29 \left(1 - \frac{\Delta\rho}{\rho_a}\right)$	24.7	24.7
X_{He} (%)	-	20.0
X_{Prop} (%)	-	5.0
Wind Direction	All	N, NE, E, SE, S, SW, W, NW

Table 3-2 Observed Touchdown Distances from Flow Visualization Tests for Unit 1: Harrington Station

RUN	WIND SPEED (MPH)	WIND DIRECTION	LOAD	STACK HEIGHT (FT)	DISTANCE TO TOUCHDOWN (FT)
1	30	N	50%	250	1000
2	30	NE	50%	250	1300
3	30	E	50%	250	1000-1300
4	30	SE	50%	250	0-500
5	30	S	50%	250	750-1000
6	30	SW	50%	250	500-1000
7	30	W	50%	250	1000
8	30	NW	50%	250	750

Table 3-3 Maximum Ground Concentration ($\mu g/m^3$) and Distance to Maximum for Unit 1: Harrington Station

RUN	WIND SPEED (MPH)	WIND DIRECTION	LOAD	STACK HEIGHT (FT)	DISTANCE TO MAXIMUM GROUND CONCENTRATION (FT)	MAXIMUM GROUND CONCENTRATION ($\mu g/m^3$) (~10 min Avg)	(3 hrs Avg)
1	30	N	50%	250	1750	209	117
2	30	NE	50%	250	915	168	94
3	30	E	50%	250	1750	135	76
4	30	SE	50%	250	915	994	558
5	30	S	50%	250	915	256	144
6	30	SW	50%	250	915	832	167
7	30	W	50%	250	915	559	314
8	30	NW	50%	250	915	736	413

Table 3-4 Ground Level Concentration Results - Unit 1

RUN NUMBER	1
UNIT NUMBER	1
WIND DIRECTION	N
WIND SPEED (FT/S)	44
PERCENT LOAD	50
SO2 RELEASE RATE (GM/S)	78
STACK LOCATION (FT) X=	0
Y=	100
STACK HEIGHT (FT)	250
STRATIFICATION	NEUTRAL
STACK VELOCITY (FT/S)	16.80

SAMPLE POSITION X	Y	CONCENTRATION COEFFICIENT K*10**6 (FT)**-2	SO2 CONCENTRATION MICRO GM PER CU.M	SO2 CONCENTRATION PPM
0	0	.019	1.18	.0004
915	-420	.170	10.63	.0040
915	-210	1.709	106.93	.0401
915	0	2.379	148.88	.0558
915	210	.264	16.54	.0062
915	420	.019	1.18	.0004
1750	-540	.151	9.45	.0035
1750	-270	1.728	108.11	.0405
1750	0	3.333	208.55	.0782
1750	270	.302	18.91	.0071
1750	540	.009	.59	.0002
2875	-540	.595	37.22	.0140
2875	-270	1.350	84.48	.0317
2875	0	2.162	135.29	.0507
2875	270	.264	16.54	.0062
2875	540	.066	4.14	.0016
4500	-540	.718	44.90	.0168
4500	-270	.529	33.08	.0124
4500	0	.680	42.54	.0160
4500	270	0.000	0.00	0.0000
4500	540	.094	5.91	.0022
5355	0	2.247	140.61	.0527
-1750	0	0.000	0.00	0.0000
MAXIMUM VALUES		3.333	208.55	.0782

RUN NUMBER	2
UNIT NUMBER	1
WIND DIRECTION	NE
WIND SPEED (FT/S)	44
PERCENT LOAD	50
SO2 RELEASE RATE (GM/S)	78
STACK LOCATION (FT) X=	68
Y=	68
STACK HEIGHT (FT)	250
STRATIFICATION	NEUTRAL
STACK VELOCITY (FT/S)	16.80

SAMPLE POSITION X	Y	CONCENTRATION COEFFICIENT K*10**6 (FT)**-2	SO2 CONCENTRATION MICRO GM PER CU.M	SO2 CONCENTRATION PPM
0	0	.009	.59	.0002
915	-420	.009	.59	.0002
915	-210	.576	36.04	.0135
915	0	2.691	168.37	.0631
915	210	.519	32.49	.0122
915	420	.302	18.91	.0071
1750	-540	0.000	0.00	0.0000
1750	-270	.576	36.04	.0135
1750	0	2.521	157.74	.0592
1750	270	.840	52.58	.0197
1750	540	.302	18.91	.0071
2875	-540	.019	1.18	.0004
2875	-270	.878	54.94	.0206
2875	0	1.832	114.61	.0430
2875	270	.840	52.58	.0197
2875	540	.566	35.45	.0133
4500	-540	.094	5.91	.0022
4500	-270	1.105	69.12	.0259
4500	0	1.067	66.76	.0250
4500	270	1.511	94.53	.0354
4500	540	.566	35.45	.0133
5355	0	1.680	105.16	.0394
-1750	0	.028	1.77	.0007
MAXIMUM VALUES		2.691	168.37	.0631

RUN NUMBER 3
UNIT NUMBER 1
WIND DIRECTION E
WIND SPEED (FT/S) 44
PERCENT LOAD 50
SO2 RELEASE RATE (GM/S) 78
STACK LOCATION (FT) X= 100
Y= 0
STACK HEIGHT (FT) 250
STRATIFICATION NEUTRAL
STACK VELOCITY (FT/S) 16.80

SAMPLE POSITION X	Y	CONCENTRATION COEFFICIENT K*10**6 (FT)**-2	SO2 CONCENTRATION MICRO GM PER CU.M	SO2 CONCENTRATION PPM
0	0	0.000	0.00	0.0000
915	-420	0.000	0.00	0.0000
915	-210	.094	5.91	.0022
915	0	1.662	103.98	.0390
915	210	.198	12.41	.0047
915	420	.028	1.77	.0007
1750	-540	0.000	0.00	0.0000
1750	-270	.236	14.77	.0055
1750	0	2.162	135.29	.0507
1750	270	.595	37.22	.0140
1750	540	.066	4.14	.0016
2875	-540	.047	2.95	.0011
2875	-270	.387	24.22	.0091
2875	0	1.633	102.21	.0383
2875	270	.699	43.72	.0164
2875	540	.312	19.50	.0073
4500	-540	.189	11.82	.0044
4500	-270	.510	31.90	.0120
4500	0	.614	38.40	.0144
4500	270	1.784	111.66	.0419
4500	540	.415	25.99	.0097
5355	0	1.709	106.93	.0401
-1750	0	0.000	0.00	0.0000
MAXIMUM VALUES		2.162	135.29	.0507

RUN NUMBER		4
UNIT NUMBER		1
WIND DIRECTION		SE
WIND SPEED (FT/S)		44
PERCENT LOAD		50
SO2 RELEASE RATE (GM/S)		78
STACK LOCATION (FT)	X=	68
	Y=	-68
STACK HEIGHT (FT)		250
STRATIFICATION		NEUTRAL
STACK VELOCITY (FT/S)		16.80

SAMPLE POSITION X	Y	CONCENTRATION COEFFICIENT K*10**6 (FT)**-2	SO2 CONCENTRATION MICRO GM PER CU.M	SO2 CONCENTRATION PPM
0	0	0.000	0.00	0.0000
915	-420	1.237	77.39	.0290
915	-210	2.483	155.38	.0583
915	0	9.394	587.83	.2204
915	210	15.880	993.70	.3726
915	420	4.220	264.08	.0990
1750	-540	.236	14.77	.0055
1750	-270	1.652	103.39	.0388
1750	0	6.514	407.64	.1529
1750	270	9.875	617.96	.2317
1750	540	3.474	217.41	.0815
2875	-540	.481	30.13	.0113
2875	-270	1.331	83.30	.0312
2875	0	3.172	198.50	.0744
2875	270	3.521	220.36	.0826
2875	540	5.060	316.66	.1187
4500	-540	.623	38.99	.0146
4500	-270	1.350	84.48	.0317
4500	0	1.907	119.34	.0448
4500	270	3.776	236.31	.0886
4500	540	2.474	154.79	.0580
5355	0	2.171	135.88	.0510
-1750	0	.028	1.77	.0007
MAXIMUM VALUES		15.880	993.70	.3726

RUN NUMBER 5
UNIT NUMBER 1
WIND DIRECTION S
WIND SPEED (FT/S) 44
PERCENT LOAD 50
SO2 RELEASE RATE (GM/S) 78
STACK LOCATION (FT) X= 0
Y= -100
STACK HEIGHT (FT) 250
STRATIFICATION NEUTRAL
STACK VELOCITY (FT/S) 16.80

SAMPLE POSITION X	Y	CONCENTRATION COEFFICIENT K*10**6 (FT)**-2	SO2 CONCENTRATION MICRO GM PER CU.M	SO2 CONCENTRATION PPM
0	0	.019	1.18	.0004
915	-420	0.000	0.00	0.0000
915	-210	1.935	121.11	.0454
915	0	4.097	256.40	.0962
915	210	1.312	82.12	.0308
915	420	.312	19.50	.0073
1750	-540	.019	1.18	.0004
1750	-270	.510	31.90	.0120
1750	0	2.870	179.60	.0673
1750	270	4.078	255.22	.0957
1750	540	.623	38.99	.0146
2875	-540	.104	6.50	.0024
2875	-270	.472	29.54	.0111
2875	0	1.879	117.57	.0441
2875	270	2.190	137.06	.0514
2875	540	2.162	135.29	.0507
4500	-540	.151	9.45	.0035
4500	-270	.557	34.86	.0131
4500	0	1.303	81.53	.0306
4500	270	3.654	228.63	.0857
4500	540	1.945	121.70	.0456
5355	0	1.473	92.16	.0346
-1750	0	0.000	0.00	0.0000
MAXIMUM VALUES		4.097	256.40	.0962

RUN NUMBER 6
UNIT NUMBER 1
WIND DIRECTION SW
WIND SPEED (FT/S) 44
PERCENT LOAD 50
SO2 RELEASE RATE (GM/S) 78
STACK LOCATION (FT) X= 68
Y= -68
STACK HEIGHT (FT) 250
STRATIFICATION NEUTRAL
STACK VELOCITY (FT/S) 16.80

SAMPLE POSITION X	Y	CONCENTRATION COEFFICIENT K*10**6 (FT)**-2	SO2 CONCENTRATION MICRO GM PER CU.M	SO2 CONCENTRATION PPM
0	0	.633	39.58	.0148
915	-420	1.775	111.07	.0417
915	-210	4.022	251.67	.0944
915	0	9.913	620.33	.2326
915	210	11.999	750.89	.2816
915	420	13.302	832.42	.3122
1750	-540	.765	47.85	.0179
1750	-270	2.568	160.69	.0603
1750	0	6.920	433.05	.1624
1750	270	9.224	577.20	.2164
1750	540	6.373	398.78	.1495
2875	-540	1.482	92.75	.0348
2875	-270	1.567	98.07	.0368
2875	0	3.521	220.36	.0826
2875	270	3.757	235.13	.0882
2875	540	6.146	384.60	.1442
4500	-540	.935	58.49	.0219
4500	-270	1.123	70.30	.0264
4500	0	1.869	116.98	.0439
4500	270	3.748	234.54	.0880
4500	540	3.550	222.14	.0833
5355	0	1.935	121.11	.0454
-1750	0	0.000	0.00	0.0000
MAXIMUM VALUES		13.302	832.42	.3122

RUN NUMBER	7
UNIT NUMBER	1
WIND DIRECTION	W
WIND SPEED (FT/S)	44
PERCENT LOAD	50
SO2 RELEASE RATE (GM/S)	78
STACK LOCATION (FT) X=	-100
Y=	0
STACK HEIGHT (FT)	250
STRATIFICATION	NEUTRAL
STACK VELOCITY (FT/S)	16.80

SAMPLE POSITION X	Y	CONCENTRATION COEFFICIENT K*10**6 (FT)**-2	SO2 CONCENTRATION MICRO GM PER CU.M	SO2 CONCENTRATION PPM
0	0	3.153	197.32	.0740
915	-420	.245	15.36	.0058
915	-210	2.285	142.97	.0536
915	0	8.941	559.47	.2098
915	210	2.823	176.65	.0662
915	420	.151	9.45	.0035
1750	-540	.047	2.95	.0011
1750	-270	1.416	88.62	.0332
1750	0	6.108	382.24	.1433
1750	270	5.353	334.98	.1256
1750	540	.274	17.13	.0064
2875	-540	.189	11.82	.0044
2875	-270	1.095	68.53	.0257
2875	0	3.795	237.50	.0891
2875	270	2.785	174.28	.0654
2875	540	1.718	107.52	.0403
4500	-540	.651	40.76	.0153
4500	-270	1.435	89.80	.0337
4500	0	2.747	171.92	.0645
4500	270	4.352	272.35	.1021
4500	540	1.737	108.70	.0408
5355	0	3.078	192.60	.0722
-1750	0	0.000	0.00	0.0000
MAXIMUM VALUES		8.941	559.47	.2098

RUN NUMBER 8
UNIT NUMBER 1
WIND DIRECTION NW
WIND SPEED (FT/S) 44
PERCENT LOAD 50
SO2 RELEASE RATE (GM/S) 78
STACK LOCATION (FT) X= -68
Y= 68
STACK HEIGHT (FT) 250
STRATIFICATION NEUTRAL
STACK VELOCITY (FT/S) 16.80

SAMPLE POSITION X	Y	CONCENTRATION COEFFICIENT K*10**6 (FT)**-2	SO2 CONCENTRATION MICRO GM PER CU.M	SO2 CONCENTRATION PPM
0	0	.661	41.36	.0155
915	-420	1.067	66.76	.0250
915	-210	7.222	451.95	.1695
915	0	11.763	736.12	.2760
915	210	3.937	246.36	.0924
915	420	1.142	71.49	.0268
1750	-540	.529	33.08	.0124
1750	-270	5.759	360.38	.1351
1750	0	8.610	538.80	.2020
1750	270	5.306	332.02	.1245
1750	540	.812	50.81	.0191
2875	-540	1.586	99.25	.0372
2875	-270	3.229	202.05	.0758
2875	0	4.409	275.90	.1035
2875	270	2.728	170.74	.0640
2875	540	1.822	114.02	.0428
4500	-540	1.246	77.98	.0292
4500	-270	2.861	179.01	.0671
4500	0	2.247	140.61	.0527
4500	270	3.739	233.95	.0877
4500	540	1.775	111.07	.0417
5355	0	3.115	194.96	.0731
-1750	0	0.000	0.00	0.0000
MAXIMUM VALUES		11.763	736.12	.2760

Table 4-1 Prototype and Model Source Parameters for Unit 2: Harrington Station

DESCRIPTION	PROTOTYPE	MODEL
Stack Diameter (ft)	19.3	.077
Stack Area (ft^2)	292.0	.0047
Stack Height (ft)	300.0	1.2
Gas Temperature (^oF) @ (26.57" Hg)	313.0	-
Load (%)	50.0	50.0
Gas Velocity (ft/s) - V_s	41.0	2.60
Source Strength - SO_2 (g/s) - V_a	165.5	-
Free Stream Velocity (ft/s)	44.0	2.79
$R = \frac{V_s}{V_a}$	.93	.93
$\Delta\rho/\rho_a = (\frac{T_s - T_a}{T_a})$	.32	.32
$Fr_s = \frac{V_2}{g \frac{\Delta\rho}{\rho_a} D}$	8.46	8.46
Q_s (cfm)	719680	.72
Mol wts = $29 (1- \frac{\Delta\rho}{\rho_a})$	19.8	19.8
X_{He} (%)	-	40.0
X_{Prop} (%)	-	5.0
Wind Direction	All	N, NE, E, SE, S, SW, W, NW

Table 4-2 Observed Touchdown Distances from Flow Visualization Tests for Unit 2: Harrington Station

RUN	WIND SPEED (MPH)	WIND DIRECTION	LOAD	STACK HEIGHT (FT)	DISTANCE TO TOUCHDOWN (FT)
9	30	N	50%	300	2000
10	30	NE	50%	300	2000
11	30	E	50%	300	2200
12	30	SE	50%	300	1800
13	30	S	50%	300	2000
14	30	SW	50%	300	1500
15	30	W	50%	300	1300
16	30	NW	50%	300	1200

Table 4-3 Maximum Ground Concentration ($\mu g/m^3$) and Distance to Maximum for Unit 2: Harrington Station

RUN	WIND SPEED (MPH)	WIND DIRECTION	LOAD	STACK HEIGHT (FT)	DISTANCE TO MAXIMUM GROUND CONCENTRATION (FT)	MAXIMUM GROUND CONCENTRATION ($\mu g/m^3$) (~10 min Avg)	(3 hrs Avg)
9	30	N	50%	300	4500	90	50
10	30	NE	50%	300	5355	124	70
11	30	E	50%	300	5355	54	30
12	30	SE	50%	300	5355	162	91
13	30	S	50%	300	5355	77	43
14	30	SW	50%	300	4500	255	143
15	30	W	50%	300	4500	218	122
16	30	NW	50%	300	4500	115	65

Table 4-4 Ground Level Concentration Results - Unit 2

RUN NUMBER	9
UNIT NUMBER	2
WIND DIRECTION	N
WIND SPEED (FT/S)	44
PERCENT LOAD	50
SO2 RELEASE RATE (GM/S)	166
STACK LOCATION (FT) X=	-210
Y=	-165
STACK HEIGHT (FT)	300
STRATIFICATION	NEUTRAL
STACK VELOCITY (FT/S)	41.00

SAMPLE POSITION X	Y	CONCENTRATION COEFFICIENT K*10**6 (FT)**-2	SO2 CONCENTRATION MICRO GM PER CU.M	SO2 CONCENTRATION PPM
0	0	.007	.91	.0003
915	-420	0.000	0.00	0.0000
915	-210	0.000	0.00	0.0000
915	0	.020	2.72	.0010
915	210	.088	11.78	.0044
915	420	.014	1.81	.0007
1750	-540	.007	.91	.0003
1750	-270	.020	2.72	.0010
1750	0	.068	9.06	.0034
1750	270	.225	29.90	.0112
1750	540	.020	2.72	.0010
2875	-540	.007	.91	.0003
2875	-270	.095	12.69	.0048
2875	0	.231	30.81	.0116
2875	270	.286	38.06	.0143
2875	540	.109	14.50	.0054
4500	-540	.061	8.16	.0031
4500	-270	.218	29.00	.0109
4500	0	.218	29.00	.0109
4500	270	.674	89.71	.0336
4500	540	.354	47.12	.0177
5355	0	.463	61.62	.0231
-1750	0	.034	4.53	.0017
MAXIMUM VALUES		.674	89.71	.0336

RUN NUMBER	10
UNIT NUMBER	2
WIND DIRECTION	NE
WIND SPEED (FT/S)	44
PERCENT LOAD	50
SO2 RELEASE RATE (GM/S)	166
STACK LOCATION (FT) X=	-260
Y=	35
STACK HEIGHT (FT)	300
STRATIFICATION	NEUTRAL
STACK VELOCITY (FT/S)	41.00

SAMPLE POSITION X	Y	CONCENTRATION COEFFICIENT K*10**6 (FT)**-2	SO2 CONCENTRATION MICRO GM PER CU.M	SO2 CONCENTRATION PPM
0	0	.014	1.81	.0007
915	-420	.007	.91	.0003
915	-210	.122	16.31	.0061
915	0	.259	34.43	.0129
915	210	.048	6.34	.0024
915	420	.020	2.72	.0010
1750	-540	0.000	0.00	0.0000
1750	-270	.095	12.69	.0048
1750	0	.619	82.46	.0309
1750	270	.245	32.62	.0122
1750	540	.048	6.34	.0024
2875	-540	.007	.91	.0003
2875	-270	.245	32.62	.0122
2875	0	.660	87.90	.0330
2875	270	.265	35.34	.0133
2875	540	.129	17.22	.0065
4500	-540	.061	8.16	.0031
4500	-270	.395	52.56	.0197
4500	0	.572	76.12	.0285
4500	270	.640	85.18	.0319
4500	540	.259	34.43	.0129
5355	0	.932	124.14	.0466
-1750	0	.027	3.62	.0014

MAXIMUM VALUES	.932	124.14	.0466

RUN NUMBER	11
UNIT NUMBER	2
WIND DIRECTION	E
WIND SPEED (FT/S)	44
PERCENT LOAD	50
SO2 RELEASE RATE (GM/S)	166
STACK LOCATION (FT) X=	-165
Y=	210
STACK HEIGHT (FT)	300
STRATIFICATION	NEUTRAL
STACK VELOCITY (FT/S)	41.00

SAMPLE POSITION X	Y	CONCENTRATION COEFFICIENT K*10**6 (FT)**-2	SO2 CONCENTRATION MICRO GM PER CU.M	SO2 CONCENTRATION PPM
0	0	.020	2.72	.0010
915	-420	.020	2.72	.0010
915	-210	.027	3.62	.0014
915	0	.027	3.62	.0014
915	210	.020	2.72	.0010
915	420	.007	.91	.0003
1750	-540	0.000	0.00	0.0000
1750	-270	.068	9.06	.0034
1750	0	.048	6.34	.0024
1750	270	.014	1.81	.0007
1750	540	.027	3.62	.0014
2875	-540	.054	7.25	.0027
2875	-270	.150	19.94	.0075
2875	0	.170	22.65	.0085
2875	270	.020	2.72	.0010
2875	540	.007	.91	.0003
4500	-540	.095	12.69	.0048
4500	-270	.286	38.06	.0143
4500	0	.265	35.34	.0133
4500	270	.191	25.37	.0095
4500	540	.048	6.34	.0024
5355	0	.408	54.37	.0204
-1750	0	.014	1.81	.0007
MAXIMUM VALUES		.408	54.37	.0204

RUN NUMBER 12
UNIT NUMBER 2
WIND DIRECTION SE
WIND SPEED (FT/S) 44
PERCENT LOAD 50
SO2 RELEASE RATE (GM/S) 166
STACK LOCATION (FT) X= 35
Y= 260
STACK HEIGHT (FT) 300
STRATIFICATION NEUTRAL
STACK VELOCITY (FT/S) 41.00

SAMPLE POSITION X	Y	CONCENTRATION COEFFICIENT K*10**6 (FT)**-2	SO2 CONCENTRATION MICRO GM PER CU.M	SO2 CONCENTRATION PPM
0	0	.027	3.62	.0014
915	-420	.102	13.59	.0051
915	-210	.238	31.72	.0119
915	0	.150	19.94	.0075
915	210	.014	1.81	.0007
915	420	.007	.91	.0003
1750	-540	.075	9.97	.0037
1750	-270	.660	87.90	.0330
1750	0	.776	103.30	.0387
1750	270	.129	17.22	.0065
1750	540	0.000	0.00	0.0000
2875	-540	.517	68.87	.0258
2875	-270	.823	109.64	.0411
2875	0	.993	132.30	.0496
2875	270	.333	44.40	.0167
2875	540	.061	8.16	.0031
4500	-540	.163	21.75	.0082
4500	-270	.646	86.08	.0323
4500	0	1.021	135.92	.0510
4500	270	.599	79.74	.0299
4500	540	.184	24.47	.0092
5355	0	1.218	162.20	.0608
-1750	0	.034	4.53	.0017
MAXIMUM VALUES		1.218	162.20	.0608

RUN NUMBER 13
UNIT NUMBER 2
WIND DIRECTION S
WIND SPEED (FT/S) 44
PERCENT LOAD 50
SO2 RELEASE RATE (GM/S) 166
STACK LOCATION (FT) X= 210
Y= 165
STACK HEIGHT (FT) 300
STRATIFICATION NEUTRAL
STACK VELOCITY (FT/S) 41.00

SAMPLE POSITION X	Y	CONCENTRATION COEFFICIENT K*10**6 (FT)**-2	SO2 CONCENTRATION MICRO GM PER CU.M	SO2 CONCENTRATION PPM
0	0	.007	.91	.0003
915	-420	0.000	0.00	0.0000
915	-210	.177	23.56	.0088
915	0	.109	14.50	.0054
915	210	0.000	0.00	0.0000
915	420	0.000	0.00	0.0000
1750	-540	.007	.91	.0003
1750	-270	.388	51.65	.0194
1750	0	.469	62.52	.0234
1750	270	.020	2.72	.0010
1750	540	.014	1.81	.0007
2875	-540	.075	9.97	.0037
2875	-270	.299	39.87	.0150
2875	0	.449	59.81	.0224
2875	270	.048	6.34	.0024
2875	540	.014	1.81	.0007
4500	-540	.061	8.16	.0031
4500	-270	.177	23.56	.0088
4500	0	.442	58.90	.0221
4500	270	.197	26.28	.0099
4500	540	.082	10.87	.0041
5355	0	.578	77.02	.0289
-1750	0	.020	2.72	.0010
MAXIMUM VALUES		.578	77.02	.0289

RUN NUMBER		14
UNIT NUMBER		2
WIND DIRECTION		SW
WIND SPEED (FT/S)		44
PERCENT LOAD		50
SO2 RELEASE RATE (GM/S)		166
STACK LOCATION (FT)	X=	260
	Y=	-35
STACK HEIGHT (FT)		300
STRATIFICATION		NEUTRAL
STACK VELOCITY (FT/S)		41.00

SAMPLE POSITION X	Y	CONCENTRATION COEFFICIENT K*10**6 (FT)**-2	SO2 CONCENTRATION MICRO GM PER CU.M	SO2 CONCENTRATION PPM
0	0	.007	.91	.0003
915	-420	0.000	0.00	0.0000
915	-210	.034	4.53	.0017
915	0	.204	27.18	.0102
915	210	.191	25.37	.0095
915	420	.068	9.06	.0034
1750	-540	.007	.91	.0003
1750	-270	.231	30.81	.0116
1750	0	1.204	160.39	.0601
1750	270	1.068	142.26	.0533
1750	540	.143	19.03	.0071
2875	-540	.225	29.90	.0112
2875	-270	.912	121.42	.0455
2875	0	1.830	243.75	.0914
2875	270	1.300	173.07	.0649
2875	540	.619	82.46	.0309
4500	-540	.218	29.00	.0109
4500	-270	.497	66.15	.0248
4500	0	1.368	182.14	.0683
4500	270	1.912	254.63	.0955
4500	540	.286	38.06	.0143
5355	0	1.681	223.82	.0839
-1750	0	.027	3.62	.0014
MAXIMUM VALUES		1.912	254.63	.0955

RUN NUMBER	15
UNIT NUMBER	2
WIND DIRECTION	W
WIND SPEED (FT/S)	44
PERCENT LOAD	50
SO2 RELEASE RATE (GM/S)	166
STACK LOCATION (FT) X=	165
Y=	-210
STACK HEIGHT (FT)	300
STRATIFICATION	NEUTRAL
STACK VELOCITY (FT/S)	41.00

SAMPLE POSITION X	Y	CONCENTRATION COEFFICIENT K*10**6 (FT)**-2	SO2 CONCENTRATION MICRO GM PER CU.M	SO2 CONCENTRATION PPM
0	0	.027	3.62	.0014
915	-420	.007	.91	.0003
915	-210	.048	6.34	.0024
915	0	.333	44.40	.0167
915	210	.061	8.16	.0031
915	420	.014	1.81	.0007
1750	-540	.007	.91	.0003
1750	-270	.014	1.81	.0007
1750	0	.082	10.87	.0041
1750	270	.408	54.37	.0204
1750	540	.027	3.62	.0014
2875	-540	0.000	0.00	0.0000
2875	-270	.034	4.53	.0017
2875	0	.259	34.43	.0129
2875	270	.619	82.46	.0309
2875	540	.510	67.96	.0255
4500	-540	.075	9.97	.0037
4500	-270	.156	20.84	.0078
4500	0	.517	68.87	.0258
4500	270	1.640	218.38	.0819
4500	540	1.442	192.10	.0720
5355	0	.742	98.77	.0370
-1750	0	.007	.91	.0003
MAXIMUM VALUES		1.640	218.38	.0819

RUN NUMBER 16
UNIT NUMBER 2
WIND DIRECTION NW
WIND SPEED (FT/S) 44
PERCENT LOAD 50
SO2 RELEASE RATE (GM/S) 166
STACK LOCATION (FT) X= -35
Y= -260
STACK HEIGHT (FT) 300
STRATIFICATION NEUTRAL
STACK VELOCITY (FT/S) 41.00

SAMPLE POSITION X	Y	CONCENTRATION COEFFICIENT K*10**6 (FT)**-2	SO2 CONCENTRATION MICRO GM PER CU.M	SO2 CONCENTRATION PPM
0	0	.014	1.81	.0007
915	-420	.007	.91	.0003
915	-210	.027	3.62	.0014
915	0	.259	34.43	.0129
915	210	.272	36.25	.0136
915	420	.122	16.31	.0061
1750	-540	0.000	0.00	0.0000
1750	-270	.082	10.87	.0041
1750	0	.259	34.43	.0129
1750	270	.660	87.90	.0330
1750	540	.429	57.09	.0214
2875	-540	.020	2.72	.0010
2875	-270	.088	11.78	.0044
2875	0	.306	40.78	.0153
2875	270	.599	79.74	.0299
2875	540	.333	44.40	.0167
4500	-540	.082	10.87	.0041
4500	-270	.102	13.59	.0051
4500	0	.374	49.84	.0187
4500	270	.415	55.27	.0207
4500	540	.864	115.08	.0432
5355	0	.599	79.74	.0299
-1750	0	0.000	0.00	0.0000
MAXIMUM VALUES		.864	115.08	.0432

Table 5-1 Prototype and Model Source Parameters for Unit 3: Harrington Station

DESCRIPTION	PROTOTYPE	MODEL
Stack Diameter (ft)	19.3	.077
Stack Area (ft^2)	292.0	.0047
Stack Height (ft)	300.0	1.2
Gas Temperature (^oF) @ (26.57" Hg)	313.0	-
Load (%)	50.0	50.0
Gas Velocity (ft/s) - V_s	41.0	41.0
Source Strength - SO_2 (g/s) - V_a	165.5	165.5
Free Stream Velocity (ft/s)	44.0	44.0
$R = \frac{V_s}{V_a}$	.93	.93
$\Delta\rho/\rho_a = \left(\frac{T_s - T_a}{T_a} \right)$	.32	.32
$Fr_s = \frac{V^2}{g \frac{\Delta\rho}{\rho_a} D}$	8.46	8.46
Q_s (cfm)	719680	.72
Mol wts = $29 \left(1 - \frac{\Delta\rho}{\rho_a}\right)$	19.8	19.8
χ_{He} (%)	-	40.0
χ_{Prop} (%)	-	5.0
Wind Direction	All	SE, SW

Table 5-2 Observed Touchdown Distances from Flow Visualization Tests for Unit 3: Harrington Station

RUN	WIND SPEED (MPH)	WIND DIRECTION	LOAD	STACK HEIGHT (FT)	DISTANCE TO TOUCHDOWN (FT)
17	30	SE	50%	300	1700
18	30	SW	50%	300	1500

Table 5-3 Maximum Ground Concentration ($\mu g/m^3$) and Distance to Maximum for Unit 3: Harrington Station

RUN	WIND SPEED (MPH)	WIND DIRECTION	LOAD	STACK HEIGHT (FT)	DISTANCE TO MAXIMUM GROUND CONCENTRATION (FT)	MAXIMUM GROUND CONCENTRATION ($\mu g/m^3$) (~10 min Avg)	(3 hrs Avg)
17	30	SE	50%	300	4500	99	54
18	30	SW	50%	300	2875	323	181

Table 5-4 Ground Level Concentration Results - Unit 3

RUN NUMBER 17
UNIT NUMBER 3
WIND DIRECTION SE
WIND SPEED (FT/S) 44
PERCENT LOAD 50
SO2 RELEASE RATE (GM/S) 166
STACK LOCATION (FT) X= 18
Y= 480
STACK HEIGHT (FT) 300
STRATIFICATION NEUTRAL
STACK VELOCITY (FT/S) 41.00

SAMPLE POSITION X	Y	CONCENTRATION COEFFICIENT K*10**6 (FT)**-2	SO2 CONCENTRATION MICRO GM PER CU.M	SO2 CONCENTRATION PPM
0	0	.007	.91	.0003
915	-420	.007	.91	.0003
915	-210	.007	.91	.0003
915	0	.007	.91	.0003
915	210	0.000	0.00	0.0000
915	420	.007	.91	.0003
1750	-540	.034	4.53	.0017
1750	-270	.102	13.59	.0051
1750	0	.027	3.62	.0014
1750	270	.007	.91	.0003
1750	540	.007	.91	.0003
2875	-540	.211	28.09	.0105
2875	-270	.191	25.37	.0095
2875	0	.163	21.75	.0082
2875	270	.027	3.62	.0014
2875	540	.007	.91	.0003
4500	-540	.238	31.72	.0119
4500	-270	.742	98.77	.0370
4500	0	.150	19.94	.0075
4500	270	.211	28.09	.0105
4500	540	.034	4.53	.0017
5355	0	.612	81.55	.0306
-1750	0	0.000	0.00	0.0000
MAXIMUM VALUES		.742	98.77	.0370

RUN NUMBER 18
UNIT NUMBER 3
WIND DIRECTION SW
WIND SPEED (FT/S) 44
PERCENT LOAD 50
SO2 RELEASE RATE (GM/S) 166
STACK LOCATION (FT) X= 480
Y= 18
STACK HEIGHT (FT) 300
STRATIFICATION NEUTRAL
STACK VELOCITY (FT/S) 41.00

SAMPLE POSITION X	Y	CONCENTRATION COEFFICIENT K*10**6 (FT)**-2	SO2 CONCENTRATION MICRO GM PER CU.M	SO2 CONCENTRATION PPM
0	0	.014	1.81	.0007
915	-420	0.000	0.00	0.0000
915	-210	.102	13.59	.0051
915	0	.109	14.50	.0054
915	210	.007	.91	.0003
915	420	.007	.91	.0003
1750	-540	.088	11.78	.0044
1750	-270	1.170	155.86	.0584
1750	0	2.021	269.13	.1009
1750	270	.714	95.15	.0357
1750	540	.034	4.53	.0017
2875	-540	.953	126.86	.0476
2875	-270	1.599	212.94	.0799
2875	0	2.429	323.49	.1213
2875	270	1.361	181.23	.0680
2875	540	.524	69.77	.0262
4500	-540	.374	49.84	.0187
4500	-270	1.783	237.41	.0890
4500	0	1.306	173.98	.0652
4500	270	2.116	281.81	.1057
4500	540	.306	40.78	.0153
5355	0	2.075	276.37	.1036
-1750	0	.041	5.44	.0020
MAXIMUM VALUES		2.429	323.49	.1213

Table 5.5 Movie Log
Harrington Power Station--Unit 3

Run	Wind	Unit	Load
1	N	1	50%
2	NE	1	50
3	E	1	50
4	SE	1	50
5	S	1	50
6	SW	1	50
7	W	1	50
8	NW	1	50
9	N	2	50
10	NE	2	50
11	E	2	50
12	SE	2	50
13	S	2	50
14	SW	2	50
15	W	2	50
16	NW	2	50
17	SE	3	50
18	SW	3	50
19	SE	1	50

Unit 1--Changing Wind Direction--Plan View
Unit 2--Changing Wind Direction--Plan View
Unit 3--Changing Wind Direction--Plan View
END