CIRCULATION OF VENTED GASES AROUND
BIOMEDICAL RESEARCH FACILITY

Prepared by

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ABSTRACT

Tests were made to determine air quality entering the ventilation system around the proposed biomedical research facility (BRF). Comparisons are made of the nondimensional concentrations with the six separate stacks located in line on the BRF roof and those with one discharge stack (third from south) serving all vents through a manifold system. The maximum concentrations measured with the singlestack configuration are one order-of-magnitude less than those using the six-stack configuration. The effect of velocity ratio (exit velocity of exhaust gases to wind velocity at exit height) is evaluated. The higher velocity ratio causes larger plume rise and smaller values of nondimensional concentration. Two stack heights for the single-stack configuration--flush and 3.05 m (prototype height) were used to establish the effect of stack height on concentrations. Using the 3.05 m stack, higher plume rise was observed and the nondimensional concentrations were reduced by at least a factor of 4 compared to values obtained with the flush stack and the same velocity ratio.

1. INTRODUCTION

Maintenance of good air quality at air intakes into the proposed Biomedical Research Facility (BRF) and its surroundings is essential. The present study is to determine the characteristics of wind driven circulation of vented gases around the BRF and to establish a stack arrangement that will not result in contamination of air entering the ventilation system or excessive pollution of areas devoted to pedestrian use.

A 1:240 scale model of the BRF and adjacent buildings (provided by the University of New Mexico) was used to study movement of exhaust gases. The BRF model was placed in the industrial wind tunnel (see Appendix I) that is capable of simulating natural winds. A visual tracer (smoke) was introduced into the vent effluent and the circulation patterns were recorded for different wind directions, using both still and motion picture photography.

Two different configurations were studied:

1. Configuration I: six separate stacks in a line on and flush with the BRF roof.
2. Configuration II: one discharge stack (the third from south) serving all stacks through a manifold system and the proposed connecting three-floor passageway between the old and new buildings removed.

In addition to qualitative information obtained by flow visualization, quantitative data were obtained for both configurations by measurement of tracer gas concentration at air-intake locations.

Similarity of the flow upstream of the BRF model in the wind tunnel to the flow in the atmosphere was established through measurements and analysis of mean velocity and turbulent intensity profiles for flow approaching the model.

2. EXPERIMENTAL PROCEDURE

2.1. Plume Visualization

Smoke was used to visually assess the transport of the plume from the (BRF) exhausts. The smoke was produced by passing the required gas mixture (10.2 percent ethane, 3.6 percent carbondioxide and 86.2 percent nitrogen) through a container of titanium tetrachloride located outside the wind tunnel and transported through the tunnel wall by means of tygon tube terminating at the inlet of the exhausts. The plume was illuminated with high intensity lamps and a visible record was obtained by means of black and white photographs taken with supergraphic camera (lens focal length 305 mm) and color slides taken with one Canon F-1 camera (focal length 35.7 mm). The black and white photographs are actually a composite of four superimposed pictures taken consecutively. This procedure was performed to obtain an average plume trajectory and not lose the detail of the turbulent motion as happens at larger shutter speeds. The black and white photographs and the color slides were taken at an angle perpendicular to the wind tunnel axis such that the field of view extends from the stack to approximately 130 m downwind in prototype.

A series of 16 mm motion pictures were taken of most of the tests. A Bolex movie camera was used with a speed of 7 m/sec. The movies consisted of taking an initial close-up of the smoke release after which the camera was moved parallel to the tunnel axis from the BRF model approximately 130 m downwind in prototype.

2.2 Gas Tracer Technique

The purpose of this phase of the experimental study is to provide quantitative information on the transport and dispersion of the plume emitted form the BRF for different configuration of the exhaust ports. Concentration measurement were taken for the samples obtained at the four air conditioning intakes showed in Figure (1). Concentration values were measured four times and averaged so that an average concentration representative of the true mean could be obtained.

The test procedure consisted of: 1) setting the proper wind tunnel speed (u_∞ = 6 m/sec or 2 m/sec), 2) releasing a metered mixture of source gas (ethane, nitrogen and carbondioxide) of the required density from the release probe, 3) withdraw samples of air from the tunnel at the locations of the air conditioning intake, and 4) analyze the samples with flame ionization gas chromatograph (FIGC). A schematic of the gas sampling equipment setup is shown in Figure (1-b).

The procedure for analyzing air samples from the tunnel was as follows: 1) a 2 cc sample volume (represents approximately a 2 second averaging time) drawn from the wind tunnel is introduced into the flame ionization detector (FID), 2) the output from the electrometer (in millivolts) is sent to the Fluid Dynamics and Diffusion Laboratory (FDDL) dedicated minicomputer system, 3) the analog signal is converted to a digital record at a rate of 208 values per second which are then averaged in groups of 16, 4) a digital record is integrated and an ethane concentration determined by multiplying the integrated signal (mvs) times a calibration factor (ppm/mvs), 5) the ethane concentration is stored in the computer for subsequent use, and 6) a summary of the computer analysis (ethane concentration, peak height, integrated voltage, etc.) is printed out on the remote terminal at the wind tunnel. Prior to any data collection a known concentration of ethane is introduced into the FID to determine the calibration factor. This factor is input into the computer for use in converting the data.

The FID operates on the principal that the electrical conductivity of a gas is directly proportional to the concentration of charged particles within the gas. The ions in this case are formed by the effluent gas being mixed in the FID with hydrogen and then burned in air. The ions and electrons formed enter an electrode gap and decrease the gap resistance. The resulting voltage drop is amplified by an electrometer and fed to the FDDL computer. When no effluent gas is flowing, a carrier gas flows (nitrogen) through the FID. Due to certain impurities in the carrier some ions and electrons are formed creating a background voltage or zero shift. When the effluent gas enters the FID the voltage increases above this zero shift in proportion to the degree of ionization or correspondingly the amount of tracer gas present. Since the chromotograph used in this study features a temperature control on the flame and electrometer; there is very low zero drift. In case of any zero drift the computer program which integrates the effluent peak also substracts out the zero drift.

The wind-tunnel concentration data for all tests in this report are presented in the following dimensionless form

$$K = \frac{C}{C_o} \quad \frac{U\,L^2}{V}$$

C: is the observed concentration, C_o is the source strength, U is the wind speed at the exhaust height, L the exit diameter and V is the total volume flow rate of exhaust gases.

To determine a corresponding full-scale concentration from the model K values the K model (K_m) is set equal to K-prototype (K_p) i.e.

$$\left[\frac{C}{C_o} \quad \frac{U\,L^2}{V}\right]_p = \left[\frac{C}{C_o} \quad \frac{U\,L^2}{V}\right]_m$$

3. DISPERSION RESULTS

3.1 Plume Visualization

Visualization of plumes from the model stacks was accomplished by using smoke as the effluent. This technique enabled a qualitative study of exhaust transport to the four air-conditioning intakes. Typical sets of black and white photographs are included. Figure 2 shows the plume dispersion for a west wind (270° north azimuth). Photograph 2a illustrates the plume for Configuration I (six stacks and the connecting passageway in place) with a velocity ratio $\frac{V}{U} = 1$. A considerable amount of the plume is trapped in the cavity between the two buildings and around the air intakes. Photographs 2b and 2c show the plume for Configuration II (single stack and the connecting passageway completely removed) with velocity ratio $\frac{V}{U} = 3$. A remarkable plume rise takes place due to higher relative momentum of the exit gases. The air-conditioning intakes are out of the area of visible plume spread. A more satisfactory plume rise is achieved with a 0.0127 m stack height (3.05 prototype) shown in photograph 2c than is seen in photograph 2b with a stack flush with the roof.

Another set of photographs is shown in Figure 3 for the northwest wind. This set was selected in order to visualize the plume dispersion around intake No. 4 (see Figure 1). This intake shows high concentration with Configuration I for northwest wind (see Table 1 for the quantitative results). Photograph 3a shows that for Configuration I, intake No. 4 is completely embedded in the plume. Photograph 3b shows a considerable improvement of the air quality by using Configuration II with a velocity ratio $\frac{V}{U} = 3$. It should be noticed in photograph 2b that traces of the smoke are shed by the roof of the penthouse for the flush stack.

Photograph 3c confirms that even better air quality could be achieved with a stack height of 3.05 m (prototype), the plume is free of the penthouse roof.

It should be pointed out that removing the connecting passageway between the old and the new building prevents the trapped gases from recirculating within this cavity. A similar favorable effect is expected if the proposed solid passageway were replaced by one with openings between floors 1 and 2 and floors 2 and 3.

3.2 Effluent Concentrations

In order to provide quantitative information on the transport of effluent emitted from the BRF stack, concentration measurements were made at the locations shown on Figure 1 for different wind directions. A metered quantity of gas tagged with ethane C_2H_6 was released from the model stacks. For comparison among various tests the data have been nondimensionalized in the following form:

$$K = \frac{C}{C_o} \frac{UL^2}{\forall}$$

- C is the sample strength as measured by the gas chromatograph in millivolt-sec
- C_o is the source strength in millivolt-sec
- U is the wind velocity at the level of the gas exit in m/sec
- L is the scale length taken to be the stack diameter of 0.004 m (model)
- $\forall$ is the total volume of gases emitted in m^3/sec

Both Configurations I and II were tested to establish the effect of velocity ratio $\frac{V}{U}$ and stack height on values of the nondimensional concentration.

Table 1 gives a summary of the nondimensional concentrations for five different wind directions. It should be pointed out that with Configuration II, one stack only is active, and the velocity ratio $\frac{V}{U}$ should be increased so that the same amount of gases will be released for the same wind velocity. From the table it is clear that the maximum concentration for Configuration II and $\frac{V}{U} = 3$ is an order of magnitude smaller than those for Configuration I with $\frac{V}{U} = 1$. Table 2 shows a considerable reduction of the maximum nondimensional concentration with higher velocity ratio $\frac{V}{U}$. Comparison is made between the cases of $\frac{V}{U} = 1$ and $\frac{V}{U} = 3$. The higher velocity ratio causes larger plume rise and hence less gases are trapped between the two buldings and around the air-conditioning intakes.

Measurements were also made for Configuration II with flush stacks and with a 3.05 m (prototype) stack. Table 3 shows more improvement of the air quality with the 3.05 m stack than with the flush stack. The effect of the stack is more pronounced in the case with $\frac{V}{U} = 3$. Table 3b shows a reduction of maximum concentration for the 3.05 m stack by a factor of at least 4 when compared with the flush stack.

4. SUMMARY OF FINDINGS

Removing the connecting passageway between the old and the proposed BRF building prevents the traped gases from ciculating within the cavity in between the two buildings.

Using a single elevated (3.05 m) stack, the plume is free of the penthouse roof and the maximum nondimensional concentrations are reduced by a factor of about 40, when compared with six flush exhaust ports.

The configuration of one discharge stack (third from south) serving all vents through a manifold permits high velocity ratio of exhaust gases velocity to the mean wind velocity at the exit height for the same wind conditions. Higher velocity ratio produce larger plume rise. The plume with $\frac{V}{U} = 1$ produces maximum concentration values of about six times those produced by the plume with $\frac{V}{U} = 3$ for the same exit configurations and surrounding wind speed.

APPENDIX I

Physical Model of the Natural Wind

Velocity measurements were made to assess the similarity of the wind-tunnel velocity profiles to those in the atmosphere. Two vertical wind profiles were measured at free stream velocities U_∞ of 6.00 m/sec and 2 m/sec. A 0.0254 m roughness upwind of the model was used. Figures 1A and 2A show the model arrangement and location of measurement in the industrial wind tunnel.

To examine the flows characteristics in the wind tunnel and to aid in comparing the atmospheric flows, the velocity profiles (see Figure 3A) were analyzed to obtain the surface roughness z_o, the friction velocity u_*, the turbulent Reynolds number Re_{z_o} (based on the roughness z_o and the friction velocity u_*) and the power-law exponent n. The estimated values for each profile are given in Table 1A. The values of z_o and u_* were determined such that they give the best fit (by least squares) to the following equation which is a characteristic of atmospheric (Businger, 1972)[1] and wind-tunnel flows (Cermak, 1975)[2],

$$\frac{u}{u_*} = \frac{1}{k} \ln \left(\frac{z}{z_o}\right) \ .$$

[1]Businger, J. A., "The Atmospheric Boundary Layer," Chapter 6 in Remote Sensing of the Troposphere, edited by V. E. Derr, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1972.

[2]Cermak, J. E., "Applications of Fluid Mechanics to Wind Engineering--A Freeman Scholar Lecture," Transactions of the ASME, Journal of Fluids Engineering, Vol. 97, March 1975, pp. 9-38.

For wind-tunnel similarity the model z_o should equal the atmospheric value divided by the scale factor of 240. The expected value for z_o in the vicinity of the BRF is around 25 cm. This results in desired values for a model z_o around 0.1 cm. As can be seen from Table 1A the wind profiles give z_o in good agreement with the required range. Furthermore, the exponent for the power-law mean velocity distribution:

$$\frac{U}{U_\infty} = \left(\frac{z}{z_\infty}\right)^n$$

is found to be 0.22. This value is in good agreement with values obtained in strong winds over urban areas. The values of turbulent Reynolds number in Table 1A are well above the limit of Reynolds number dependence. The Reynolds number independence is achieved for Re_{z_o} higher than 2.5.

The turbulence intensity profiles are displayed in Figure 3A, the approach turbulence profiles varies from 28% near the floor to 8.0% at 50 cm height.

In summary the velocity profiles show that the boundary layer in the wind tunnel closely approximate that expected for the vicinity of the BRF.

APPENDIX II

Calculation of Prototype Concentration

To determine a corresponding full-scale concentration from the K values, the K-model (Km) is set equal to K-prototype (Kp)

$$K_m = K_p = \left[\frac{C}{C_o} \frac{UL^2}{V}\right]_p$$

for stack 3.05 m height and .95 m diameter with the exit gases velocity V = 19.3 m/sec and wind speed U = 6.4 m/sec (14 mph) at the exit level. The maximum value of K is $.24 \times 10^{-5}$ (see Table 1 for $\frac{V}{U} = 3$).

$$\frac{C}{C_o} = .24 \times 10^{-5} \quad \frac{V}{UL^2} = (.24) \; \frac{13.68 \times 10^{-5}}{6.43 \times (.95)^2}$$

$$\frac{C}{C_o} = 5.7 \times 10^{-6}$$

for lower values of wind speed we will have higher velocity ratio and thus smaller K values.

FIGURES AND TABLES

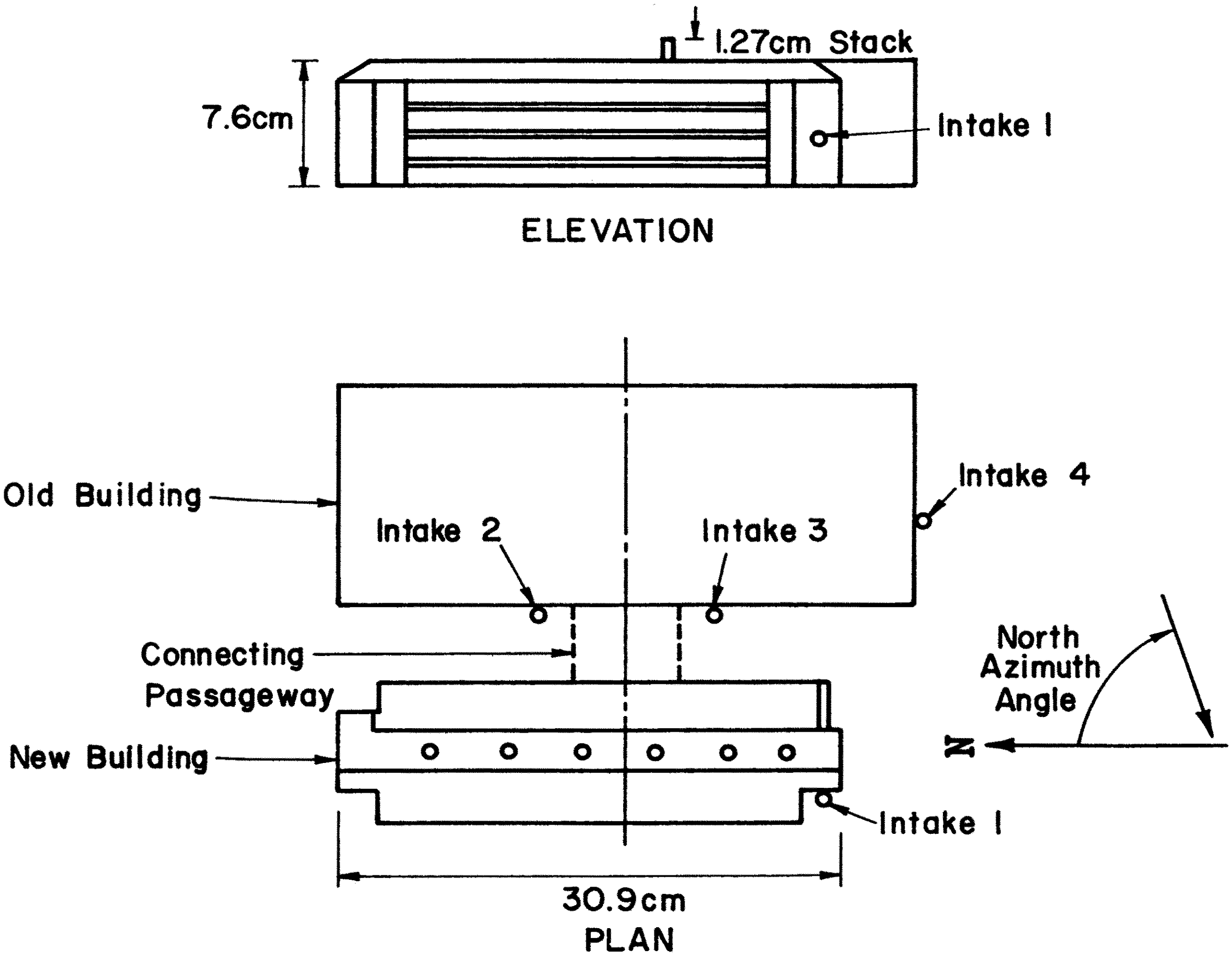


Figure 1. Sketch of Model:

Configuration I: six exhaust vents working and the connecting passageway in place.

Configuration II: single stack working and the connecting passageway removed (third from south).

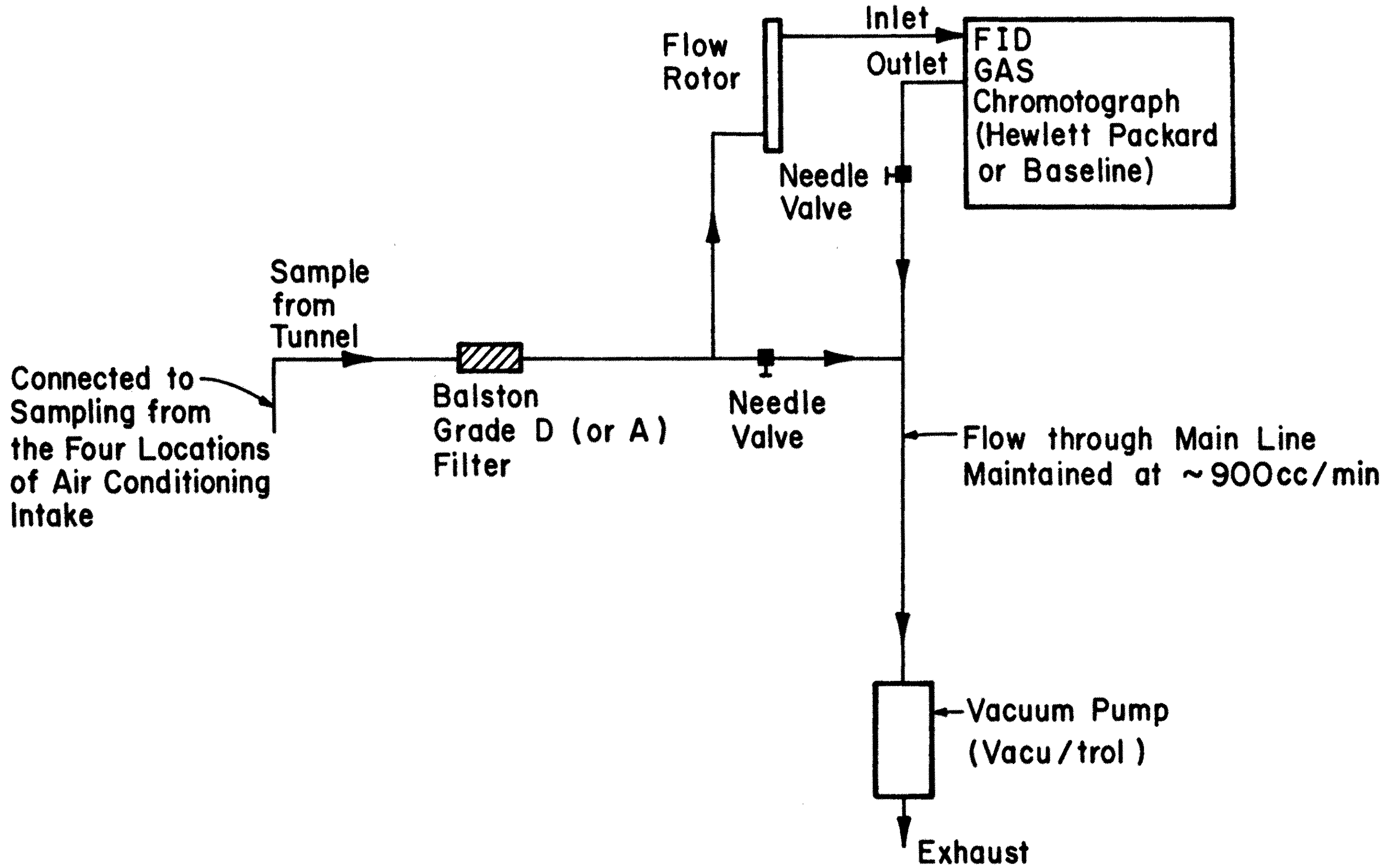
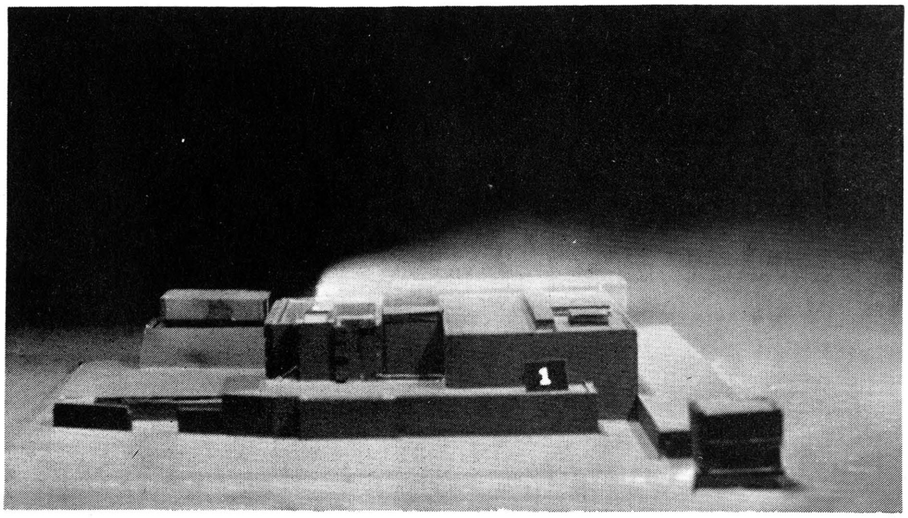
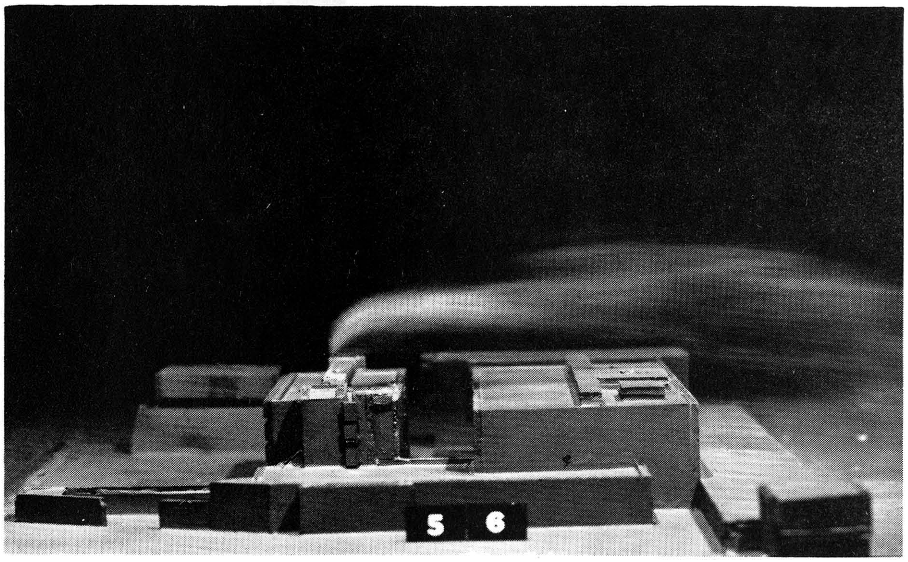


Figure 1.B. Schematic of gas sampling equipment set-up.

a. Configuration I
$\frac{V}{U} = 1$



b. Configuration II
flush stack
$\frac{V}{U} = 3$



c. Configuration II
3.05 m stack
$\frac{V}{U} = 3$

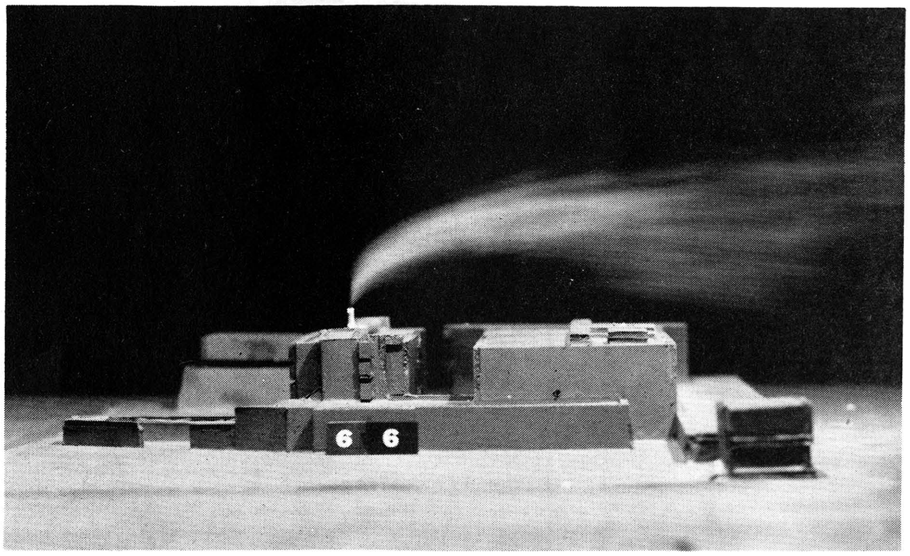
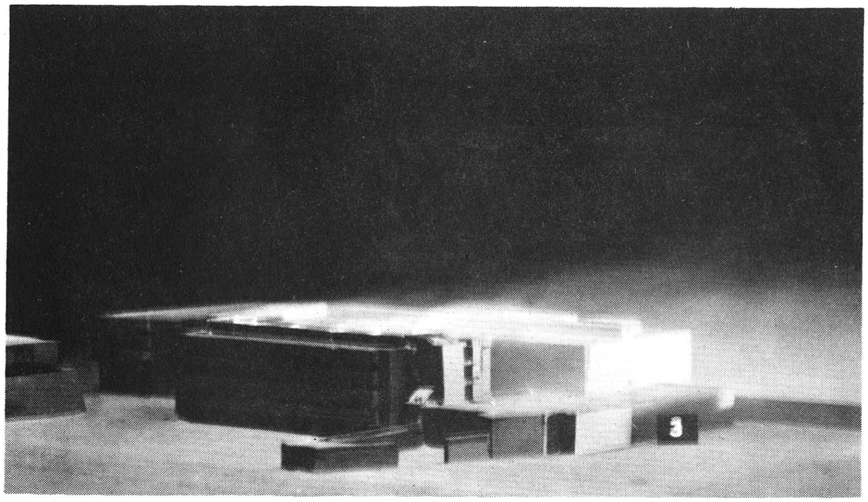
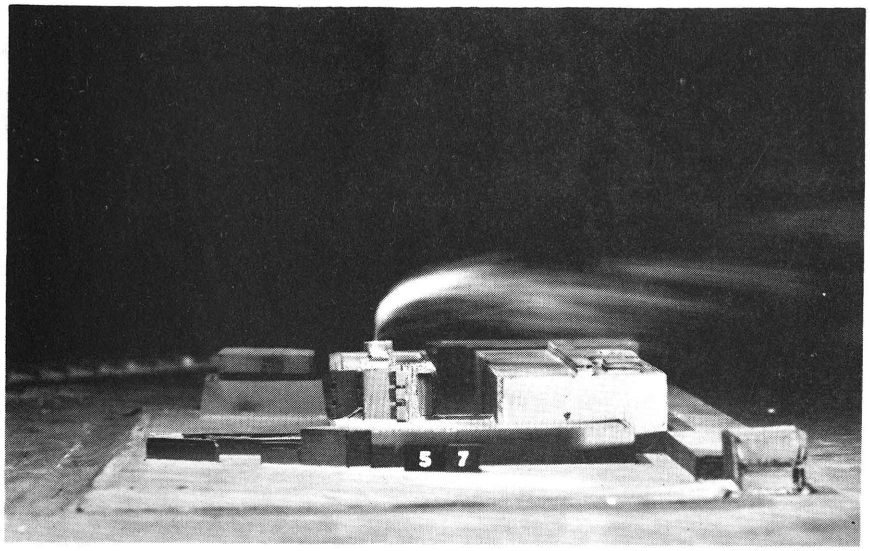


Figure 2. Plume visualizations for west (270°) wind.

a. Configuration I
$\frac{V}{U} = 1$



b. Configuration II
flush stack
$\frac{V}{U} = 3$



c. Configuration II
3.05 m prototype stack
$\frac{V}{U} = 3$

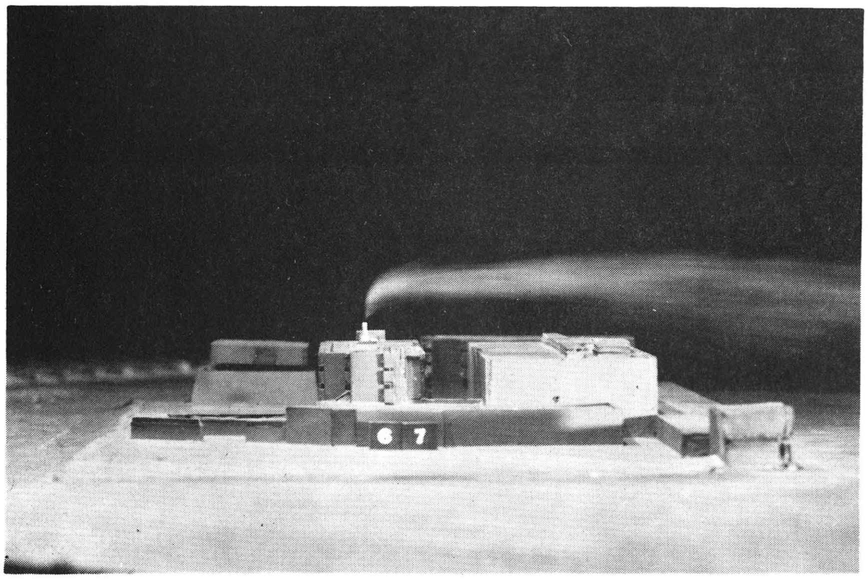


Figure 3. Plume visualization for northwest (315°) wind.

Table 1. Summary of the non-dimensional concentrations around the Biomedical Research Facility.

Description	Non-dimensional Concentrations K x 10^5*															
	Configuration I**, $\frac{V}{U}$ = 1, flush				Configuration II, $\frac{V}{U}$ = 1, flush				Configuration II, $\frac{V}{U}$ = 3, flush				Configuration II $\frac{V}{U}$ = 3, 3.05 m stack			
Port #	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Wind Direction																
S 180°	0.44	0.11	0.60	0.50	0	0	0	0	0	0	0	0	0	0	0	0
SW 225°	0	14.55	0.06	0	0.11	0.10	0.02	0	0	0	0	0	0	0	0	0
W 270°	2.19	10.80	5.12	7.99	0	6.1	3.82	0	0	1.02	0.38	0	0	0.14	0.03	0
NW 315°	5.08	6.95	10.70	11.46	0	0	0	3.46	0	0	0	1.03	0	0	0	0.24
N 000°	0.10	0.13	0.13	0.44	0	0	0	1.66	0.01	0.05	0.05	0.78	0	0	0	0.04

$*K = \frac{C}{C_o} \frac{UL^2}{V}$ (U is the wind speed at the stack height, L stack diameter, V is the gas volume flow rate.)

**Configurations:

(I) six stacks in new building with connecting passageway between buildings,
(II) one stack (third from south) with the connecting passageway removed.

Table 2. Effect of velocity ratio $\frac{V}{U}$.

Wind Direction	Maximum Concentration* K		Intake No.
	$\frac{V}{U} = 1$	$\frac{V}{U} = 3$	
S 180°	4.39×10^{-6}	0	1
SW 225°	1.11×10^{-6}	0	1
W 270°	6.10×10^{-5}	1.02×10^{-5}	2
NW 315°	3.46×10^{-5}	1.03×10^{-5}	4
N 000°	1.66×10^{-5}	7.82×10^{-6}	4

*The non-dimensional concentrations $K = \frac{C}{C_o} \frac{U L^2}{\dot{V}}$

measurements are taken while the third vent from south flushed with the building, is used.

Table 3. Comparison between concentration values with flush and 3.05 m stack for Configuration II.

(a) V/U = 1.0

Wind Direction	Maximum Concentration flush stack	Maximum Concentration 3.05 m stack	Intake No.
S 180°	4.39×10^{-6}	0	1
SW 225°	1.11×10^{-6}	0	1
W 270°	6.1×10^{-5}	5.28×10^{-5}	2
NW 315°	3.46×10^{-5}	4.90×10^{-5}	4
N 000°	1.66×10^{-5}	1.07×10^{-5}	4

(b) V/U = 3.0

W 270°	10.18×10^{-6}	1.38×10^{-6}	2
NW 315°	10.28×10^{-6}	2.46×10^{-6}	4
N 000°	7.8×10^{-6}	0.40×10^{-6}	4

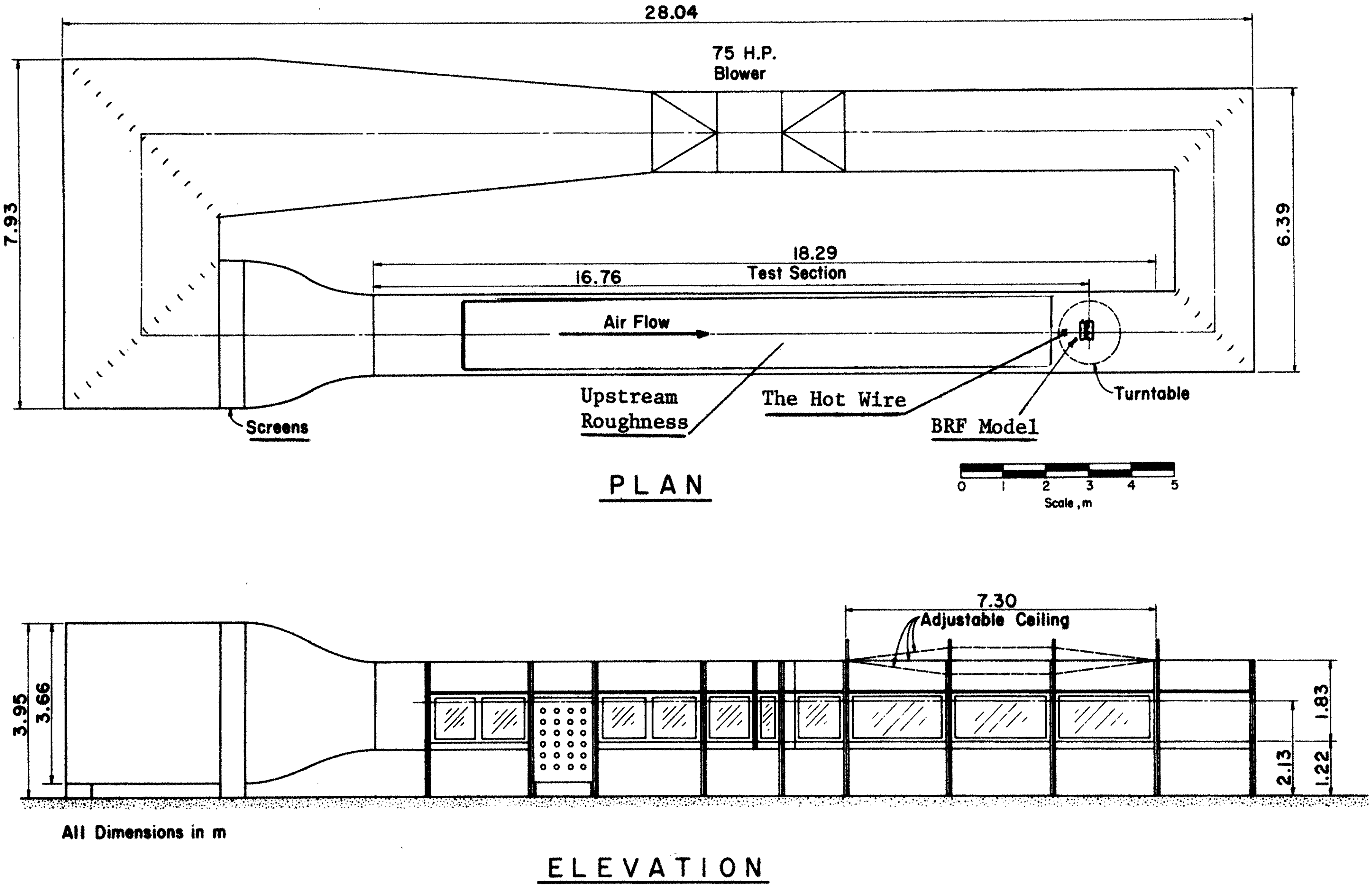


Figure 1.A. Arrangement of the BRF model in Industrial Aerodynamic Wind Tunnel.

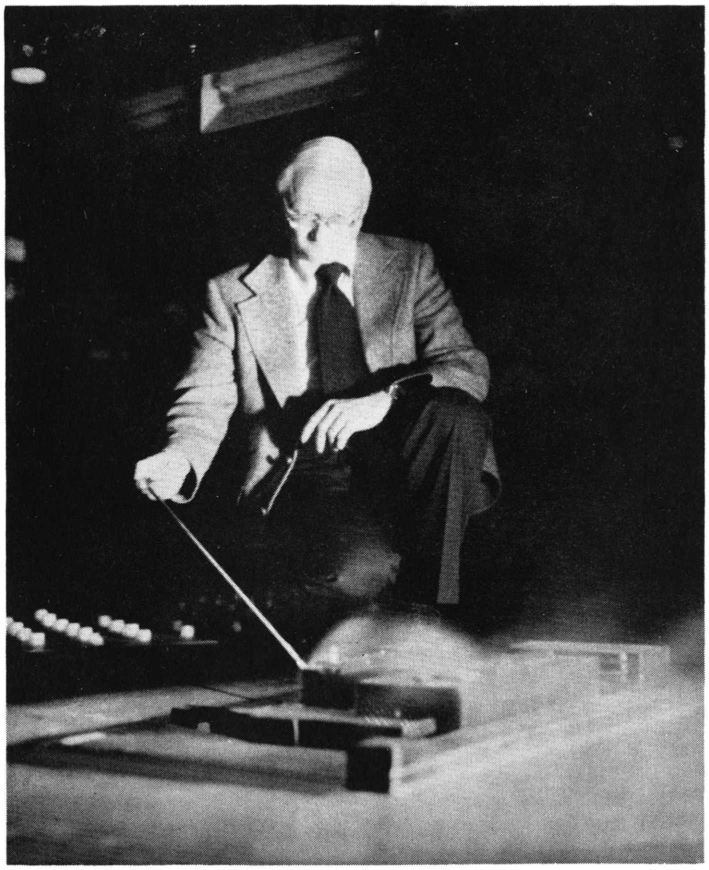


Figure 2.A. View of the BRF Model on the Turntable of the Industrial Wind Tunnel.

Table 1.A.

Free-Stream Velocity U_∞ m/sec	z_o		u_* m/sec	n	Re_{z_o} $\frac{z_o u_*}{\nu}$
	Model cm	Prototype cm			
6.00	0.0873	21.96	0.328	0.22	17.9
2.00	0.0958	22.99	0.142	0.23	8.5

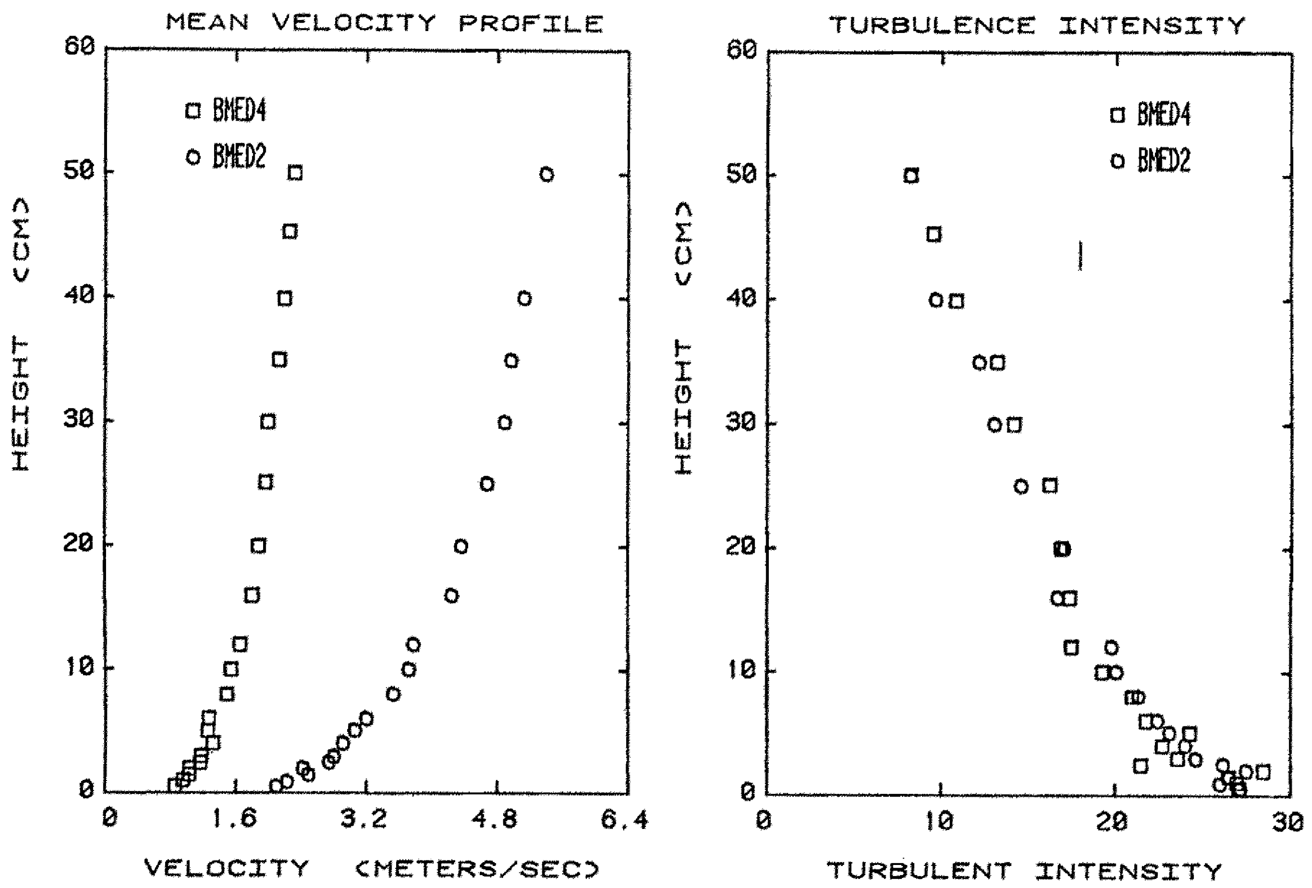


Figure 3.A. Mean velocity and turbulence intensity profiles.

BMED4 U_∞ = 2 m/sec

BMED2 U_∞ = 6 m/sec