Annual Progress Report

GASEOUS PLUME DIFFUSION ABOUT ISOLATED STRUCTURES OF SIMPLE GEOMETRY

14 June 1969 - 14 June 1970

AEC Report No. COO-2053-1

FLUID MECHANICS PROGRAM
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COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO

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March, 1970

CER69-70RNM29

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1. Introduction:

In the atmospheric boundary layer, the dispersion of gases released from an elevated source may be predicted on the basis of some semi-empirical model, but very little research has been accomplished for the dispersion within the cavity-wake region. Problems for instance, include situations where the leakage of radioactive gases in the vicinity of a building cause a serious contamination in a downstream wake region. Another familiar case is that the expanding edge of a plume may re-enter the wake region and produce a secondary source.

Only a few systematic quantitative studies of dispersion in the wake region have been completed. Due to the difficulty of producing an analytical prediction, it is hoped that the use of wind tunnel experiments to estimate the distribution of concentration as aggravated by buildings will be proven to be a reliable prediction procedure.

A set of experiments has been completed in the Fluid Dynamics and Diffusion Laboratory at Colorado State University in both neutral and inversion meteorological conditions.

These experiments were designed in cooperation with the meteorological group of the Idaho Falls Nuclear Reactor test site. It was planned to perform geometrically and dynamically similar experiments for diffusion of gases in building wakes both in the atmosphere and in the meteorological wind tunnel. It is hoped that the duplicate sets of data will provide a foundation of confidence for use of the wind tunnel as an engineering tool for nuclear reactor station analysis. In addition, the wind tunnel information will complement prototype data for those situations difficult to reproduce in the atmosphere. Gaseous release and sampling positions were selected to correspond to the proposed prototype physical layout. Table 1 summarizes the sampling station information for a 1:50 model to prototype scale.

2. Construction of the Model:

The plexi-glass model was constructed to a linear scale of 1:50. As shown in Figure (1), the 15 cm-cube is scaled to an equivalent cubic structure of 25 feet on a side. There are three holes (Diameter = 1 cm) - top, middle and bottom - used for the typical exits of the tracer gas. The tracer gas was conditioned to the local ambient temperature before release. Gas temperatures were monitored by thermocouples installed at each exit (see Figure 1).

Fine screens installed inside the exit holes provided a low velocity uniform flow (eliminating the jet-effect).

The screens were removed when the smoke visualization technique was used.

3. Apparatus:

(a) Velocity profiles and temperature profiles

A pitot-static tube was used to measure both the vertical and horizontal wind profiles, the output signal (velocity head) was analyzed by a Transonic model A, type 120 electronic pressure meter. The temperature profiles were measured by copper constantan thermocouples.

(b) Smoke visualization

Smoke was generated 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 releasing hole. A visible record was obtained by means of pictures taken with a speed-graphic camera utilizing polaroid film.

In addition, a stereo-camera was constructed by appropriate positioning of two 35 mm cameras. Finally a 16 mm movie camera was used successfully to help visualize the fluid motion fluctuations.

(c) Gas tracer technique

Krypton-85 was used as a tracer gas for obtaining concentration distributions. It is a radioactive noble gas. Krypton-85 has a half life of 10.6 years so that there is no appreciable decay during a diffusion experiment.

Krypton-85 has many advantages over the other tracers used in wind tunnel diffusion studies. When it is diluted with air about a million times before use, it has properties very similar to those of air. Its detection procedure is fairly simple and direct. Above all, the Krypton-85 technique is economical and reliable.

The sample gas was calibrated by comparision with a Thalium 204 standard using a sensitive end window counter arrangement. (see Figures 2 and 3). Gas was transferred to a special mylar covered planchet for calibration and appropriately corrected for geometry, backscatter, and absorption.

Eight halogen quenched thin stainless steel wall G-M tubes (Tracerlab type 1108) were used to study the concentration of the sampled gases. The flow rate of flushing the sampled gas through the eight G-M tubes was controlled by eight flowmeters (Fischer and Porter Co., Model 10A103 multiple tube panel). The output of the concentration was obtained from the counts per minute by three sets of scalers (Nuclear - Chicago Corp. Model 192A "Ultrascaler" as shown in Figure 4).

4. Experimental Procedure:

The experiment consisted of two primary parts, (1) a qualitative study of the dispersion tendency and flow field in the vicinity of the model structure by visual observation of the smoke plume trajectories and (2) a quantitative study of gas concentration distributions in the downstream region from the model (out of the cavity). The test conditions are summarized in Table 2. The test program also incorporated two other test variables (a) different meteorological stratifications - i.e. neutral or stable, and (b) different aerodynamic effects - i.e. various wind approach angles.

In order to obtain a comparable prototype bulk Richardson number (atmospherical Froude number), the free-stream velocity used in the experiment was limited to 2 m/sec. A stably stratified shear layer was maintained by controlling the free stream to wall temperature difference.

The tracer release system is shown schematically in Figure 5. The calibrated Kr-85 mixture passed through the gas regulator to a simple tubular heat exchanger for the purpose of heating the gas to the ambient temperature of the release position. Samples were drawn from the wind tunnel through a rack of eight sampling tubes 3/32 inch in diameter mounted on a traversing carriage. The rack could be moved vertically and laterally by a remote control outside the tunnel. After the samples were flushed through the G-M tube for two minutes, the valves were closed and the individual sample concentrations measured with the scalers. The background level was subtracted from the observed counts.

5. Preliminary Discussion

Dispersion of the gas was affected by two factors, (1) the aerodynamic structure of the flow and (2) the temperature stratification condition. Figures (6) and (7) show typical profiles from the experimental data. Figure (8) indicates typical iso-concentration contours from the same experiment. Figure (10) displays visualization photographs for different gas release positions.

As we can visualize from the photographs, there was a very strong mixing in the cavity region. In the wake region, the turbulent mixing motion was still the dominant effect. The typical local concentration distribution curves display similar contours almost independent of the release position. The stable stratified flow suppressed the turbulent motion and resulted in higher concentrations at a given down wind distance.

TABLE 1

THE EQUIVALENCE OF THE MODEL AND THE PROTOTYPE (1:50)

	Sampling Station in Model Scale	Corresponding in Field Scale
Concentration Station	x = ½ m	25 m
	1 m	50 m
	2 m	100 m
	3 m	150 m
	4 m	200 m
	--	400 m
	z = 0 ~ 40 cm	z = 0 ~ 20 m
	y = -60 cm ~ + 60 cm	y = -30 m ~ + 30 m

Note: The coordinate system used is the conventional meteorological coordinate.

TABLE 2

θ	Vertical, Horizontal	Neutral, Inversion Stratified	Top, Middle, Hole Bottom
0°	V	N	T.M.B.
		I	T.M.B.
	H	N	T.M.B.
		I	T.M.B.
45°	V	N	---
		I	T.M.B.
	H	N	---
		I	T.M.B.
90°	V	N	M.B.
		I	---
	H	N	M.B.
		I	---
135°	V	N	---
		I	M.B.
	H	N	---
		I	---
180°	V	N	M.B.
		I	M.B.
	H	N	---
		I	M.B.

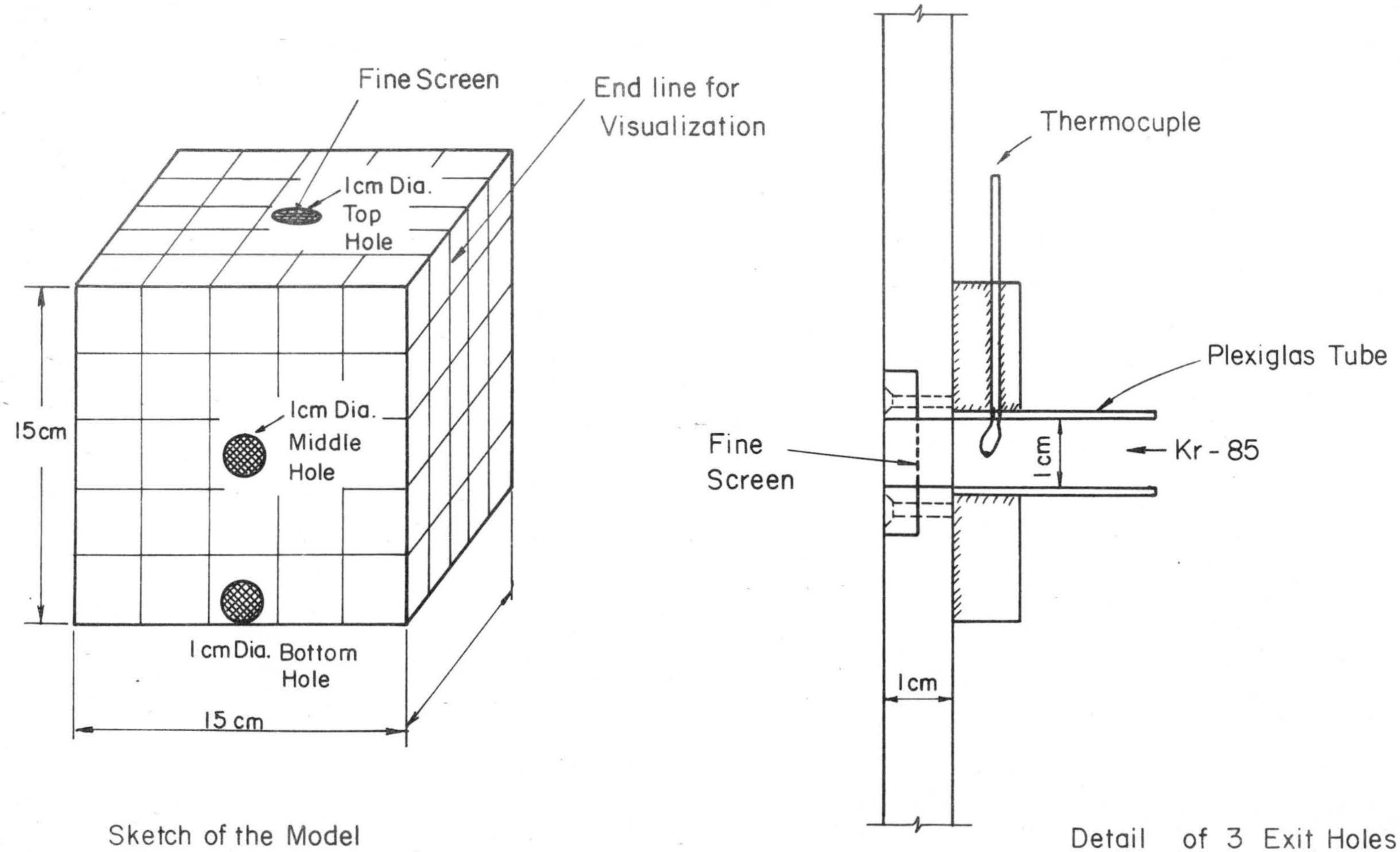


Figure 1. Sketch of the model

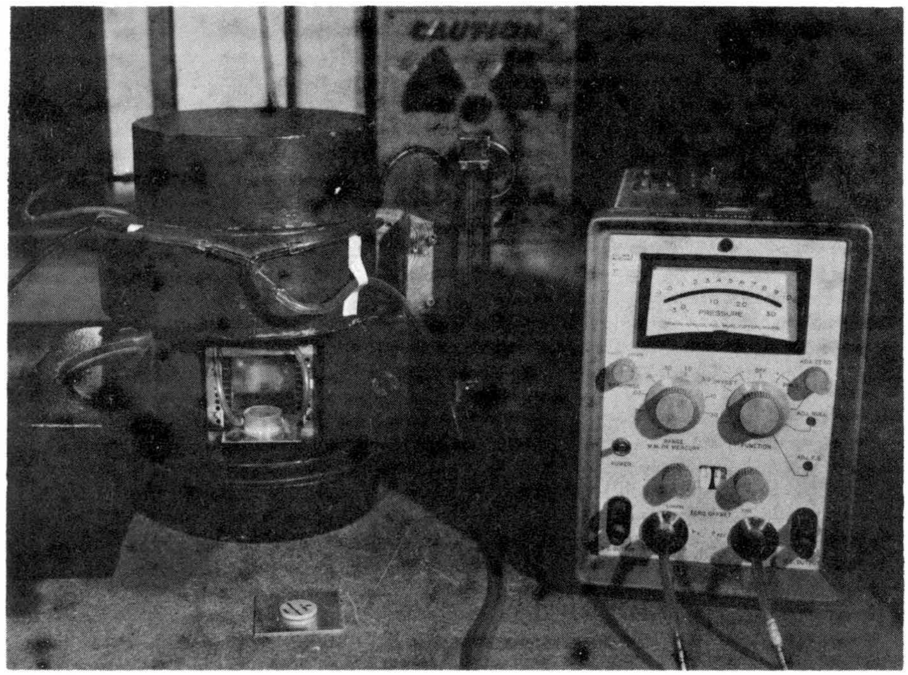


Figure 2. Krypton-85 calibration arrangement

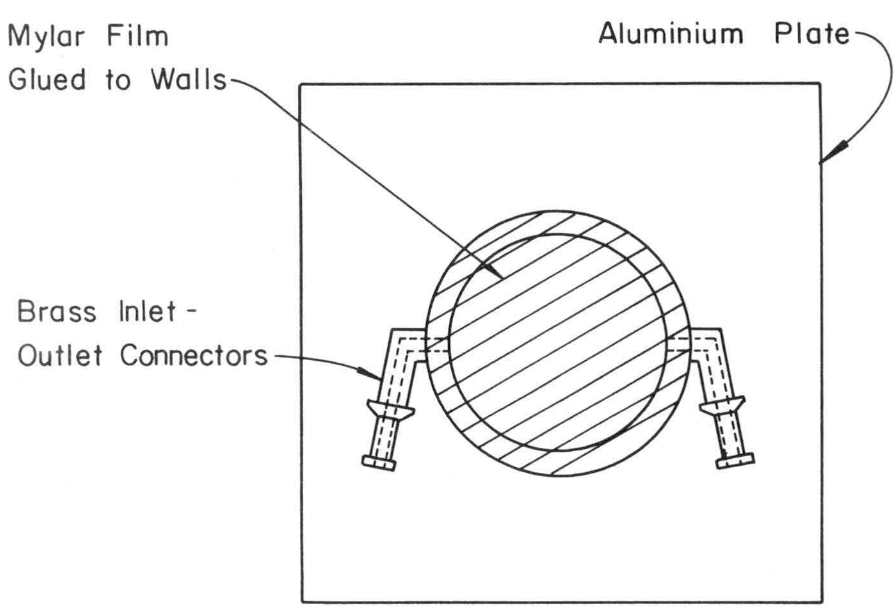


Figure 3. The gas planchet

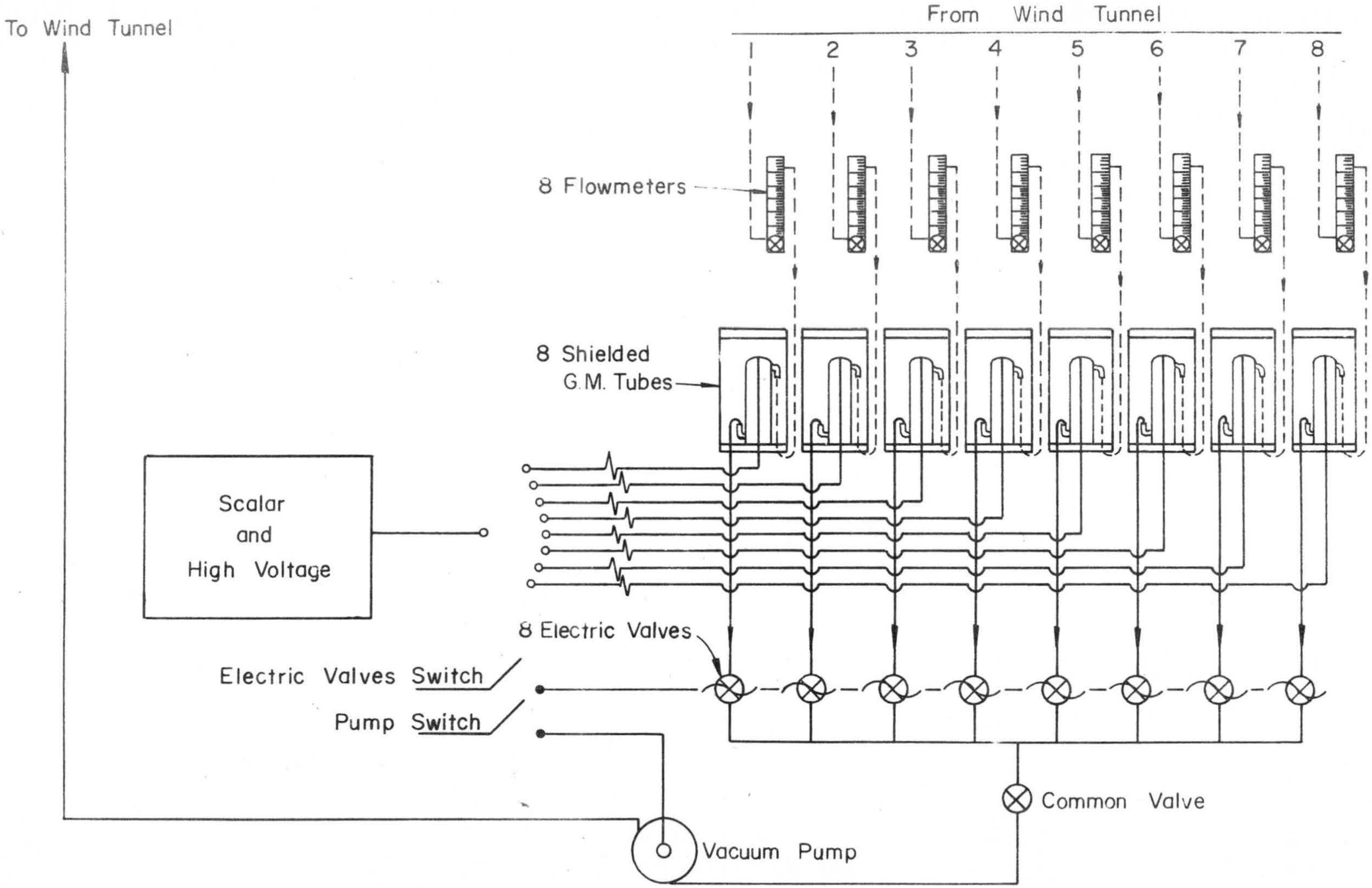


Figure 4. Detection system

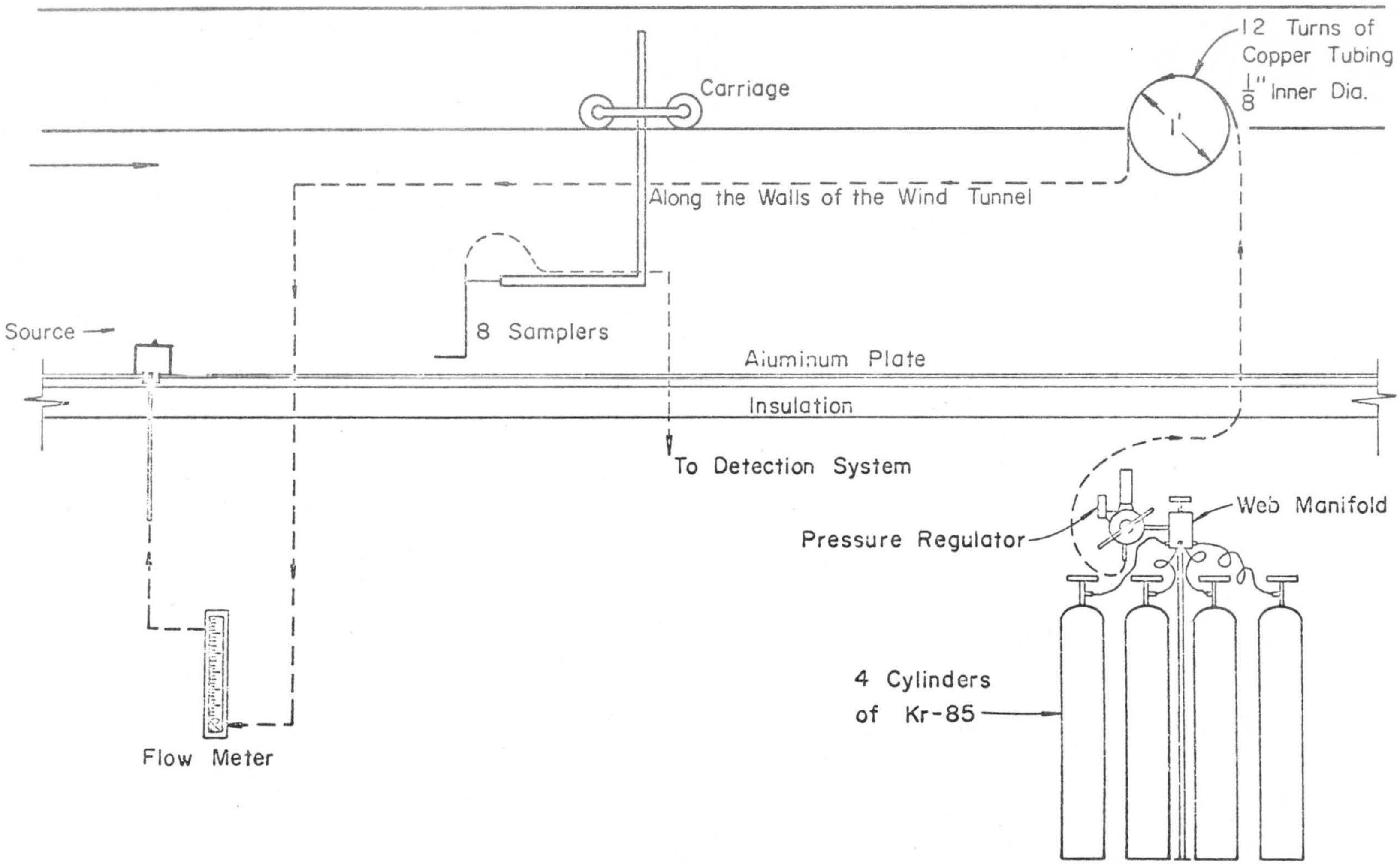


Figure 5. Release system

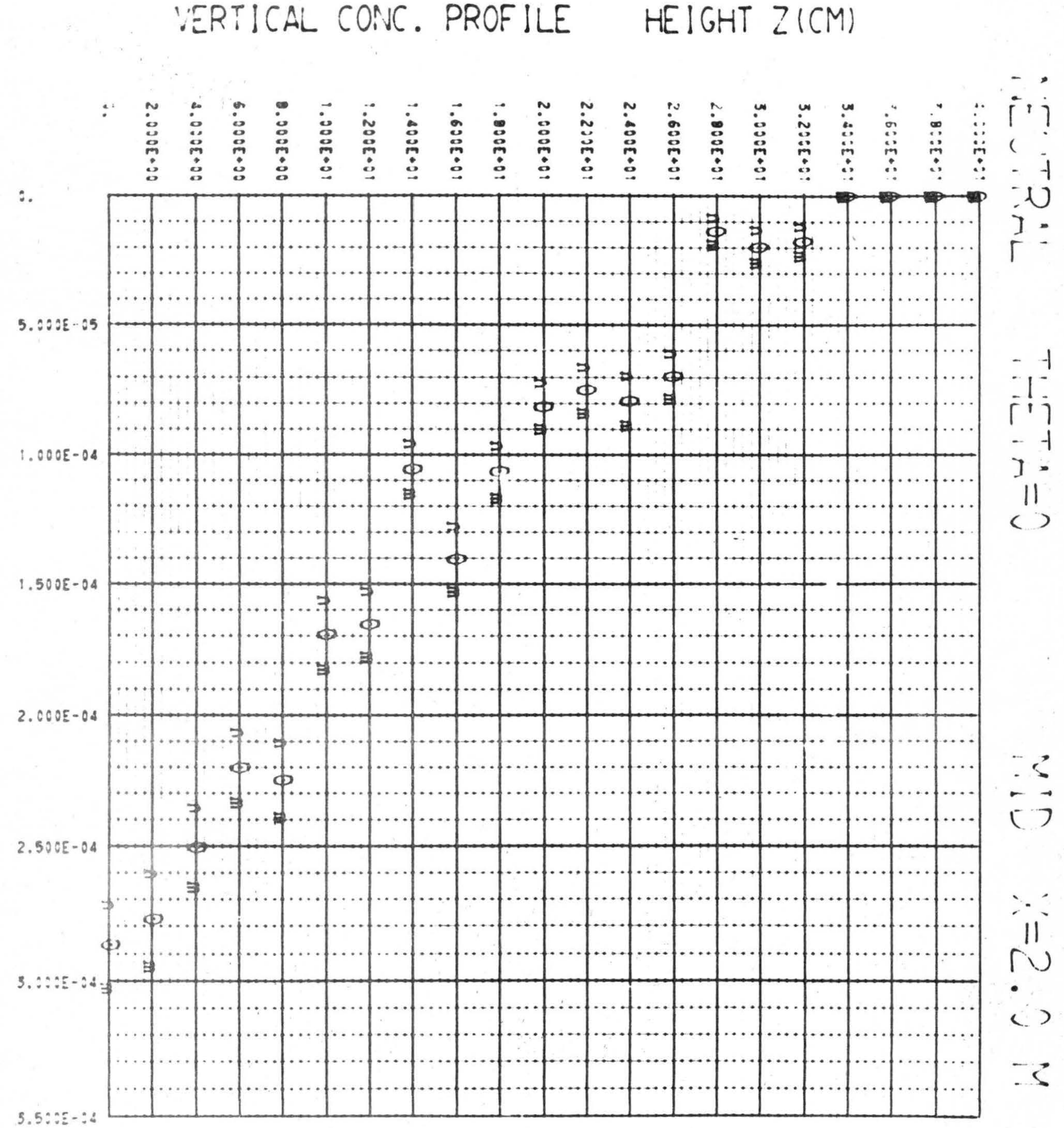


Figure 6. Vertical concentration profile

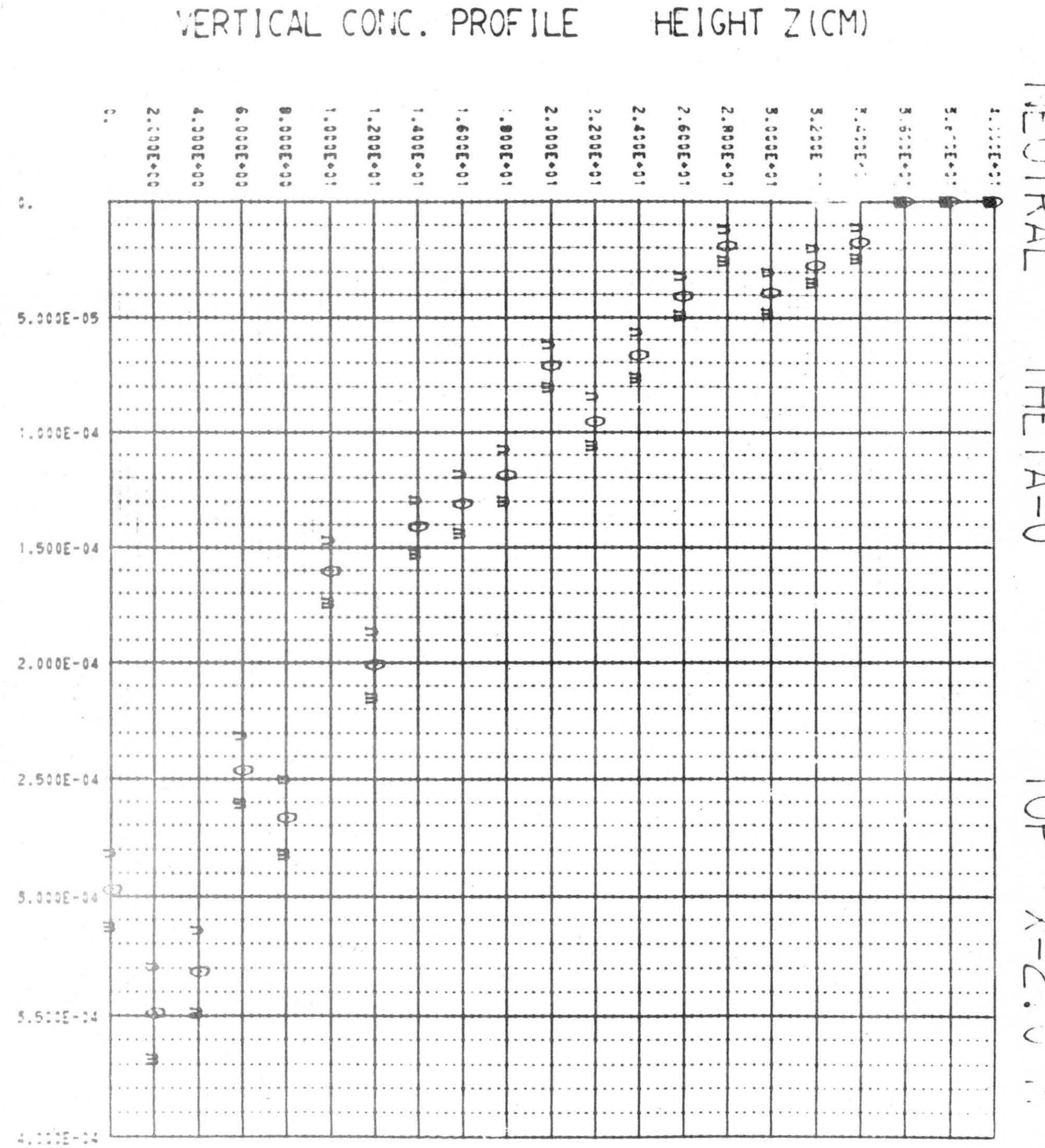


Figure 7. Vertical concentration profile

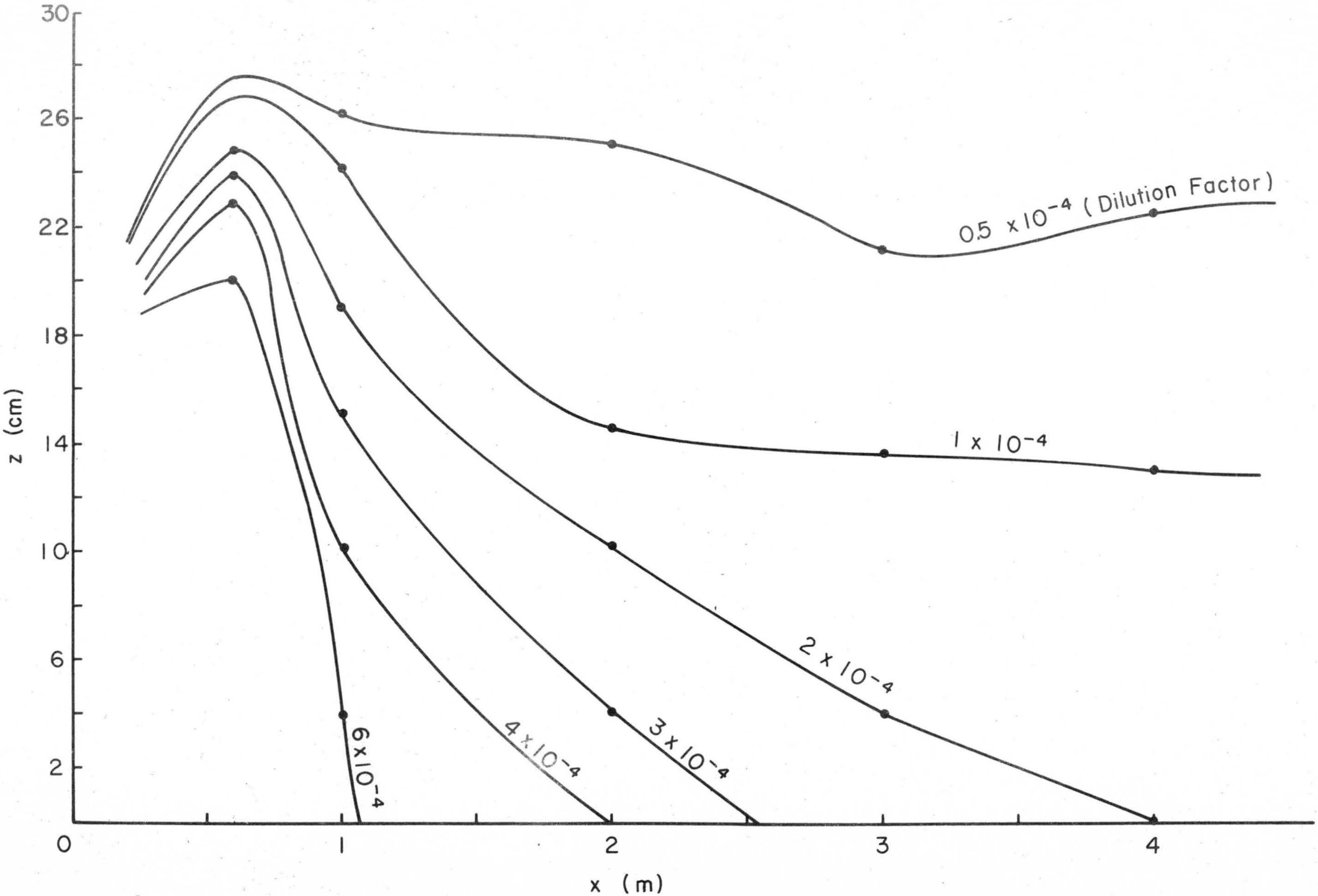


Figure 8. Iso-concentration contours

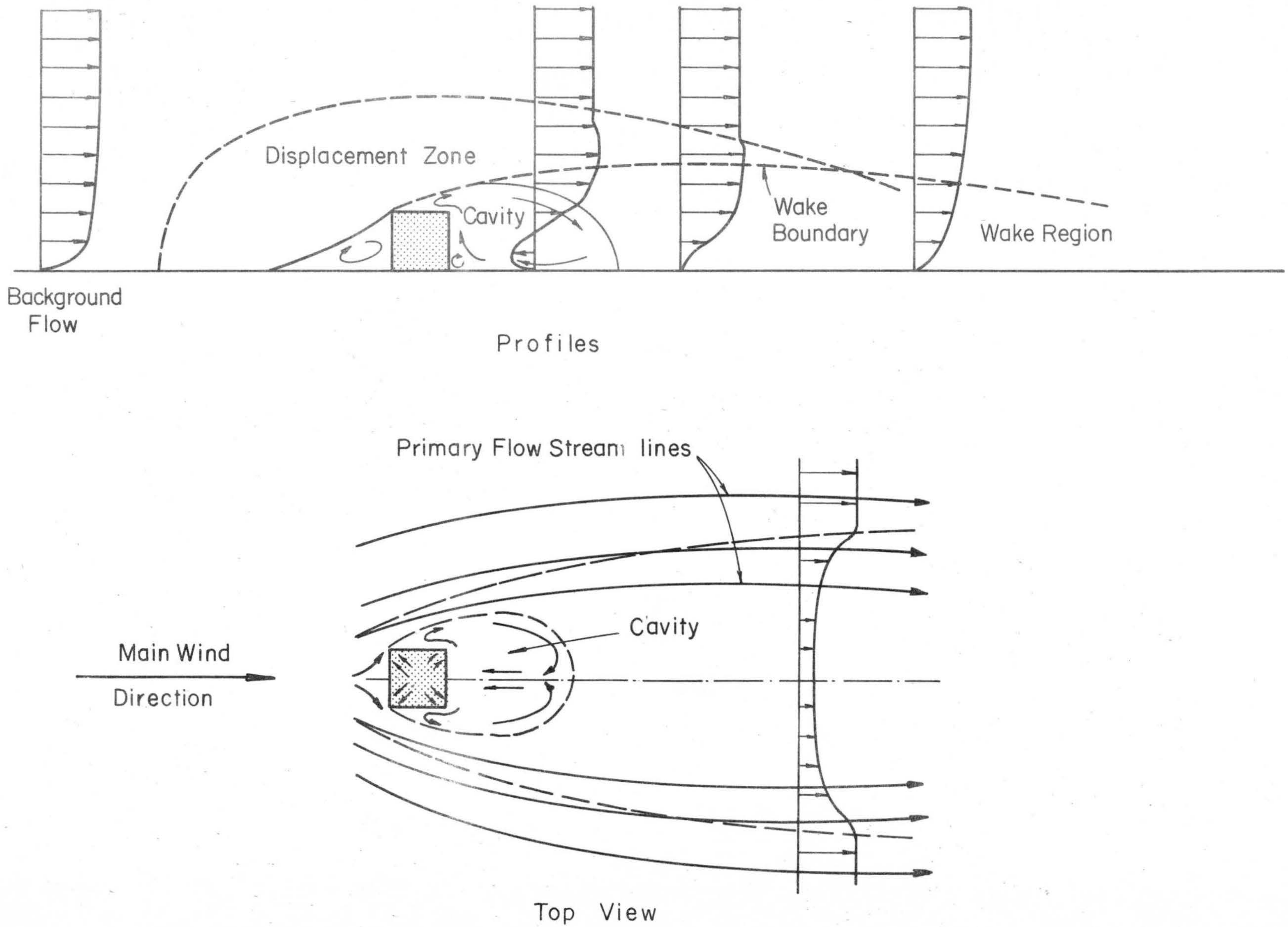
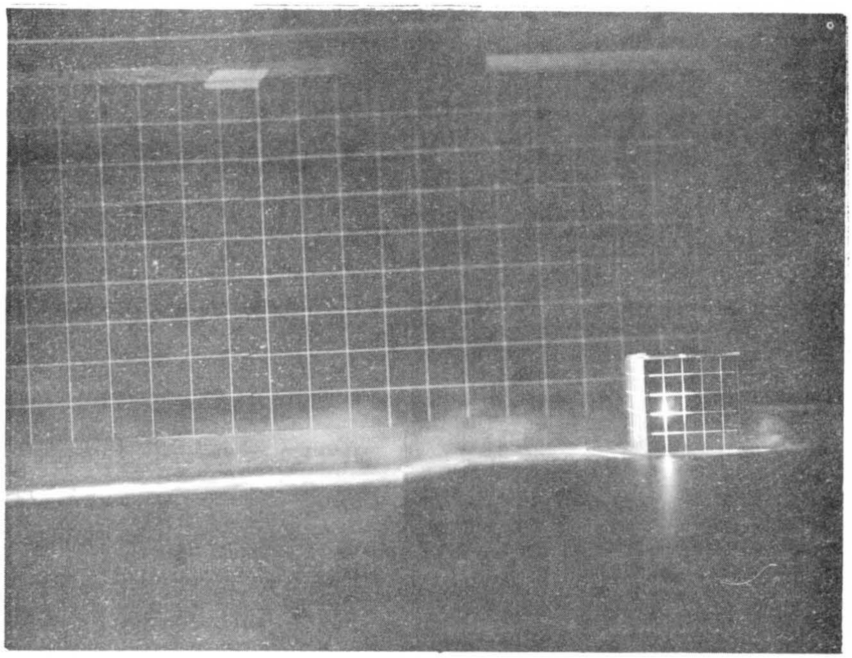


Figure 9. Flow field near a cube



θ = 0 Neutral stratification, bottom exit port

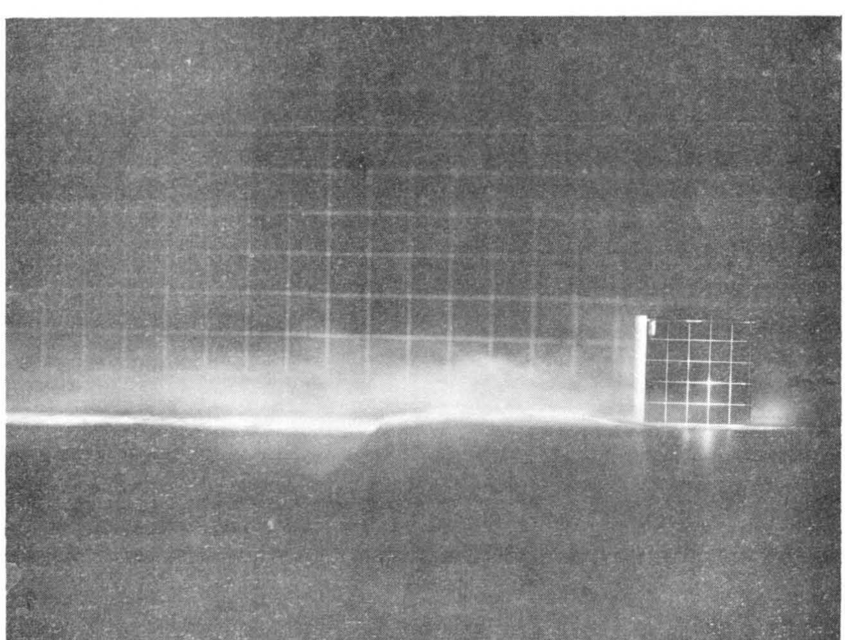


Figure 10. θ = 0 Neutral stratification, middle exit port