WIND-TUNNEL MODEL STUDY OF SHOREHAM NUCLEAR POWER STATION UNIT I LONG ISLAND LIGHTING COMPANY Part II

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Progress Report

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ABSTRACT

Tests were conducted in a meteorological wind tunnel to determine the distribution of gas concentrations resulting from gaseous plumes released from isolated stacks and short stacks varying in height on top of a model of the Shoreham Nuclear Power Station reactor building. The tests were conducted over a reactor complex model which included down-stream topography for a critical flow direction of 345° from "called" north. Data obtained included photographs of model smoke plume trajectories, plume ground impingement distances shown by indicator paints, and local concentration of Kr-85 at the reactor station site boundary. The effects of an additional reactor building expansion were also measured.

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I. INTRODUCTION

This report presents the results of the second phase of a wind-tunnel model study of the proposed Shoreham Nuclear Power Station, Unit I, Long Island Lighting Company, Mineola, New York. The purpose of this study was to investigate the effect of the building complex on effluent releases from a short stack on the roof of the reactor building during station shutdown conditions.

During the first phase of the evaluation of the effluent behavior a model study was made under neutral stratification without the details of surrounding topography to determine (a) if a most unfavorable wind direction existed producing maximum entrainment, and (b) if it was feasible by increasing stack velocity and flow rate to elevate the plume to a level where entrainment into the building separation cavities and dispersal at nearly ground level is absent. The results of the initial measurements, a discussion of the necessary modeling criteria, and a description of the experimental equipment were presented in Reference 1.

It was determined that for low stack efflux velocities entrainment is aggravated by the local building geometries between wind azimuth of 270° to 360°. Higher stack efflux velocities were found to reduce the tendency toward entrainment substantially. It was recommended that further model tests be made to determine the effects on plume dispersion of variations in stack height, of local terrain, and of possible changes in the nuclear building complex geometry.

In the second phase of the evaluation of effluent behavior, reported herein, the response of the characteristics of the effluent plume to stack height, downstream topography, and the addition of Unit II to the reactor complex were studied. In addition the effects of the reactor building complex on gases ejected from a separate isolated stack located approximately 250 meters south of the containment building were observed.

Section II of this report describes the variations in experimental equipment, Section III presents the experimental program and data, and Section IV summarizes the results obtained and their significance.

II. TEST APPARATUS

A. Wind Tunnel

Tests were conducted in the Army Meteorological Wind Tunnel in the Fluid Dynamics and Diffusion Laboratory at Colorado State University. The tunnel, specifically designed to study fluid phenomena of the atmosphere, has a 2 meter square by 26 meter long test section with an adjustable ceiling to provide a zero pressure gradient over modeled terrain. A trip fence, located just upstream from the test section serves to stabilize the flow pattern as well as provide a thicker turbulent boundary layer. Mean velocities may be adjusted between 0 to 37 mps, and boundary layers 0.5 m thick may be obtained.

B. Model

The model consisted of the reactor building, the stack, and the auxiliary buildings constructed to a linear scale of 1:200, a second reactor and turbine facility to simulate the presence of an expanded facility (i.e., Units I and II), and a scale model of the topography extending inland from the power station at an angle of 345°. The topography was modeled for an equivalent downwind distance of 800 meters and extended laterally 200 meters to each side of the containment building of Unit I (see Figure 1).

The model topography was built up from layers of styrofoam sheets, glued, and sanded to fit the contours. All details above the 40 foot contour were developed on the model. The model terrain was coated with a rubber base latex paint to prevent deterioration during handling and chemical attack during flow visualization.

Model stacks with equivalent heights of 4.5, 9.2, 12.2 and 15.3 meters (15, 30, 40, and 50 feet) were constructed to accommodate equivalent flow of 164 and 425 m^3/min. These were positioned at roof center on the reactor building. In addition a separate stack 65 meters high was located at map coordinates 6175 and 3325 at grade 40.

The model building complex was mounted on a large circular plywood sheet which could be rotated into various wind attack angles. The surface roughness was typically 1 cm for the prototype and could be satisfactorily modeled by the smooth tunnel floor. Figure 2 shows two views of the model in the tunnel. The model was built to dimensions taken from a Stone and Webster Drawing 11600-FM-S106A, dated 10-27-67; however, a ventilator exhaust duct was added per Stone and Webster Drawing. (AS 101) A set of static pressure taps were incorporated in the Lucite plastic walls of the reactor containment building. Model stacks were inserted into a threaded hole in the center of the vessel roof.

C. Visualization Techniques

Smoke was used to define plume behavior over the reactor complex. The smoke was produced by bubbling compressed air through a container of titanium-tetrachloride located outside the wind tunnel and transported through the tunnel wall by means of a tygon tube terminating at the stack inlet within the model containment vessel. A visible record was obtained by means of pictures taken with a series 100 Polaroid camera with integrating shutter.

Plume contact with the ground surface was determined by an indicator paint method. The indicator paint was applied to the ground surface of the model, and it consisted of white water-base latex paint mixed with "congo-red" (sodium tetrazodiphenylnapthionate - an organic indicator of pH intensity). Diluted hydrochloric acid was applied to the painted surface which sensitized the surface to the presence of anhydrous ammonia. Anhydrous ammonia was then released at the appropriate rate from the reactor stack into the air stream. A trace of the diffusion plume of ammonia, indicating the surface wind contact, showed as a pink area on the blue background of the model.

D. Gas Tracer Technique*

After the flow in the tunnel was stabilized, a mixture of Kr-85 and air was released from the model reactor stack, and samples of air were withdrawn from the tunnel and analyzed. The flow rate of Kr-85 mixture was controlled by a pressure regulator at the bottle outlet and monitored by a Fisher and Porter flowmeter. Source concentration was 0.69 μ-curie/cc of Kr-85, a beta emitter (half life - 10.3 years).

A sampling rake of eight probes was manufactured from 2 mm diameter hypodermic tubing and was mounted on a traversing carriage whose horizontal and vertical position was controlled remotely from outside the tunnel (see Figure 3). Vertical profiles were made at the site boundaries 300 meters downwind of the reactor building and directly downwind of the releasing stack. Lateral profiles were made at the same position at the height of the concentration maximum measured for the vertical profile. Samples were aspirated at a constant rate of 500 cc/min into eight TGC-308 Tracerlab Geiger Mueller side wall cylindrical counters. Samples were flushed through the counting tubes for at least two minutes, valve A in Figure 5b (Ref. 1) was closed, and each sample was subsequently counted for one minute on a Nuclear Chicago Ultra-scaler Model 192A. All

*This apparatus was developed under the Public Health Service, Contract No. DHEW, 5R01 AP00091-07.

samples counted were adjusted for background radiation (see Figures 5a and 5b, Ref. 1).

III. TEST PROGRAM AND RESULTS

A. Test Program

The test program consisted of (1) a qualitative study of the flow field around the reactor by visual observation of the smoke plume trajectory released on the reactor roof; (2) a qualitative examination of the extent of plume ground contact as displayed by indicator paint color changes, and (3) a quantitative study of gas concentrations produced by the release of Kr-85 from the roof stack. The test conditions are summarized in Table 1. The test program was accomplished in two parts: Phase A involved a stack gas release from various height model stacks on the containment building, and Phase B utilized a separate isolated stack south of the building complex.

Angular locations of the approach winds are referred to in terms of azimuth angles from "called" north. Downwind distances refer to lengths as measured from the center of the reactor containment vessel. Unless otherwise noted, the term wind velocity refers to the velocity in the free stream above the tunnel boundary layer; however, a velocity at any reference height is available by referring to the velocity profiles (Figure 6, Ref. 1).

B. Test Results: Visualization

The test results consist of photographs and sketches depicting the general nature of the plume behavior in the vicinity of the model reactor. A review of general wake and cavity flow behavior is helpful for an interpretation of the plume movements - see References 1 or 2.

Centerline sections of the smoke plume outlines are displayed on Figure 4 for a stack height variation from 4.5 to 15.3 meters on top of the reactor building. The wind approach angle throughout was

TABLE 1. Summary of Data Collection Program

Efflux Conditions Studied

Prototype			Model	
Stack Area (m^2)	Efflux Rate (m^3/min)	Jet Velocity (m/sec)	Stack Diameter (cm)	Jet Velocity (m/sec)
0.465	425.0	15.2	0.384	15.2
0.031	164.0	32.8	.160	32.8

Phase A:

Wind Direction (Azimuth)	Wind Velocity (m/sec)	Stack Diameter (cm)	Jet Velocity (m/sec)	Stack Height (m)	Unit II Present	Photos of Smoke	Surface Visual-ization	Concentration Profiles
345°	4	0.384	15.2	4.5	No	Yes	Yes	No
				9.2	No	Yes	Yes	No
				12.2	No	Yes	Yes	No
				15.3	No	Yes	Yes	No
				15.3	Yes	Yes	Yes	No
345°	4	0.160	32.8	4.5	No	No	Yes	Yes
				9.2	No	No	Yes	Yes
				12.2	No	No	Yes	Yes
				15.3	No	No	Yes	Yes
				15.3	Yes	No	Yes	Yes

Phase B: (Single stack located at map co-ordinates 6175 and 3325, Point 5 of Figure 1)

Wind Direction (Azimuth)	Wind Velocity (m/sec)	Stack Diameter (cm)	Jet Velocity (m/sec)	Stack Height (m)	Unit II Present	Photos of Smoke	Surface Visual-ization	Concentration Profiles
0°	4	0.384	15.2	65	Yes and No	Yes	Yes	No
15°	4	0.384	15.2	65	Yes and No	Yes	Yes	No
180°	4	0.384	15.2	65	Yes and No	Yes	Yes	No
345°	4	0.384	15.2	65	Yes and No	Yes	Yes	No
0°	4	0.160	32.8	65	Yes and No	No	Yes	Yes
15°	4	0.160	32.8	65	Yes and No	No	Yes	Yes
180°	4	0.160	32.8	65	Yes and No	No	Yes	Yes
345°	4	0.160	32.8	65	Yes and No	No	Yes	Yes

345° to "called" north at 4 m/sec to include the effects of "critical wind"direction* and maximum nearly terrain rise downstream.

The improvement in reduction of plume entrainment was very marked over the relatively small height increases. It is especially significant that a stack from 13 to 15 meters in height may apparently displace initial ground contact beyond the reactor site boundaries under the conditions modeled.

The impingement indicating paints qualitatively confirmed the results of the smoke visualization. Table 2 summarizes the minimum contact distances for various stack heights and flow rates. The touch down points are also tabulated as estimated from visual observation of the smoke plumes. The differences in results may be due either to

a) failure to obtain the critical indication paint acid to base sensitivity that is required for sensitive detection, or

b) the fact that smoke touchdown was selected conservatively as the minimum downstream distance to a plume excursion ground contact. (Hence, smoke results are considered most reliable for conservative calculation.)

The introduction of Unit II to the Shoreham Nuclear Power Station Complex slightly aggravated the entrainment condition as observed both by the smoke or impingement paint visualization. Figure 5 compares the smoke plume sections for the 15.3 m stack for the cases of Unit I alone and Units I and II present together. Table 2

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*The "critical angle" for maximum plume entrainment appeared to lie between 330° and 360° according to the results of Ref. 1.

incorporates measurements of the minimum contact distances when Unit II is present. The plume minimum contact distace is still displayed beyond site boundaries for a stack height of 15.3 m.

Smoke and ammonia were also released from a 65 m single isolated stack located at site coordinates 6175 and 3325 and grade 40. Except for an approach wind azimuth of 180° the plume released was relatively unaffected by the reactor building complex. The plume remained coherent over long distances and finally appeared to contact the ground due to the terrain rise downwind. For a wind approach azimuth of 180°, however, the plume was completely entrained by the turbine building separation cavity and contacted the ground immediately downwind of the turbine building. The minimum distances to plume contact for the isolated stack have been prepared into Table 4.

C. Test Results: Concentration Measurements

In Reference 1 the concentration measurements were displayed in terms of K-isopleths from the formula $K = \frac{c}{Q/AV}$; which interprets plume dilution non-dimensionally in terms of building geometry. This expression is specifically suitable for measurements within the near-wake and cavity region. Data reported herein, however, represent measurements made at equivalent distances of 300 m from the containment vessel. In this case it was considered more suitable to interpret results in terms of a different dimensionless parameter - D , a dilution factor, where

$$D = \frac{c}{c_{stack}} = \left(\frac{c}{c_{max_x}}\right) \times \left(\frac{c_{max}}{c_{stack}}\right)$$

and

c = sample volume concentration

c_{stack} = concentration of source gas at release.

c_{max_x} = maximum concentration at downstream location of x

The Kr-85 source strength utilized for this series of measurements was 0.69 μcuries/cc.

Tables 3 and 5 record concentration measurements made at an equivalent downwind distance of 300 m from the center of the reactor building. Data includes a vertical traverse directly downstream of the stack centerline and a horizontal traverse at the height of the vertical concentration maximum.

Figures 6 and 7 display the effect of various stack release heights on top of the reactor building on concentration profiles. Table 6 summarizes the significant characteristics of these profiles. It is evident that a stack height greater than 12 meters is required to significantly reduce ground concentration at the site boundaries.

Figures 8 and 9 compare concentration profiles at various wind attack angles for the isolated stack. Concentrations are much larger and plume width is less because the gas release position was approximately 80 m from the sampling position as compared to 300 m from the previous cases.

D. Interpretation of Test Results:

The introduction of Reference 1 pointed out that theoretical models of diffusion are unapplicable for a site such as the Shoreham Nuclear Power Station since uneven terrain and buildings exist near the stack. Martin, however, compared field, wind-tunnel, and analytical calculations for concentrations downwind from a building site. He found that the analytical model varied from the field measurements by a factor of two at a downwind distance of 150 meters. Martin also found that wind tunnel measurements agreed within a few percent with the average field data near the source, and within 50% with the peak data at 150 m downwind for all conditions.

A model that has been widely used in estimating diffusion of gases from stacks is the Gaussian Plume diffusion model together with standard deviations provided from Pasquill's diffusion categories, (Reference 5). Table 7.0 compares concentrations calculated by the Gaussian Plume model with those determined in the wind tunnel.

As might be expected the wind tunnel measurements at ground level exceed the prediction of the emperical equation for an elevated source. Higher ground level dosages indicate the tendency for the plume to be dispersed toward the ground by aerodynamic ground wash. The maximum plume centerline values obtained are surprisingly close to those predicted by the Gaussian Plume model. Evidently aerodynamic turbulence contributed by the building wakes have compensated for the lack of large scale eddies in the wind-tunnel to produce close correlation. When interpreting model diffusion measurements at distances far from the building structures previous investigators have suggested model plume measurements may correlate better with peak concentration measurements for field data. (See Reference 1, pp. 18-19.)

Culkowski suggested that a practical conservative estimate for diffusion downwind of a building would be to assume a ground-level source and to recognize that the resulting ground level concentration distribution is an upper boundary of all other maximum ground concentrations.[6] Hence, ground concentrations estimated for a ground level release are also tabulated in Table 7.0. This method over estimates ground concentration by a factor of twelve for releases into the cavity region, and over estimates the case far above cavity releases by a factor of seventy. Such conservation hardly seems necessary or economical.

A number of empirical formula have been suggested to predict the amount of plume dilution which occurs once it is entrained into the building cavity.[6] Basically all formulas reduce to the form $\frac{\chi}{Q} = \frac{1}{cA\bar{u}}$ where the constant c may vary from $\frac{1}{2}$ to 2.[7] Gifford combined this equation with the Gaussian Plume formula and suggested $\frac{\chi}{Q} = 1/(\pi\sigma_y\sigma_z + cA)\bar{u}$ as an estimate of the downwind concentration from an extended area source. Examination of Figure 6 suggests it is incorrect to assume the plume is dispersed evenly across the cavity for an elevated plume. Nevertheless, based on the ground level concentraions for data from this report and Reference 1 the values of c calculated for two potentially entrained plume conditions at $\bar{u}$ = 3.5 mps are shown below.

h	v_s	Q_p	@ S	x	χ(μμc/cc)	c
4.5 m	15.2 mps	425 m^3/min	0.169 μc/cc	300 m	114	0.85
9.2 m	32.8 mps	164 m^3/min	0.69 μc/cc	300 m	47	4.40

It is probable that the plume for the 4.5 m stack is entrained into the cavity region since the value of c falls between the limits $\frac{1}{2}$ to 2 found by other investigators. In addition larger $\bar{u}$ conditions produce values of c less than $\frac{1}{2}$ for h = 4.5 m. Evidently c is not a good criteria for plumes only partially entrained by the building cavity. Also the value of c measured for buildings of rounded geometry will vary from those suggested for sharp edged configurations since the flow separation about a cylinder results in a cavity region of less width than an equivalent cross-section rectangular structure.

Bierly and Hewson apply Suttons diffusion equation to the problem of a plume subjected to aerodynamic downwash.[8] It is apparently appropriate for the case where the plume is emitted from a stack sufficiently high to be initially clear of the turbulent region but becomes drawn into it. They suggest

$$\chi = \frac{2Q}{\pi C_y C_z u x_1^{2-n}}$$

where $x_1 = (x^2 + h^2)^{1/2}$ and

$n \cong 0.20$

$C_y = C_z = 0.21\ m^{1/10}$ for 3 minute averages

$C_y = C_z = 0.4\ m^{1/10}$ for hourly averages.

If this equation is utilized for the conditions indicated for a 10 m stack upon the containment vessel the value of χ calculated $\cong 3.0$ μμc/cc for a 3 minute average, or $\simeq 0.8$ μμc/cc for hourly averages. This compares favorably with $\chi = 8$ μμc/cc for a 15.3 m model stack and $\chi = 47$ μμc/cc for a 9.2 m model stack.

Bryant has evaluated the effect of diluting stack gases on downwind concentration.[9] He concluded that dillution is of comparatively little value with regard to a buoyant plume, but it is of value to dilute a cold or buoyant plume with air at the temperature of the waste gas, particularly if the gas is to be discharged from a short stack. This conclusion assumed of course that the stack velocity is not reduced during dilution. In general however, the dispersive, capacity of the atmosphere far exceeds (in efficiency) the ability to dilute waste gases before release; hence it is usually considered more efficient in terms of energy to increase the effective release height of the plume by increasing the gas source temperature. (Reference 8, pp. 252-253.)

IV. CONCLUSIONS AND RECOMMENDATIONS

Flow about a model of Shoreham Nuclear Power Station was studied in a wind tunnel to determine the rate of dispersion of radioactive gases released from stacks on or in the vicinity of the reactor building. The effects of stack height, the addition of Unit II to the building complex, and downstream topography were noted.

Interpretation of the experimental measurements reported herein suggest that:

1. When the stack height of the ventilator located at the center of the reactor building is increased to 13 or 15 meters, significant ground contamination is not observed until beyond the site boundaries. Hence, a ventilator height of 13 meters and an exhaust rate of the order of 425 m^3/min may be satisfactory.

2. The addition of Unit II to the building complex slightly decreases the minimum downwind distance to plume contact, but not to within the site boundaries for the conditions stated above.

3. Rising downstream terrain tends to intercept a diffusion plume as it disperses; however, the building complex geometry appears to dominate dispersion such that major contact occurs before the inception of significant terrain rise.

4. The isolated stack results are somewhat ambiguous, as noted on page 9; however it would appear even conservatively that a 65 m stack should disperse the plume to points beyond the site boundaries for most wind directions.

A number of questions concerning plume dispersion downwind of the Shoreham Nuclear Power Station remain unresolved; hence, it is recommended that further model tests be made to

a) Determine the optimum combination of effluent stack release height and discharge rate for economical plant operation, and to

b) Measure the effects of stable stratification upon the dispersion of effluents during station shutdown conditions.

Recent model measurements of flow over obstacles under stabily stratified conditions have indicated that fumigation might occur downstream of an elevated gaseous source due to wave like motion set up in the "lee" of the structure (Reference 3). The effect of such large scale excursions on a diffusing plume have not been previously modeled. Studies by Martin (Reference 4) and Golden (Reference 5) involved examination of releases under stratified conditions; however, the gas plumes were emitted from very short stacks (~3 m from roof top) essentially directly into the cavity region; hence one would expect their measurements to be dominated by the building geometry and not the stratification.

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TABLE 2.0

Minimum Distances to Plume Contact in Meters for

Various Stack Heights on the Reactor Building

$\theta = 345^{o}$

$V_{\infty} = 4$ mps

$Q = 425\ m^3/min$ or $164\ m^3/min$

h (stack height in m)	X Contact by Smoke	X Contact by Indicator Paint*
4.5	~ 90-120	330
9.2	~180	390
12.2	~240-300	500
15.3	~360	550
15.3 (second reactor present)	~340	390

*No noticeable difference between $Q = 425$ or $164\ m^3/min$ releases for indicator points

TABLE 3.0

Concentration Data

(Micro micro curies per cubic centimeters)

V_∞ = 4 mps

θ = 345°

Q_P = 164.0 m^3/min

V_s = 32.8 mps

x = 300 m from center of reactor building

Vertical Profile					Lateral Profile				
Z	h 9.2	12.2	15.3	15.3 (2 reactors)	y	h 9.2	12.2	15.3	15.3 (2 reactors)
0	47.	22.	8.	6.	0	258.	279.	315.	244.
13	44.	22.	8.	13.	13	238.	210.	292.	165.
23	84.	22.	14.	7.	23	169.	108.	109.	90.
33	141.	67.	37.	32.	33	71.3	53.	54.	82.
43	184.	103.	51.	49.	43	29.3	24.	34.	23.
53	177.	155.	120.	82.	53	8.5	3.	3.	5.
66	268.	256.	223.	180.	66	0.	0.	1.	0.
79	162.	165.	280.	298.					
89	90.	62.	160.	188.	Z_m	66.	66.	79.	79.
99	48.	42.	55.	167.					
109	10.	17.	21.	66.					
119	2.	2.	9.	9.					
132	0.	0.	5.	2.					

h = stack height in m
y = lateral distance from centerline
Z = height from 40 ft contour in m (note: 40 ft contour represents base of reactor containment vessel)
Z_m = height of horizontal traverse in m
C_{stack} ~ 0.69 μc/cc

TABLE 4.0

Minimum Distances to Plume Contact in

Meters for the Isolated Stack*

$V_\infty = 4$ mps

h = 65 meters

Q = 425 or 164 m^3/min

θ	X Contact with Smoke		X Contact with Indicator Paint	
	One Reactor	Two Reactors	One Reactor	Two Reactors
0^o	730	480	None	None
15^o	670	610	None	None
180^o	420	180	None	180
345^o	None	610	None	None

*Topography present in all cases

TABLE 5.0

Concentration Data for Isolated Stack

(Micro micro curies per cubic centimeter)*

V_∞ = 4 mps

Q_p =164.0 m^3/min

V_s = 32.8 mps

	Vertical Profile					Lateral Profile			
Z	θ 315°	0°	0° (2 reactors)	+15°	y	θ 315°	0°	0° (2 reactors)	15°
51	79	-	-	-	20.4	200	168	503	367
61	38	435	480	366	10.2	766	507	1139	379
66	244	-	-	-	5.1	1223	1170	1434	1875
71	1341	1317	992	676	0.	1591	1932	1958	4567
76	2606	3630	1080	3080	5.1	686	606	846	2782
82	2523	3478	1217	4266	10.2	93	125	390	735
87	-	678	864	1625	17.9	13	10	112	25
89	289	38	463	157					
92	-	-	-	-					
100	-	1	127	60	Z_m	-	-	-	-

θ = wind approach with respect to called north
y = lateral distance from stack centerline
Z = height from 40 ft contour in m
Z_m = height of horizontal traverse in m
*Topography present in all cases

TABLE 6.0

Plume Characteristics for Various Stack Heights

at 300 m Downstream of Reactor Building

h(m)	σ(m)	λ(m)	$\bar{z}$(m)	Δz(m)	Δy(m)	z_e(m)
9.2	26.5	34.0	66	103	92	0
12.2	19.5	21.0	70	81	40	22
15.3	20.5	21.0	77	76	39	31
15.3 (Unit II)	19.0	16.0	79	79	39	36

h = height of stack above roof top
σ = characteristic width such that c/c_{max} = 0.5
λ = characteristic height such that c/c_{max} = 0.5
$\bar{z}$ = height of maximum concentration level
Δz = vertical plume extent between 10% concentration levels
Δy = horizontal plume extent between 10% concentration levels
z_e = height of lower edge of plume at 10% concentration levels

TABLE 7.0

Comparison of the Wind Tunnel and Field Measurements of Concentrations

Downwind From a Continuous Point Source Based on the Gaussian Plume Model

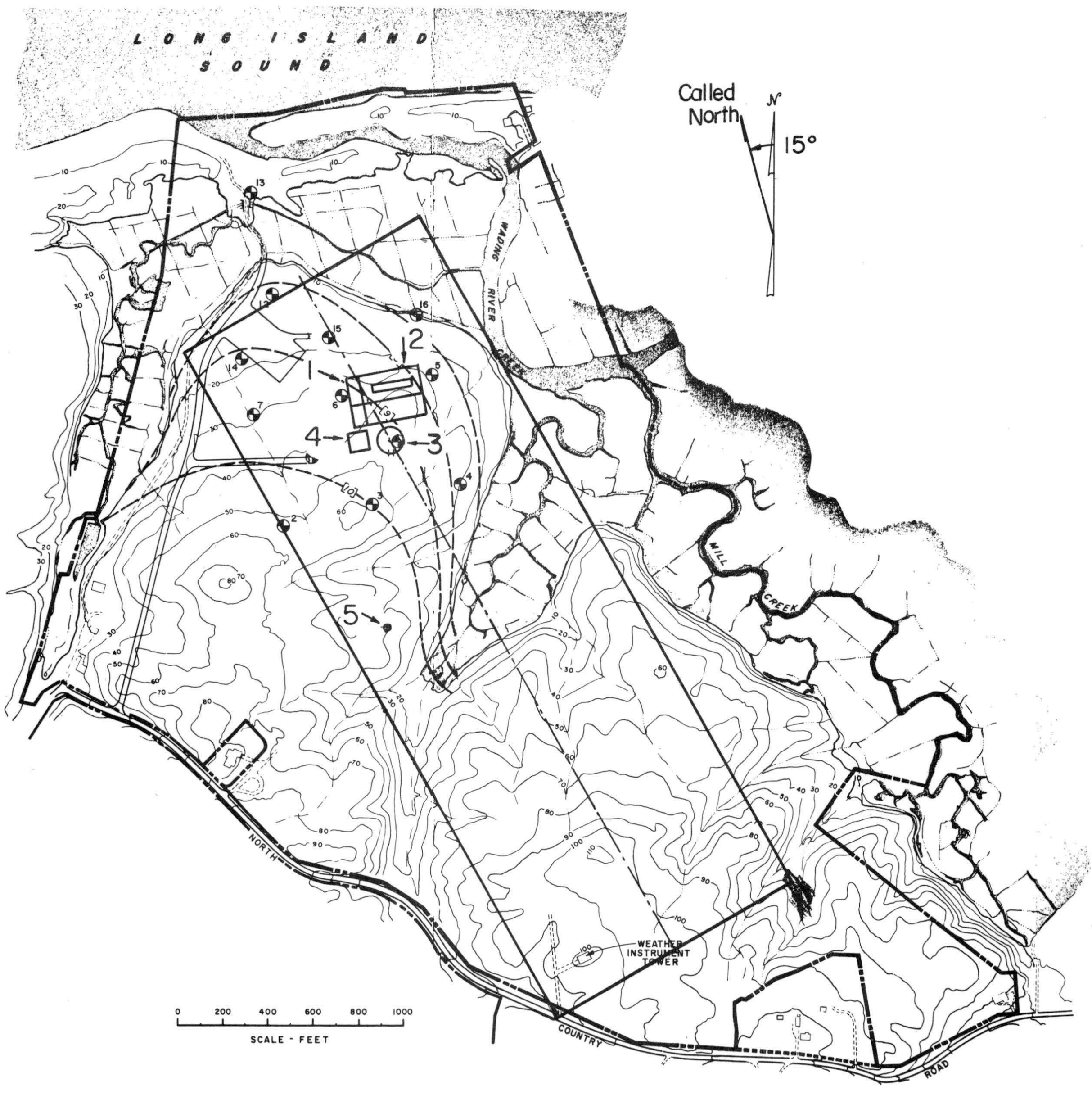
h_{stack} (m)	Meteorological Condition			Distance Downwind (m)	Height (m)	Concentration (μ μc/cc)	
	Stability	Wind Dir.	Velocity (mps)			Gaussian Equation	Wind Tunnel Measurement
9.2	Neutral	345°	4	300	0	$\sim 10^{-2}$	47
9.2	Neutral	345°	4	300	66	288	268
9.2	Neutral	345°	4	300	0	* 577	47
15.3	Neutral	345°	4	300	0	$\sim 10^{-6}$	8
15.3	Neutral	345°	4	300	79	288	280
15.3	Neutral	345°	4	300	0	* 577	8

$\dot{Q}_p$ = 164 m^3/min @ 0.69 μc/cc

U_∞ = 4 m/sec; $\overline{U} \simeq$ 3.5 m/sec.

$\sigma_y \simeq$ 23 m
$\sigma_z \simeq$ 13 m } Pasquill Category D (neutral) @300 m (Ref. 5.)

* Conservative calculation based on grand source release as suggested by Culkowski (Reference 7).



1 Control Room

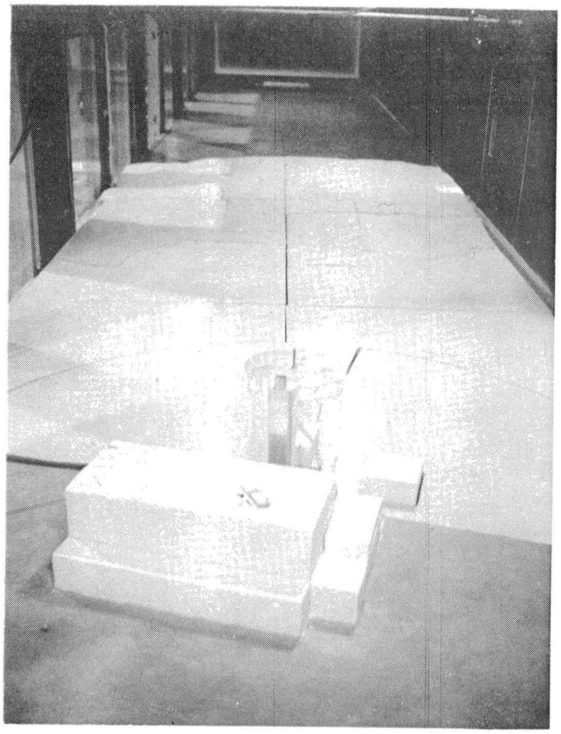
2 Turbine Gen Unit I

3 Reactor Building Unit I

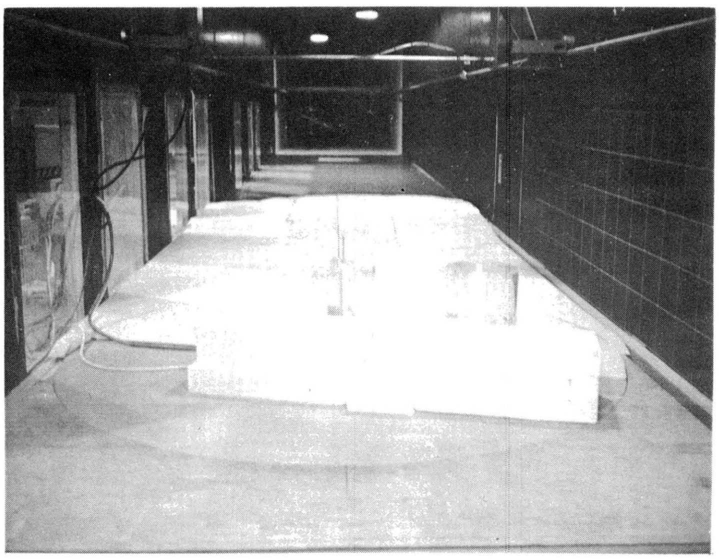
4 Rad Waste Building

5 Isolated Stack

Fig. 1 Outline of Terrain Modeled to 1:200 Scale

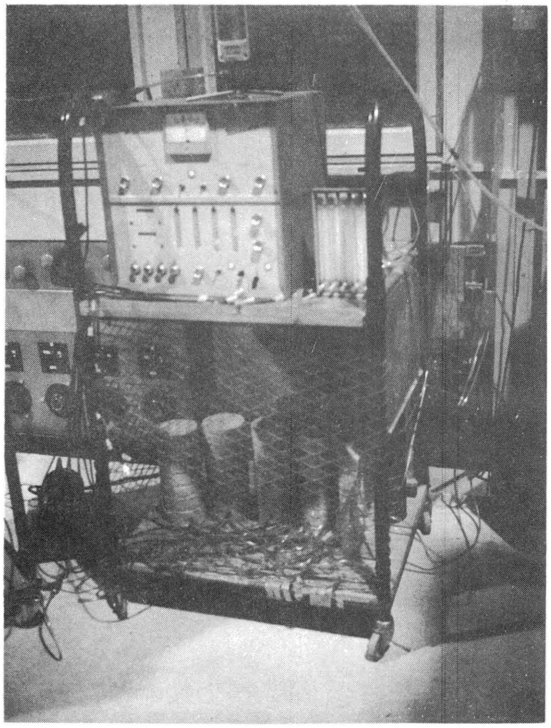


Reactor and Downwind
Topography $\theta = 345°$

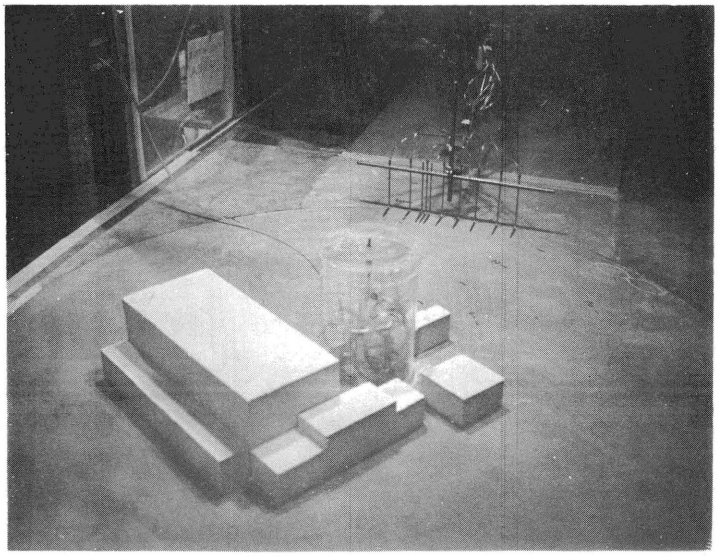


Unit I and Unit II and Downwind
Topography $\theta = 345°$

Fig. 2 Shoreham Nuclear Reactor Complex:
Model Buildings and Terrain



Kr-85 Counting Apparatus



Sampling Probe Rack Arrangement

Fig. 3 Gas Concentration Measuring Apparatus: Counting Equipment and Sample Rake

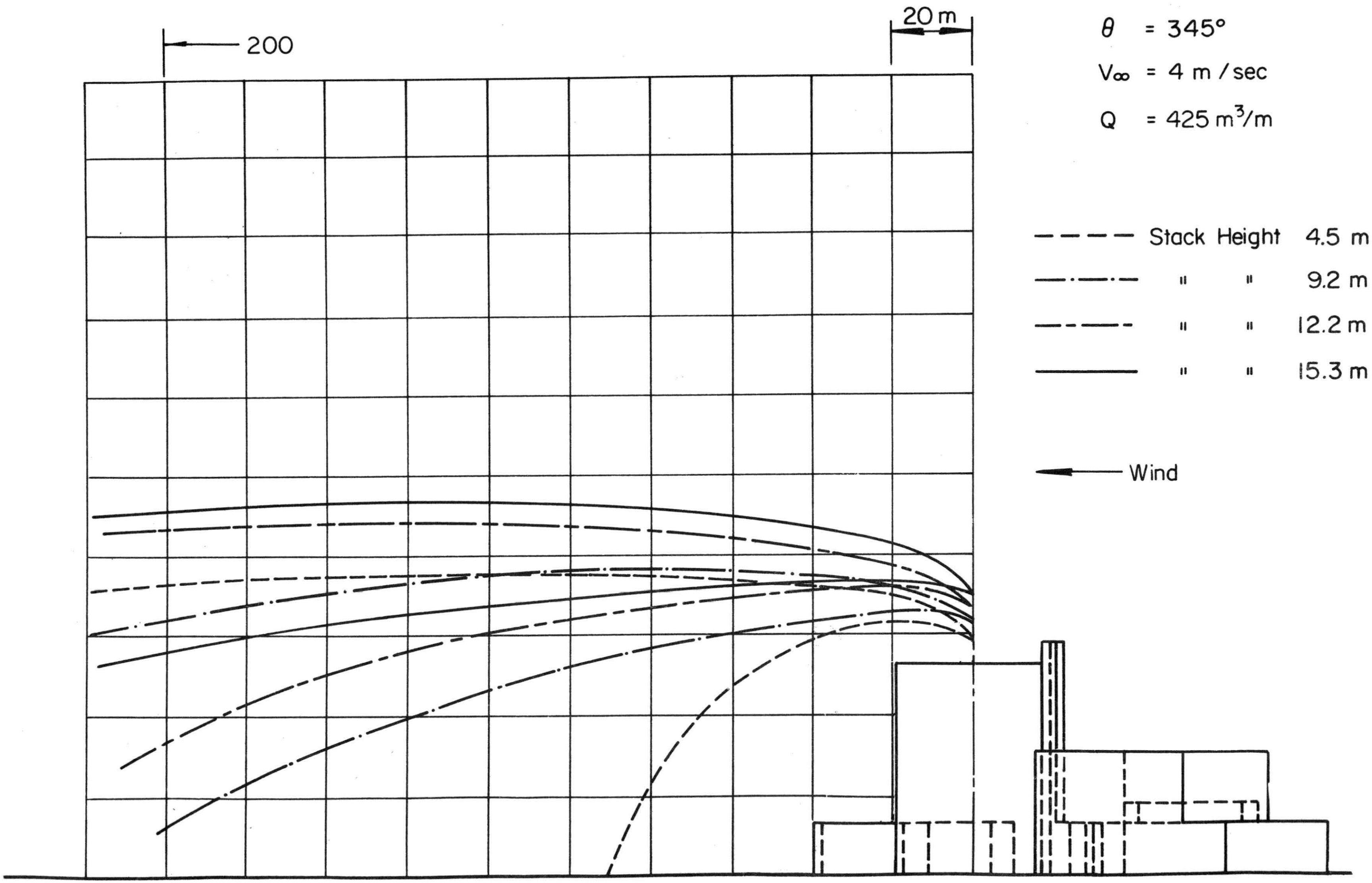


Fig. 4 Smoke Plume Sections for Various Stack Heights

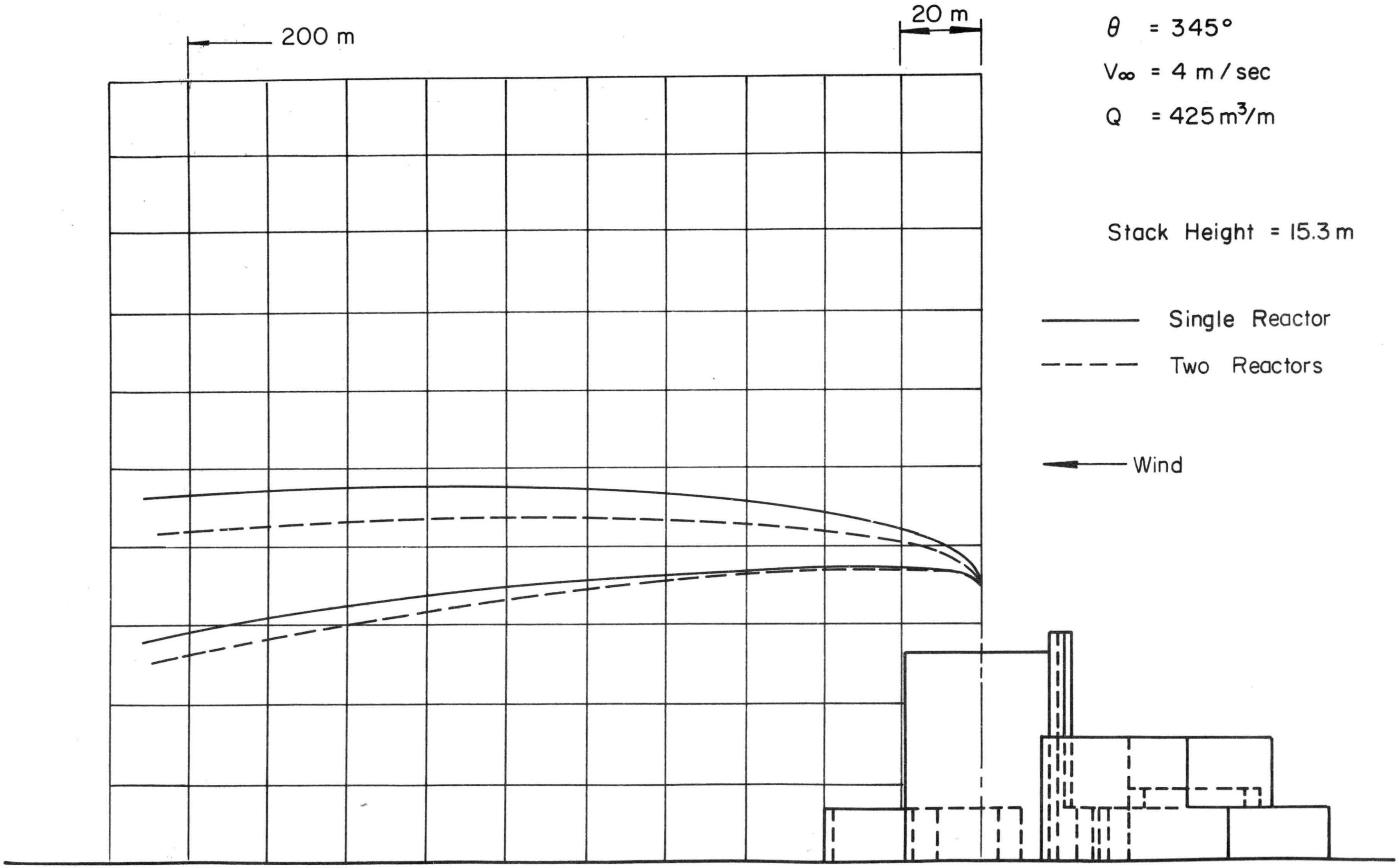


Fig. 5. Comparison of Smoke Plume Sections for Unit I and Units I and II

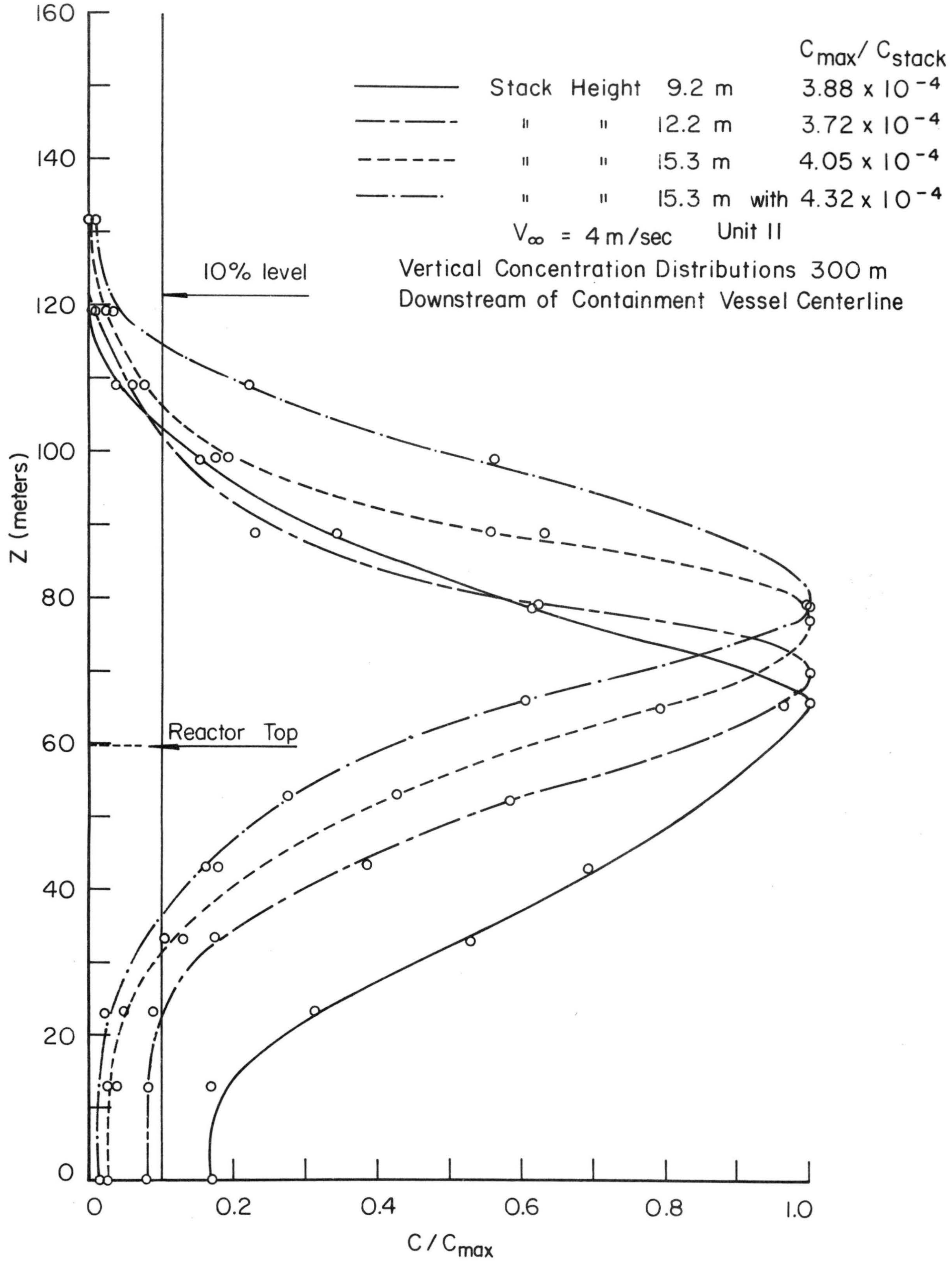


Fig. 6 Vertical Concentration Profiles for Various Stack Heights

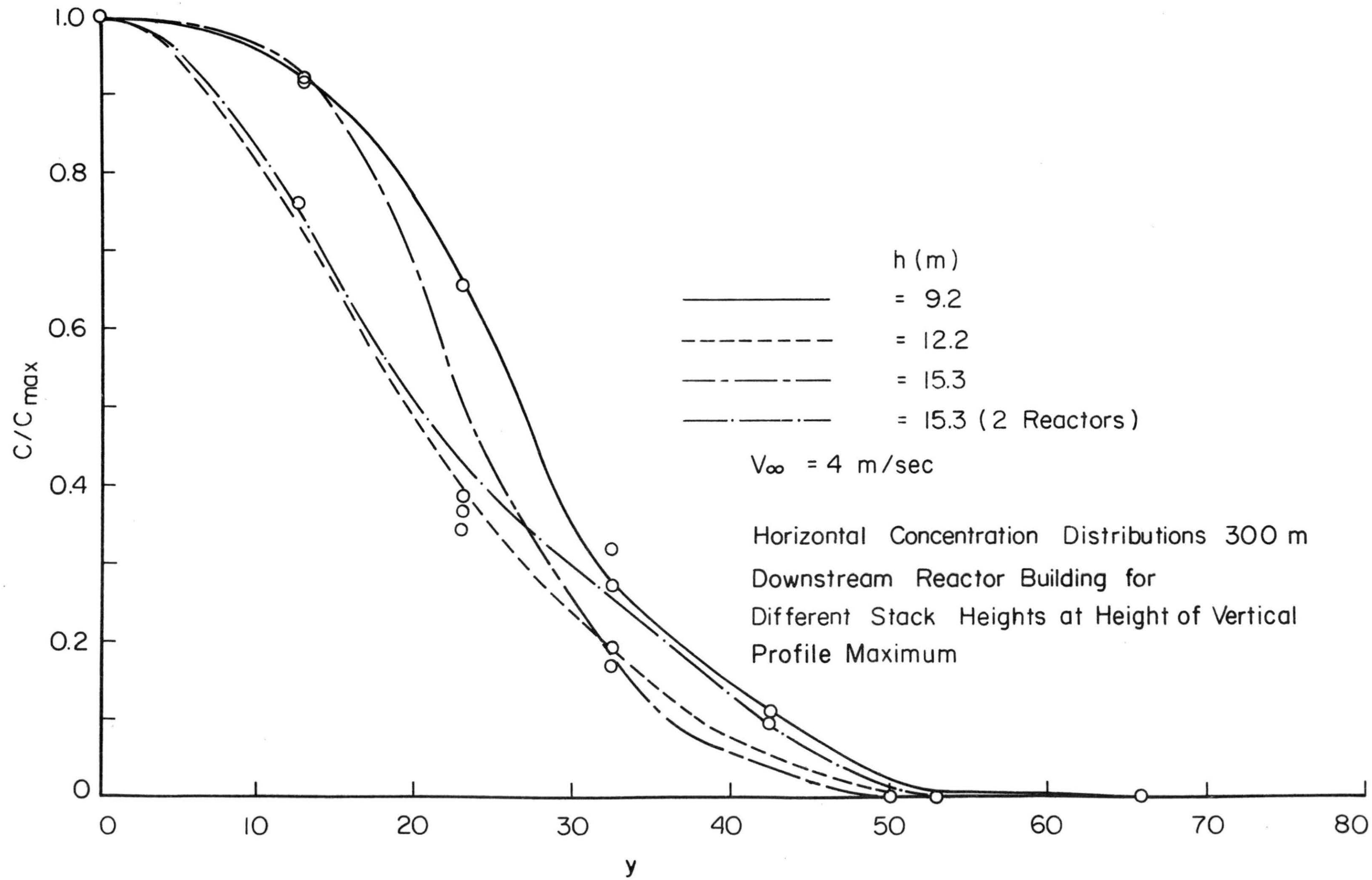


Fig. 7 Horizontal Concentration Profiles for Various Stack Heights

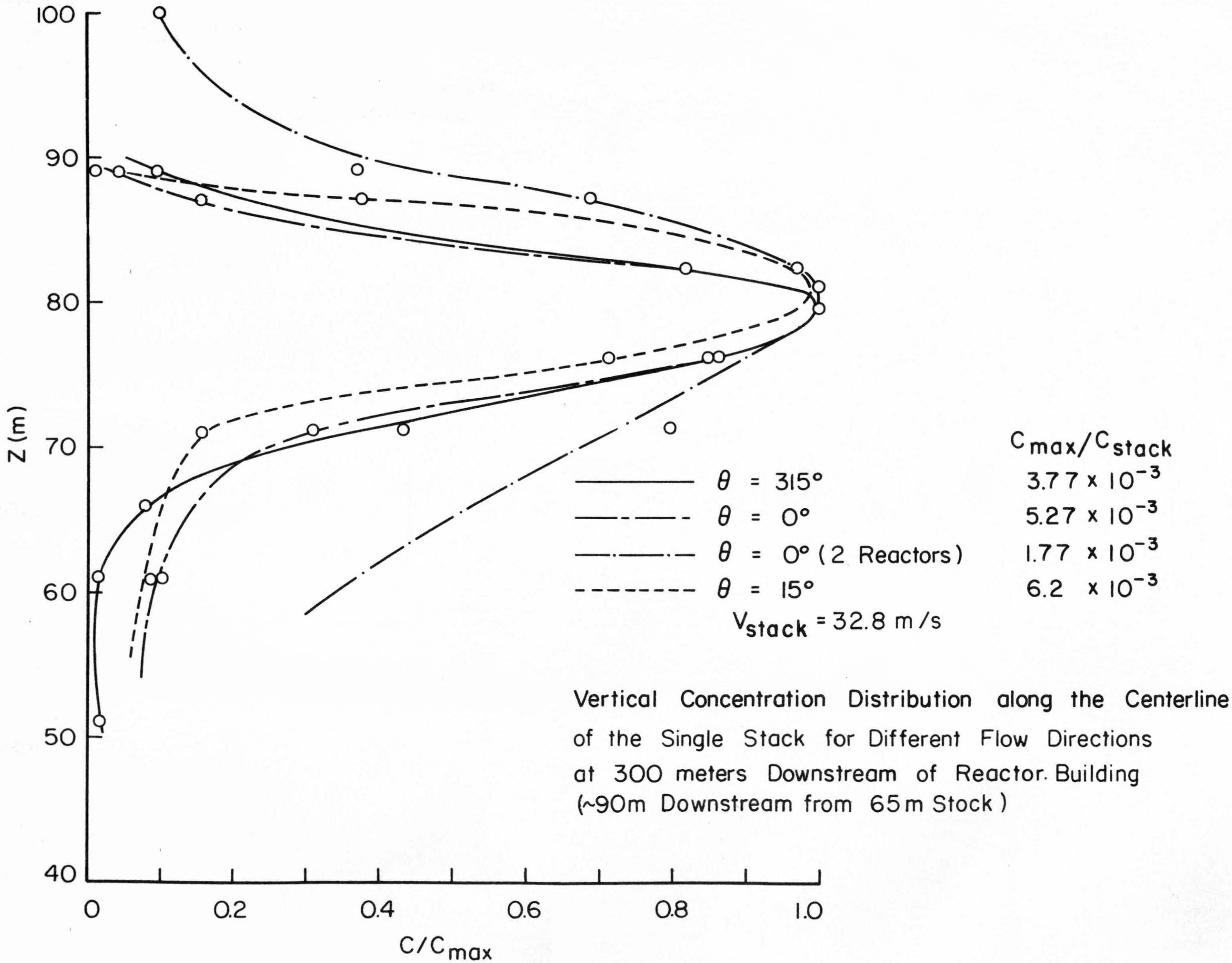


Fig. 8 Vertical Concentration Profiles for the Isolated Stack at Various Wind Approach Angles

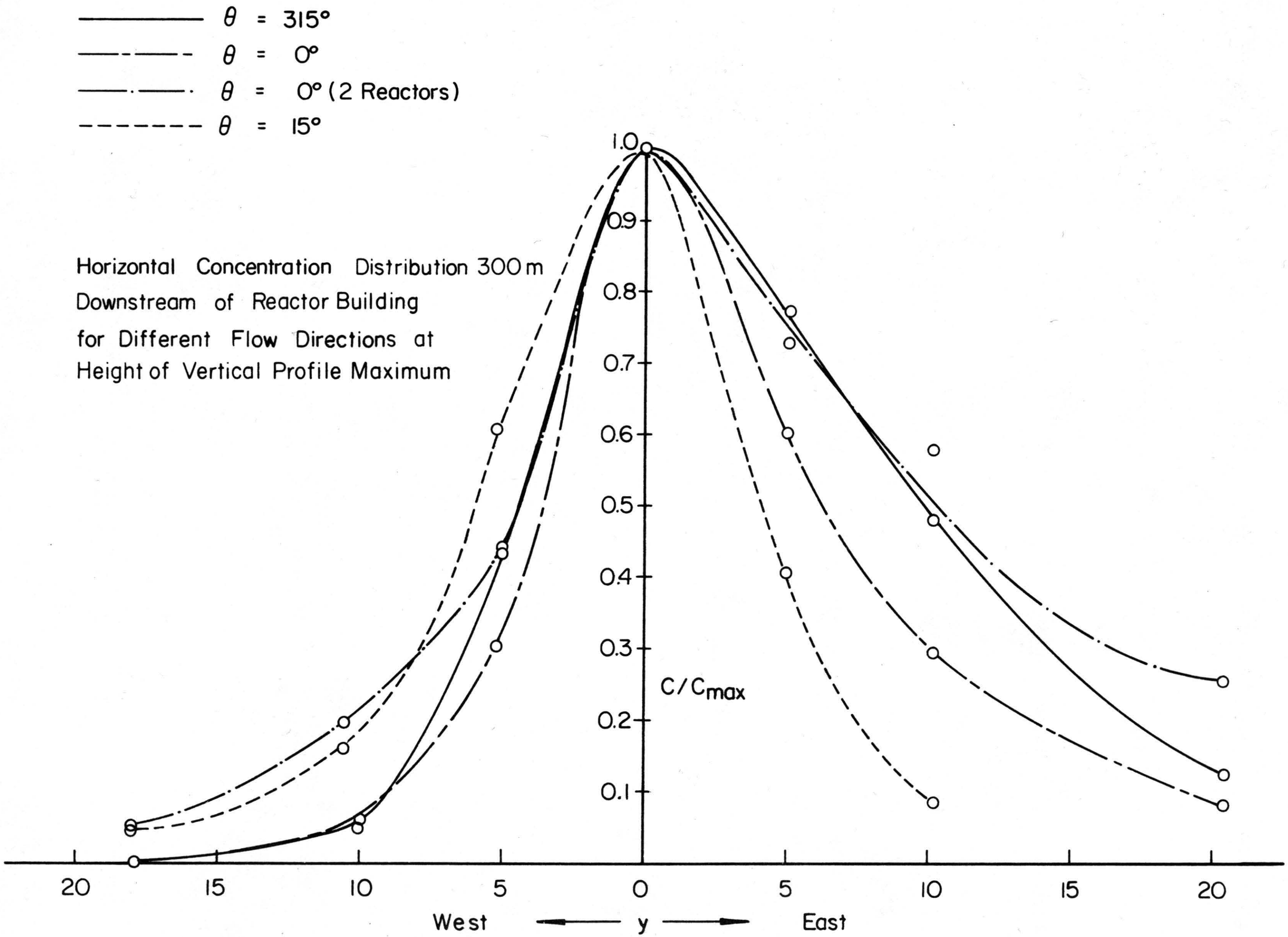


Fig. 9 Horizontal Concentration Profiles for the Isolated Stack at Various Wind Approach Angles