GASEOUS DISPERSION AND TURBULENCE IN THE WAKE OF NUCLEAR REACTOR PLANTS

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1.0 INTRODUCTION

Buildings and building complexes produce non uniform fields of flow and turbulence which can significantly modify the dispersion of a source placed in their vicinity. This paper presents the results of a meteorological wind tunnel study of entrainment and wake effects on dispersion from a 1:200 scale model of the EOCR Nuclear complex at the Idaho National Engineering Laboratory, U.S.A. The study is unique due to the range of atmospheric conditions simulated (neutral, moderately stable, stable, and unstable), the release of simultaneous tracers, the detail of the measurement field (measurements on 3° arc span to $\frac{x}{H} \simeq 70$), and the recent acquisition of a comparable and complete set of field measurements over the actual complex (Abbey, 1976). The results are compared with measurements made in the absence of the reactor complex, and some of the main effects are thus illustrated.

2.0 PREVIOUS EXPERIENCE

Diffusion in the turbulent cavity-wake regions of a building has been studied both in the field and wind tunnel with increasing interest during the past ten years. Table I provides a comparison of the conditions under which the more recent and detailed laboratory and field measurements have been obtained. Ground level plume centerline concentration vs downwind distance for a number of these studies has been qualitatively considered by Abbey (1976); nevertheless the data have yet to be uniformly normalized with respect to surface roughness, complex cross-section, sample averaging time, stability, auxiliary buildings, plume release height, etc. Smith (1975) and Robins (1975) have compared short stack behavior with Meroney and Yang (1971) and found good agreement for cube structures in the near field. The results of Huber and Snyder (1976) and Robins (1975) are consistent in the far field. Halitsky's pre-construction model study of the EBR-II in Idaho completed in 1963 agrees qualitatively with the field measurements over the comparable near field where measurements in both test series are available. Unfortunately the Reactor complex as finally constructed contained additional buildings and the large power plant building was at a different equivalent height than in the model (Halitsky, 1975).

In 1960 Gifford modified the basic ground level Gaussian plume model to include an initial dillution, in 1965 Yansky, Markee and Richter proposed a model based on modification of the plume standard deviations, and in 1970 Turner proposed a displaced virtual source method to account for building plume interaction. For short stacks in the presence of buildings Briggs (1973) has recommended plume height adjustments. Variations in these basic approaches have been tried by other authors including adjustments for downwind decay of building wake turbulence. Meroney and Yang (1971), Robins (1975), and Smith (1975) have also provided simple correlations of ground maximum concentration versus stack height/building height ratio and exhaust velocity/reference stream velocity ratio.

Concern over the ground level concentrations which may exist on a reactor site and at its boundaries has led to the wind tunnel/field program discussed herein to validate a hazard analysis strategy.

3.0 EXPERIMENTAL EQUIPMENT AND PROCEDURES

Model scaling criteria has been discussed previously by Meroney and Yang (1970). The experimental data were obtained in the low speed Meteorological Wind Tunnel at Colorado State University. A 1:200 scale model of the EOCR complex was constructed from plastic, instrumented with release ports and pressure taps, and installed 15 boundary layer heights from the test section entrance in the deep surface shear layer. There were three major phases to this study. A complete description is found in Meroney et.al. (1976).

Phase I: The cavity and wake envelope leeward of the building were defined through smoke visualization. For 108 cases representing 4 stratifications, 8 wind directions, and 3 release heights still and motion picture photographs were taken of the smoke plumes. (Figure 1) In addition 16 surface oil film conditions were studied to delineate the influence of separation, reattachment, vortex shedding and auxiliary buildings on the building wake. Identification of surface nodes and saddles premits partial reconstruction of a complex 3-dimensional flow field.

Phase II: Hot wire anemometer surveys of the wake cross section were made to characterize wake shape and extent. The mean velocity defect, and turbulence excess reveal that the building complex disturbs the background mean velocity and turbulence fields as far as 30H downwind. (See Figure 2)

Phase III: Concentration measurements were also made for 108 cases. An air-propane-ethane -ethylene mixture was emitted as a tracer gas. Samples were temporarily drawn into forty eight sample bottles over a period of 5 minutes. Concentrations were obtained by transferring quantities of each sample to a flame ionization detector through a chromatograph column to separate gases emitted from the three source locations. For each case the profiles were repeated with the buildings removed. Vertical profiles were also made on a number of downwind sample arcs. Sample concentrations have been normalized as $\frac{\chi U_H H^2}{Q}$, a dimensionless dilution factor which may be compared to field values.

These values are comparable to field concentrations measured in a non-meandering plume over a time period on the order of ten minutes.

4.0 RESULTS AND DISCUSSION

Only a brief summary of the experimental results is possible here. Emphasis is given to the asymptotic character of the near wake decay.

4.1 Phase I: Smoke visualization demonstrated that the building wake was strongly influenced by wind orientation and auxiliary buildings. When the approach flow is corner-on from the east, the lateral extent of the wake is greater than when the flow is normal to a face. The cavity region for flow approaching from corner-on orientations was generally larger. Plumes emitted at upwind forces were often deflected around the cavity region unmixed. Plumes emitted at downwind building faces were carried upwards and upwind by cavity recirculation. In stable flow plumes mixed to building wake height but did not mix substantially higher with downwind distance. In unstable flow the wake quickly disappeared into the generally more complex background motions.

4.2 Phase II: The mean velocity defect decays with a -1.13 power law decay exponent. For a complex with a width/height ratio of $\sim$ 1.0 this agrees with previous experience of Peterka and Cermak (1975). The turbulence intensity excess $(\frac{u\ rms}{U})^2 - (\frac{u_o\ rms}{U_o})^2$ decays with a -2.70 power law exponent. A wake can be detected at distances of $x/H = 30.$ at a 5% mean velocity defect level (or out to 100 H at the 1% level!) Such long wake regions are associated with the low roughness which characterizes the site.

4.3 Phase III: Longitudinal ground concentration profiles on plume centerline are shown in Figures 3 to 5 for neutral, stable, and unstable flow. For a release or an upwind face for a 45° wind approach angle the plume decays initially as $(x/H)^{-1.4}$ until $x/H \sim 15$ after which the levels approach that expected for Pasquill D, F and B stabilities respectively. This agrees with the experience of Hinds (1969) who noted upwind releases in the field often deflected around the more well mixed cavity region. Downwind face releases generally disperse such that $\frac{\chi U_H H^2}{Q}$ decays as $\sim x^{-1}$ or less.

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Figure 1: Smoke Visualization of Tracer Release at Ground Level Face of EOCR Reactor Model, $\theta = 225^{\circ}$.

Figure 2: Decay of the Mean Velocity Defect and Turbulent Intensity Excess in the Wake of the EOCR Reactor Model, $\theta = 135^{\circ}$.

Figure 3: Longitudinal Concentration Profiles Downwind of EOCR Reactor Model, Pasquill - Gifford D Stability, $\theta = 0^{\circ}$.

Figure 4: Longitudinal Concentration Profiles Downwind of EOCR Reactor Model, Pasquill - Gifford F Stability, $\theta = 0^{\circ}$.

Figure 5: Longitudinal Concentration Profiles Downwind of EOCR Reactor Model, Pasquill - Gifford B Stability, $\theta = 0^{\circ}$.

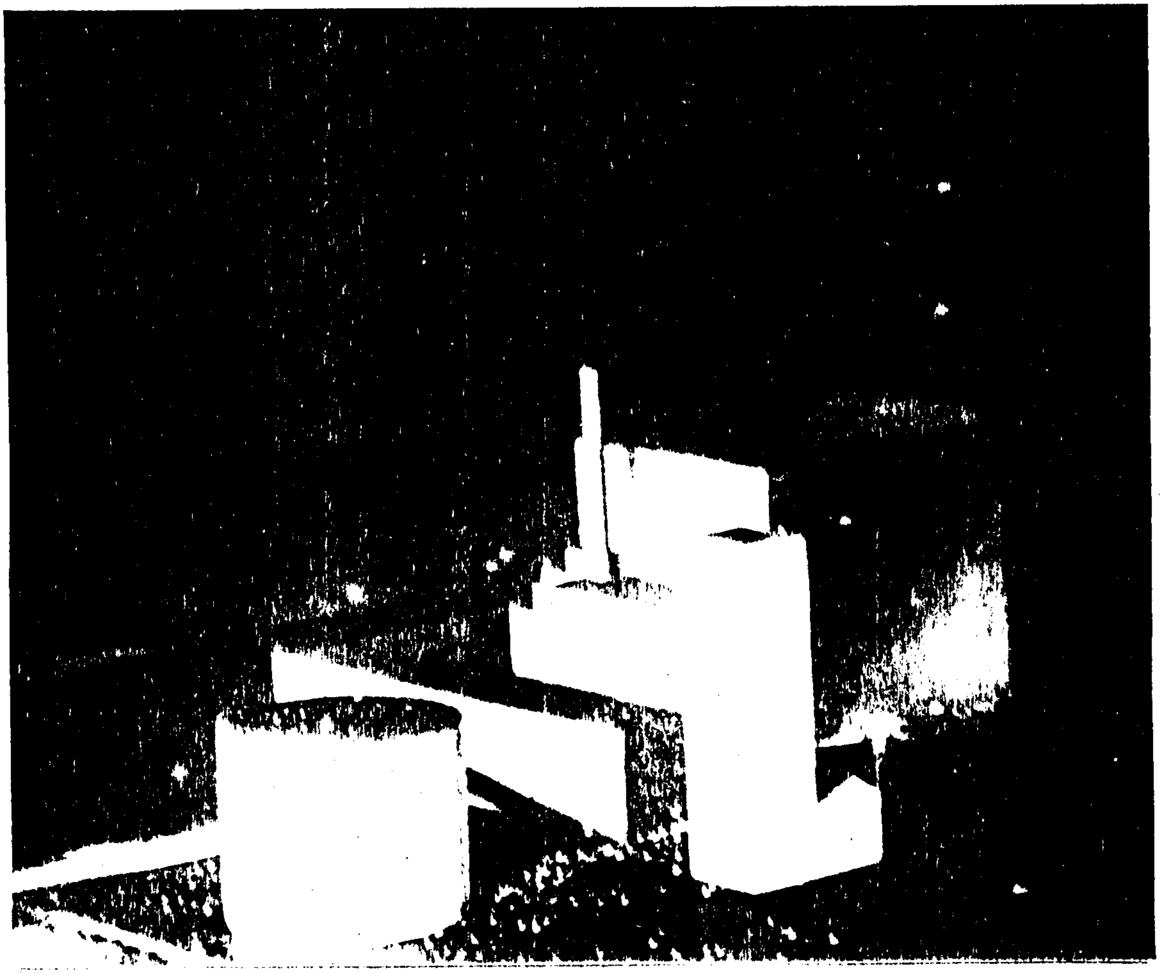

Figure 1. Smoke Visualization of Tracer Release at Ground Level Face of EOCR Reactor Model, $\theta = 225^{o}$.

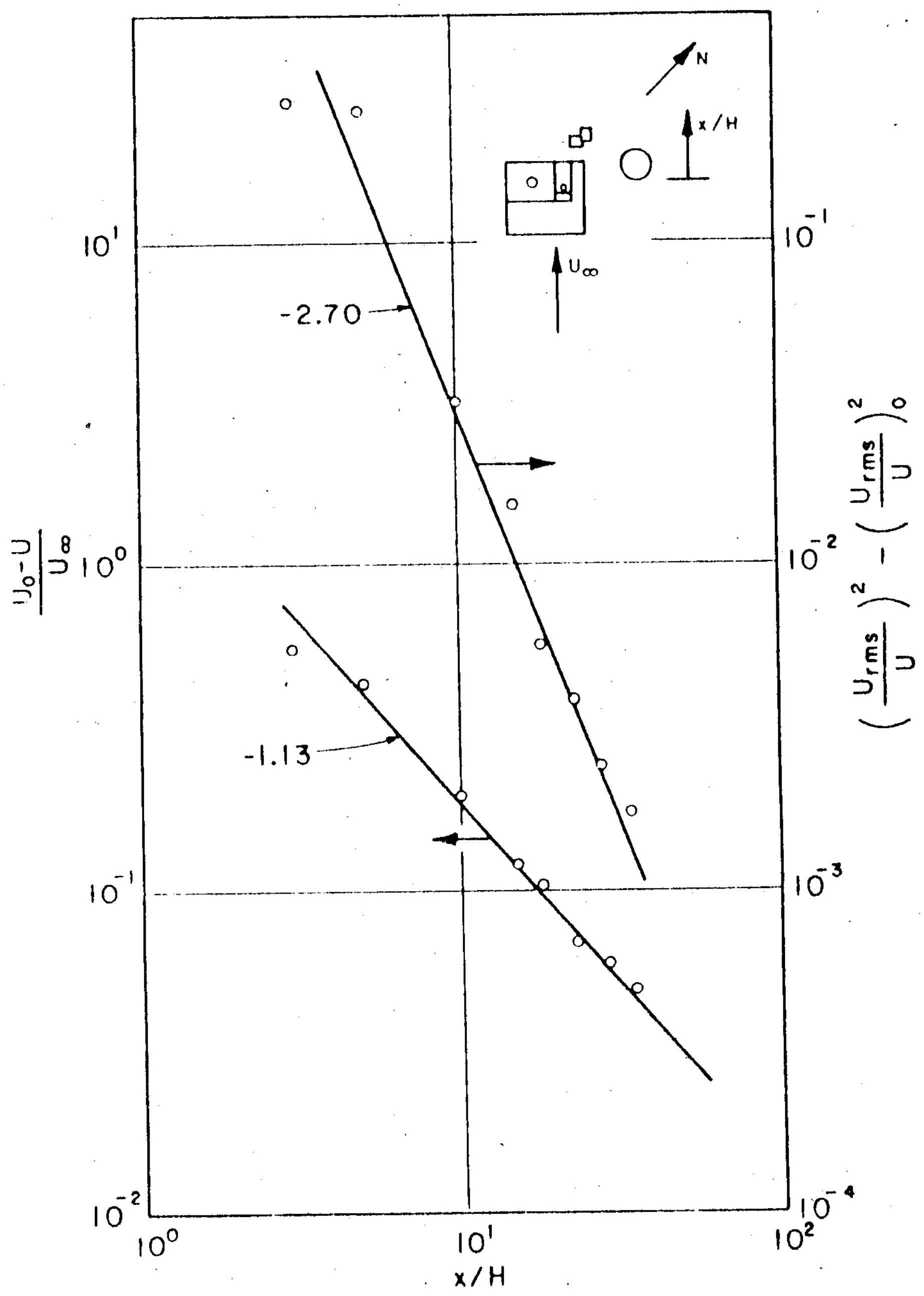

Figure 2. Decay of the Mean Velocity Defect and Turbulent Intensity Excess in the Wake of EOCR Reactor Model, θ = 135°.

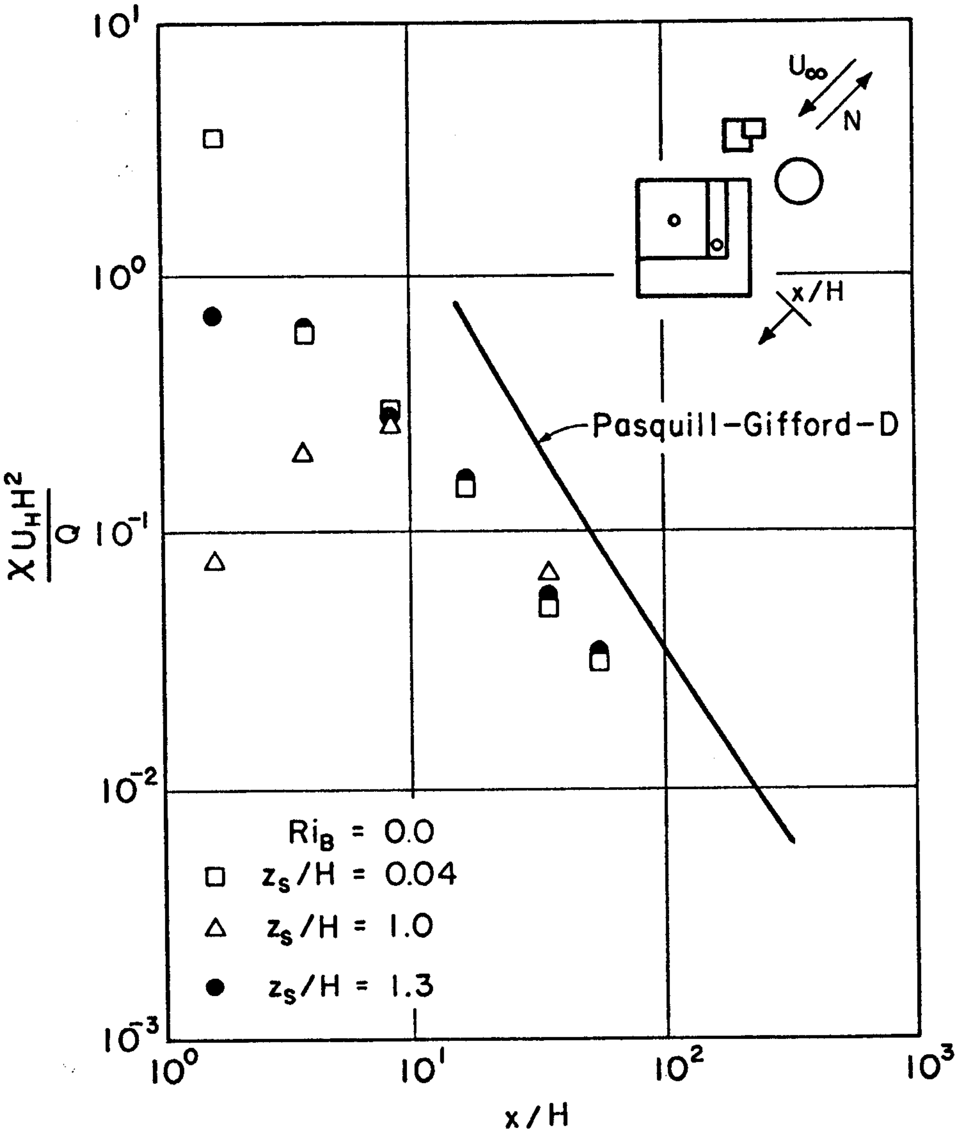

Figure 3. Longitudinal Concentration Profiles Downwind of EOCR Reactor Model, Pasquill-Gifford D Stability, $\theta = 0^\circ$.

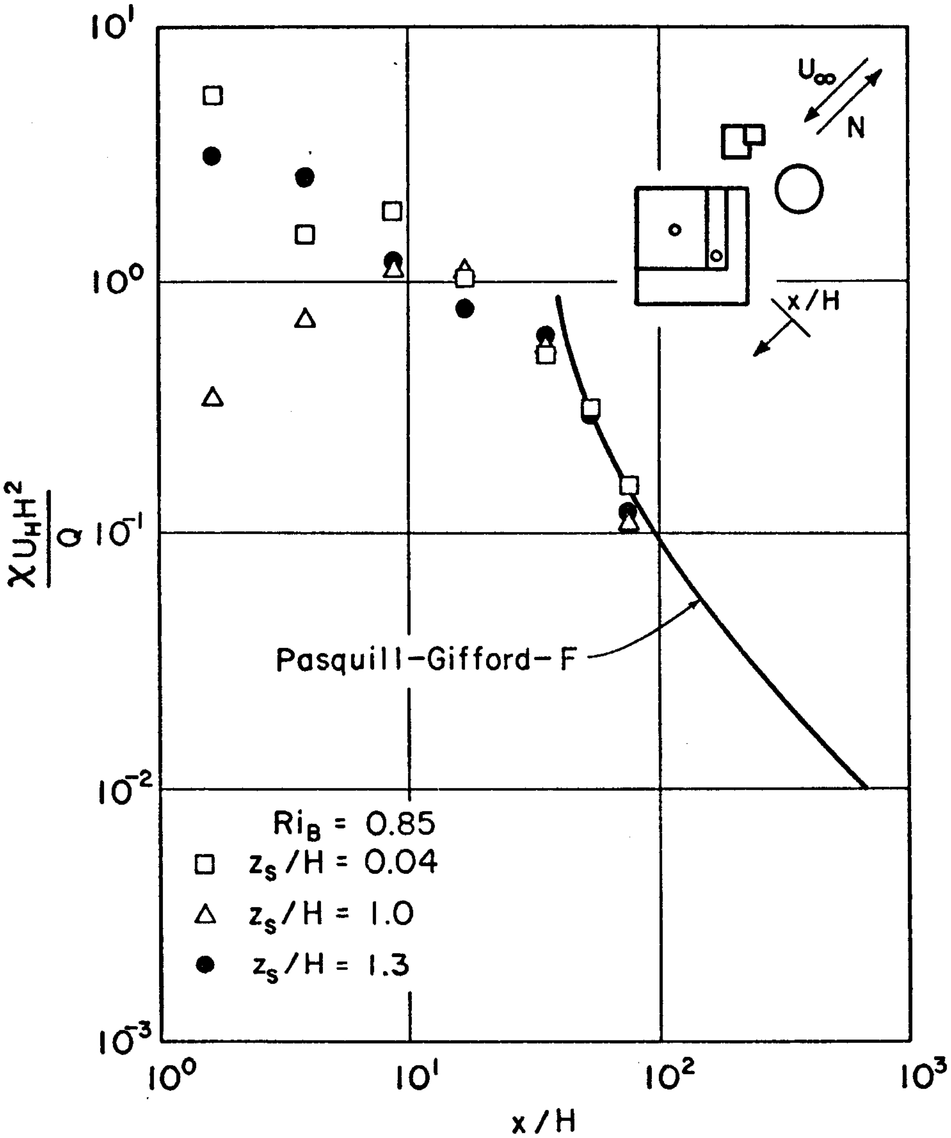

Figure 4. Longitudinal Concentration Profiles Downwind of EOCR Reactor Model, Pasquill-Gifford F Stability, $\theta = 0^\circ$.

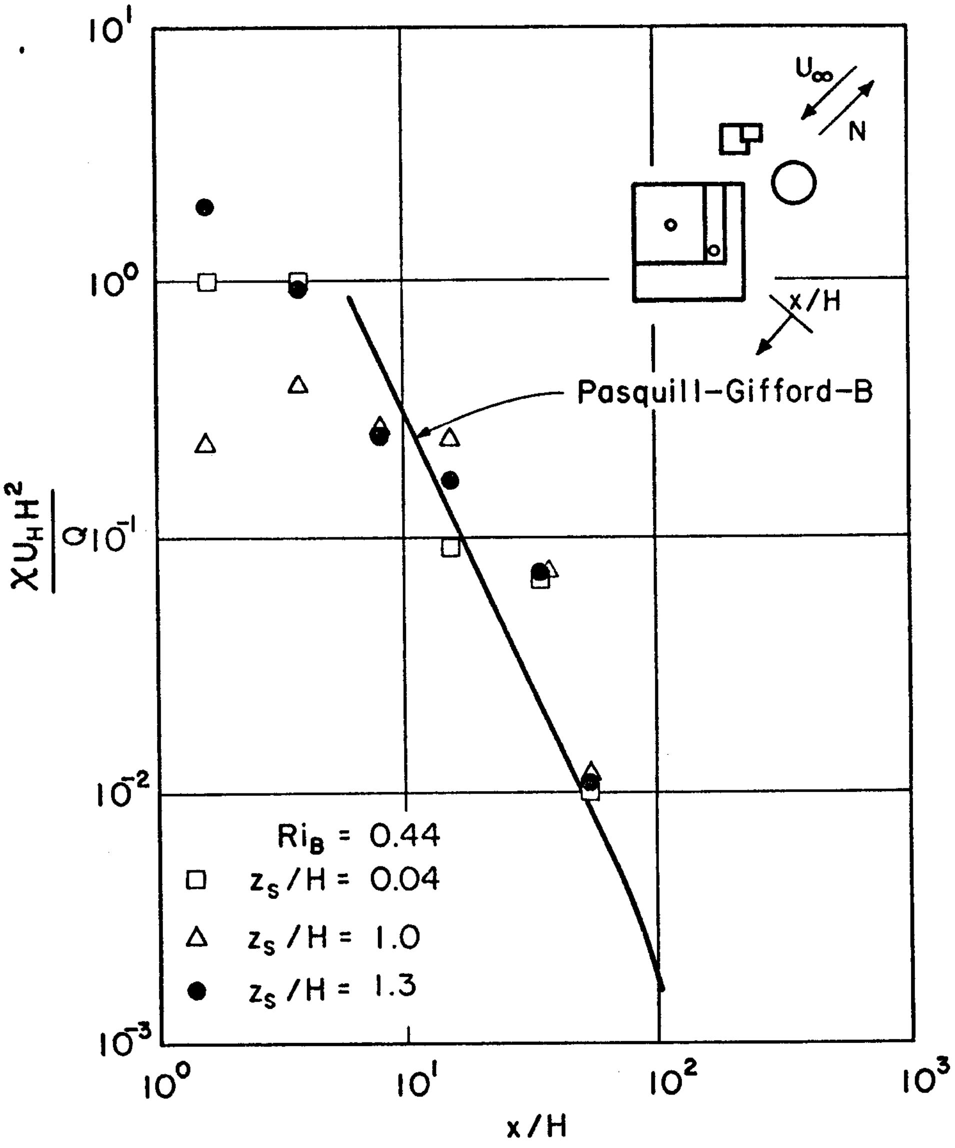

Figure 5. Longitudinal Concentration Profiles Downwind of EOCR Reactor Model, Pasquill-Gifford B Stability, $\theta = 0^\circ$.

TABLE I

Experiments on Diffusion in the Wake of Simple Building Complex

Investigator	Building Complex (scale)	$\frac{z_o}{H} \times 10^3$	$\frac{u_*}{U_H}$	$\frac{u_{rms}}{U_H}$	Re $\times 10^{-3}$	$\frac{\delta}{H}$	α^*	$\frac{z_s}{H}$	$\frac{A}{H^2}$	$\frac{x_{min}}{H}$	$\frac{x_{max}}{H}$	Cases Stability			K_{max} @ 3H	**			$\bar{t}_s$
												N	S	US		$-\gamma$	β	ζ	
Laboratory:																			
Halitsky (1963) (1975)	EBR-II Reactor (1:96)	.5	.053	--	31	3	.15	.1	5	.5	3	6	--	--	1.1	1.9	--	--	10 m
								.6											
								1.0											
Jensen & Frank (1963)	3 Story House (1:170)	400	.32	--	30	6.7	.8	1.1 $\downarrow$	3.6	1.0	16	2	--	--	.05	1.6	--	--	--
								1.5								1.0	--	--	
Martin (1965)	Phoenix Memorial Reactor (1:150)	110	.18	--	14	9	.45	1.2	3.3	1	18	4	--	--	.5	.3	--	--	10 m
												--	2	--		.8	--	--	
Yang & Meroney (1970)	Cube	1	.06	.19	14	4	.14	.1	1.0	3	25	12	--	--	2	.68	.50	.3	10 m
		13	.10	--			.21	.5				--	18	--	3	.60	.23	.3	
								1.0											
Meroney & Yang (1971)	Cube	.1	.06	.19	14	4	.14	1.0	1.0	3	60	4	--	--	1.2	.68	--	--	10 m
Robins (1975)	Cube	22	.11	.27	200	10	.20	.1	1.0	.5	40	32	--	--	1-10	.6	.3	.3	10 m
								.8											
								1.0											
Huber & Snyder (1976)	Block H:W:B = 1,2,1	2	.064	.13	34	7	.17	.1 $\downarrow$	2.0	2	30	.25	--	--	.5	.6	1.0	1.0	10 m
								2.5											
This Study	EOCR Reactor (1:200)	1.8	.064	.09	12	10	.16	.04	<2.0	1.5	70	27	--	--	.5	1.0	.65	.5	10 m
								1.0				--	54	--	.5	.7	--	--	
								1.3				--	--	27	.5	1.0	--	--	

TABLE I (cont'd)

Experiments on Diffusion in the Wake of Simple Building Complex

Investigator	Building Complex (scale)	$\frac{z_o}{H} \times 10^3$	$\frac{u_*}{U_H}$	$\frac{u_{rms}}{U_H}$	$Re \times 10^{-3}$	$\frac{\delta}{H}$	α^*	$\frac{z_s}{H}$	$\frac{A}{H^2}$	$\frac{x_{min}}{H}$	$\frac{x_{max}}{H}$	Cases Stability N	S	US	K_{max} @ 3H	** $-\gamma$	β	ζ	$\bar{t}_s$
Field:																			
Martin (1965)	Phoenix Memorial	--	--	--	2	--	--	1.2	3.25	1	18	7	--	--	1.5→	1.2	--	--	5 m
	Reactor				4							--	4	--	0.5	2.3	--	--	
Islitzer (1965)	TRA Reactor	1.6	.06	--	10	13	.15	.05	5.0	6	43	9	--	--	1.6	1.8	--	--	120-600 m
	Complex											--	2	--	2.2	3.0			
Hinds (1969)	Shed (H:W:D) 11 x 24 x 34 m	2.7	.075	.23	2	30	.18	.1	3.0	3	10	2	--	--	2.42	2.0	--	--	5_s- 15 m
Dickson et al (1969)	EBR-II Reactor	1.3	.06	--	9	10	.15	.03	5.0	4	24	4	--	--	1.0	1.2	.87		30 m
	(30 m)											--	9	--	1.0				
Smith (1975)	Block (H:W:D)	16→	.10→	.1→	.012→	160→	.13→	1.0→	3.0	.5	5	--	11	--	2.0	--	--	--	5_s- 20 m
	2 x 3.0 x 3.0 m	350	138	.6	.8	225	.33	2.0				--	--	20					
This Case (Abbey, 76)	EOCR Reactor	1.8	.06	--	10	13	.15	.04	<2.0	2	70	8	--	--	0.35	1.4	--	--	60 m
	(22.5 m)							1.0				--	12	--					
								1.3											

* $\frac{u}{u_r} = (\frac{z}{z_r})^\alpha$

** $X_{max} \sim x^\gamma$, $\sigma_y \sim x^\beta$, $\sigma_z \sim x^\zeta$