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Atmospheric Diffusion from an Off-shore Site*

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ABSTRACT

Analysis of the fate of airborne effluents from a nuclear reactor at an off-shore site requires a better understanding of over-water atmospheric dispersion than currently exists. For this reason, a diffusion study has been undertaken off the south shore of Long Island, New York, about 100 km from New York City. This study is using tracer material released from an anchored boat. Measurements of mean wind, turbulence and temperature are made on portable towers on the beach, from an aircraft and aboard the source boat. Plume geometry is documented by photography and from quantitative concentration measurements.

Experiments under a variety of meteorological conditions indicate that over-water dispersion is very sensitive to meteorological conditions. From measured diffusion parameters it has been observed that over-water dispersion is significantly less than over land, particularly when the on-shore flow is due to the sea breeze. This is because of the low aerodynamic roughness of the water, and because low level stable conditions are established because the water is at lower temperature than the air. Crosswind standard deviations of the plume a factor two less than the prediction of Pasquill category F have been observed at the shore with the source 6 km off shore.

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INTRODUCTION

There are active plans in the United States to locate nuclear power plants at off-shore sites. The plans call for the plants to be mounted on floating platforms moored within artificial breakwaters at a distance of about 5 km from shore. In order to do safety and environmental analyses of plants so sited one must be able to calculate the atmospheric transport and dispersion over the ocean. The parameters that are used in the usual Gaussian plume models have been derived from data collected from experiments done over land. Thus one must modify model inputs in order to apply them to over-water dispersion.

There are a number of physical reasons for the airborne effluent from off-shore plants to behave somewhat differently from effluents from equivalent land-based plants. In particular, decreased dispersion is to be expected. The aerodynamic roughness length of the sea is, in general, much less than that of even smooth land. Therefore, mechanical turbulence will be reduced. In spring and summer seasons warm air is frequently advected over somewhat cooler water setting up low level stable conditions. Since the ocean temperature shows almost no diurnal change such stable conditions persist throughout daylight hours, whereas over-land surface heating makes stable conditions during the day quite rare. It should be mentioned that sea breezes which are driven by the land-water temperature difference often cause a predominance of on-shore winds, and it is under these conditions that dispersion is liable to be quite limited. This is of particular importance in determining the concentration of routinely released effluent transported to the shore line. One factor that tends to lessen effluent concentration is the fact that wind speeds over the water are usually somewhat greater than over land.

The fact that decreased dispersion conditions do indeed exist for over-water flow has been confirmed by wind fluctuation experiments performed by Slade[1]. Smith and Niemann[2] have reported on diffusion experiments performed off the coast of California. Their emphasis was on diffusion from line sources and the far inland transport of material. Van der Hoven [3] has summarized a good deal of the data that exists relative to dispersion with on-shore winds; this summary, and the data upon which it was based, is focused upon problems associated with dispersion from a source located along the shore. Information is sparse on the dispersion from a point source located off shore, of particular concern is the lack of data on the characteristics of an effluent plume as it first reaches the shore.

In order to fill this gap in our information about atmospheric diffusion, a series of tracer experiments have been started. Preliminary results are presented in this paper. In general, the experiments tend to confirm that under commonly occurring conditions dispersion is significantly less than would occur over land.

OUTLINE OF EXPERIMENTS

The experiments reported in this paper are being conducted off the south shore of Long Island, about 100 km east of New York City. The shoreline at this location is straight and relatively uncomplicated. A variety of meteorological conditions occur so that it is expected that the results will be able to be generalized to other sites.

The tracer material is oil fog smoke. It is released from a short stack (~5 m) on a boat anchored at an appropriate site off shore. General plume behavior is documented by photographs that are taken from a second boat and from a light aircraft. Quantative concentration methods are taken from a van that traverses along a road that runs parallel to the shore about 200 m inland. These measurements are designed to determine concentration levels and the plume crosswind standard deviation, σ_y, to serve as input to Gaussian plume models. Since one usually desires to calculate concentrations averaged over a time of the order of an hour the meandering of the plume must be taken into account. This is done by means of multiple traverses. For each traverse the location of the plume center of mass is determined and the relative dispersion about the center of mass is computed from moments of the measured distribution of tracer. Standard deviat ons reported in this paper include the effect of meandering.

A large number of meteorological measurements are included in the study. They include wind speed and direction measured from portable towers on the beach, temperature measurements of the air and water from the boats, aircraft temperature soundings, pilot balloon wind soundings, etc. The air-water temperature difference as measured from the boats, the mean wind speed, the standard deviation of wind speed and direction as measured 16 m above the beach, and general conditions are the meteorological variables that will be reported here. Analyses of turbulence data, wind and temperature profiles will be reported at a later date.

Experiments were started in the summer of 1972. As is inevitable with field experiments a number of trials did not produce directly applicable results, usually because of unfavorable weather conditions. The conditions for the trials which are relevant to on-shore dispersion are summarized in Table I. During the 7 November 1972 trial, plume behavior typical of unstable overland dispersion was observed and the concentration of oil fog smoke on the shore was too low for meaningful measurements. During the other trials the plume was easily observed on the shore. The plume from the 3 October 1972 release exhibited a good deal of vertical looping; on the remaining four occasions the plume remained close to the surface from the time it left the source until it was inland a good distance. Figure 1 is typical photograph of the type of compact plume observed on the above-mentioned occasions. This particular photograph was taken on 17 August 1972; the boat was anchored approximately 2 km off shore.

Figure 2 shows the plume crosswind standard deviations as a function of distance from the source. All the points shown were calculated from on-shore concentration measurements. Also shown on the graph are the σ_y predictions from the Pasquill [4,5] categories. These predictions are shown for the sake of comparison only; it is not to be expected that the Pasquill categories, as usually defined, are applicable to over-water diffusion.

The inclusion of the meandering in the determination of the σ_y's presented here was found to be significant; on the average, the standard deviation of the location of the center of mass about its mean position was about 40% greater than the average of the relative standard deviations.

One can see from a comparison of the measured points and the Pasquill predictions that one can have plumes from off-shore sites considerably narrower than expected from standard predictions. In particular, we note that the measured σ_y's on three different days were a factor of two less than category F prediction; category F is often selected as a "worst case" predictor. It should be emphasized that these narrow plumes were observed on days with reasonably brisk wind speeds (~5 m/s) while "worst case" predictions usually assume wind speeds of 1 m/s.

The quantity of prime interest in safety analysis is the "dilution factor," usually defined as the "center line" concentration divided by the source emission rate. An estimate of the dilution factor for an averaging time of about 0.5 to 1 hour was estimated from the data and is shown in Figure 3 as a function of distance from the source. The estimation of the centerline

TABLE I

Date	Type of On-shore Flow	Sky Conditions	Air-Water Temperature Difference °C	Mean Wind Speed, u m/sec	Wind Standard Deviations: Speed σ_u m/sec	Wind Standard Deviations: Direction σ_θ degrees
17 Aug. 1972	Gradient	Overcast	1	4.8	.2	*
31 Aug. 1972	Sea Breeze	Clear	2	3.9	.2	3.0
3 Oct. 1972	Gradient and Sea Breeze	Scattered clouds	1	6.7	.3	3.3
7 Nov. 1972	Gradient	Overcast	0	5.2	.5	12.
23 May 1973	Gradient	Overcast light rain	0	4.6	.2	2.2
1 June 1973	Gradient	Scattered clouds	*, >0≠	9.8	.3	2.5

* Missing due to instrument failure.

≠ Equipment failure prevented actual measurement, qualitative observation indicated that ocean was somewhat cooler than the air.

concentration was made using the average crosswind integrated concentration and the σ_y (including meander) under the assumption of a Gaussian crosswind distribution. The curve shown in the figure is a "worst case" calculation, i.e. category F, 1 m/s. All of the points estimated from the experiments fall below the F, 1 m/s calculation but not by a very large amount.

The experimental program is not yet complete and, indeed, the analysis of the experiments performed to date is still underway. However, enough results are in hand to indicate that over-water dispersion can be quite limited and that the use of standard model parameters is liable to lead to significant errors.

ACKNOWLEDGEMENTS

The performance of field experiments such as the one outlined here requires the joint effort of a large number of people. The dedication and enthusiastic cooperation of the entire staff of the Brookhaven National Laboratory Meteorology Group are gratefully acknowledged. The interest and encouragement of the staff of the Division of Biomedical and Environmental Research of the United States Atomic Energy Commission are of no small importance and are also gratefully acknowledged.

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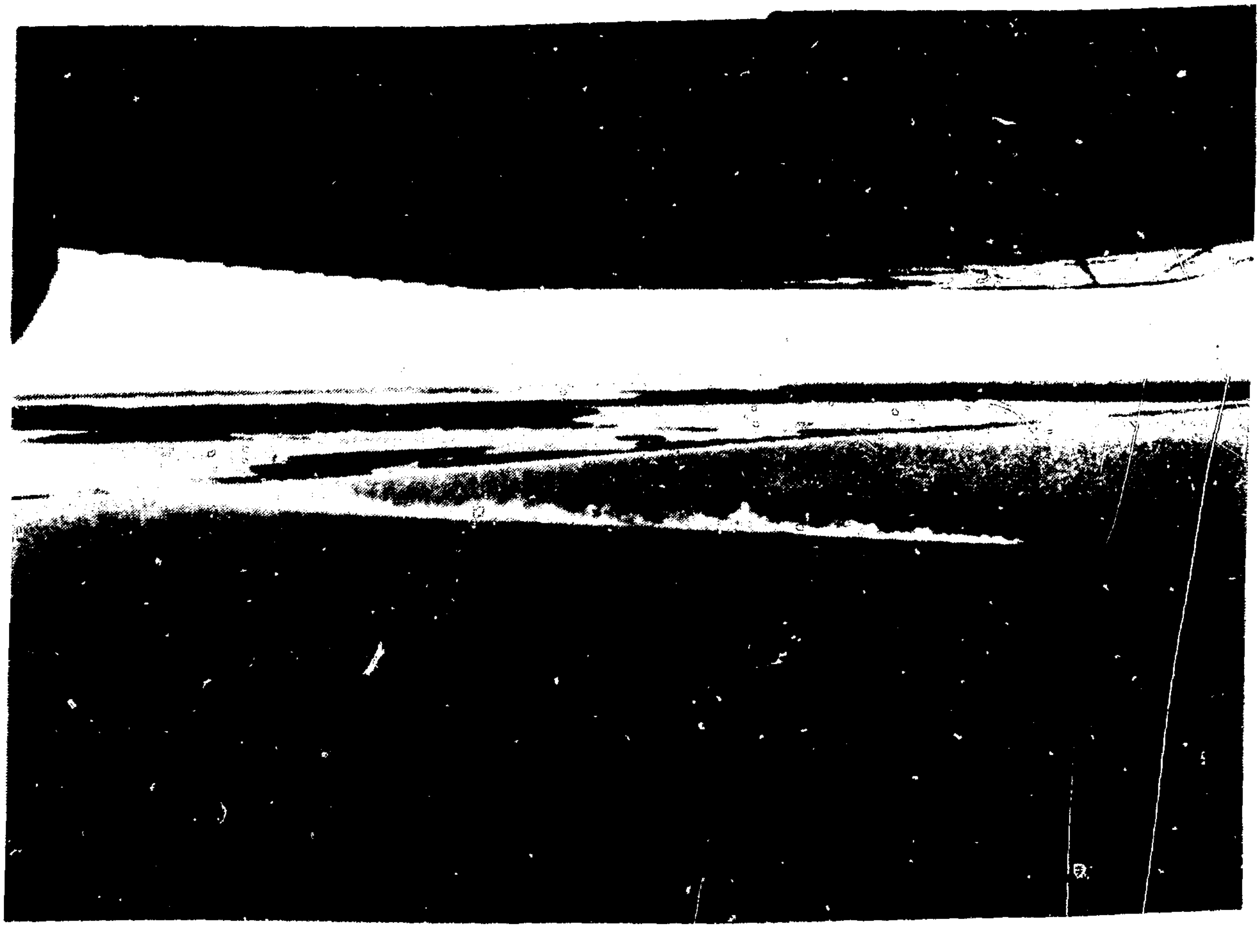
FIGURES

Figure 1. Oil fog plume from boat anchored off the south shore of Long Island, 17 August 1972. The sky was overcast and the on-shore flow was due to gradient winds.

Figure 2. Plume standard deviations as a function of distance from the source to the point of measurement. Also shown are Pasquill category predictions.

Figure 3. Dilution factors as a function of distance from the source to the point of measurement. Also shown is an "F, 1 m/s" calculation.



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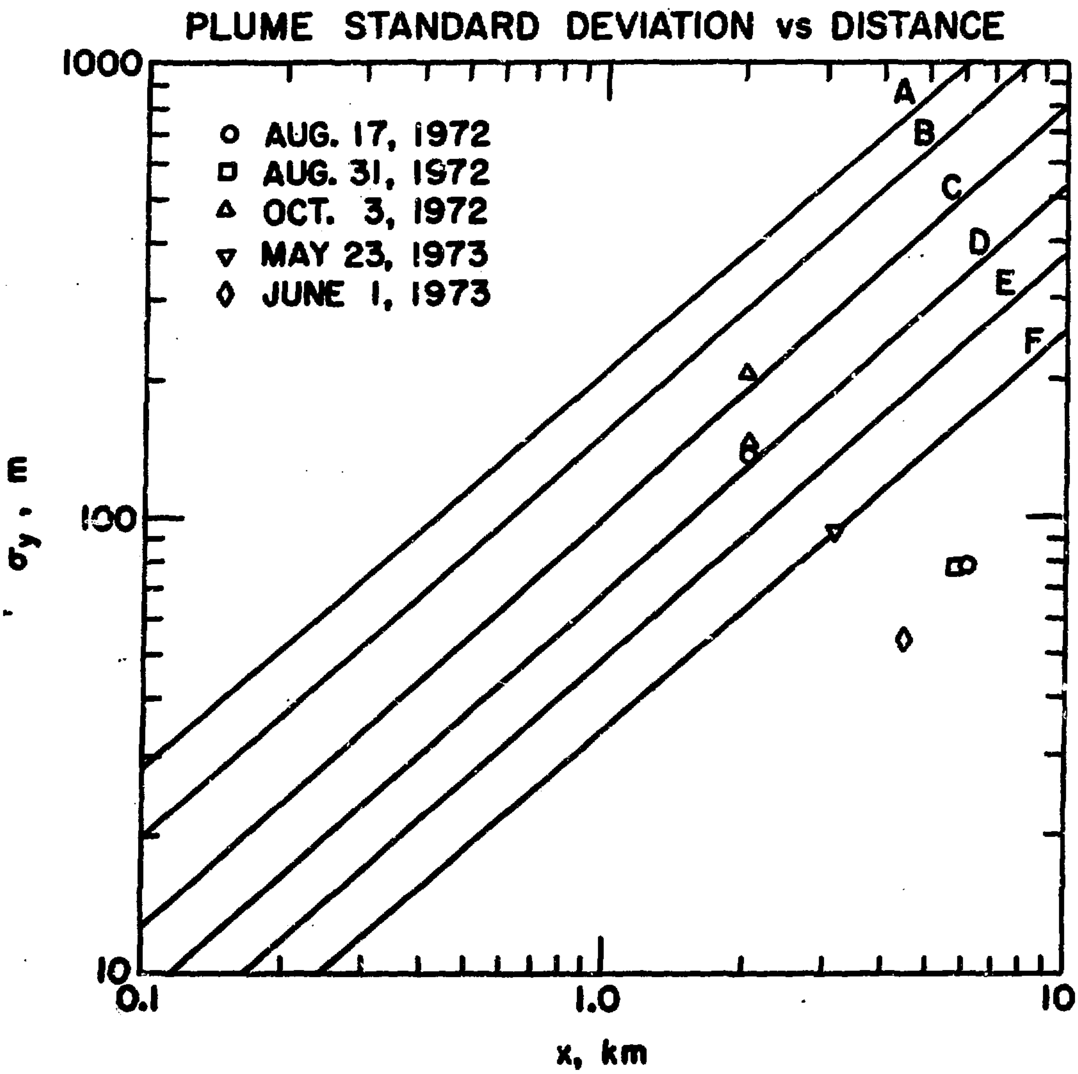

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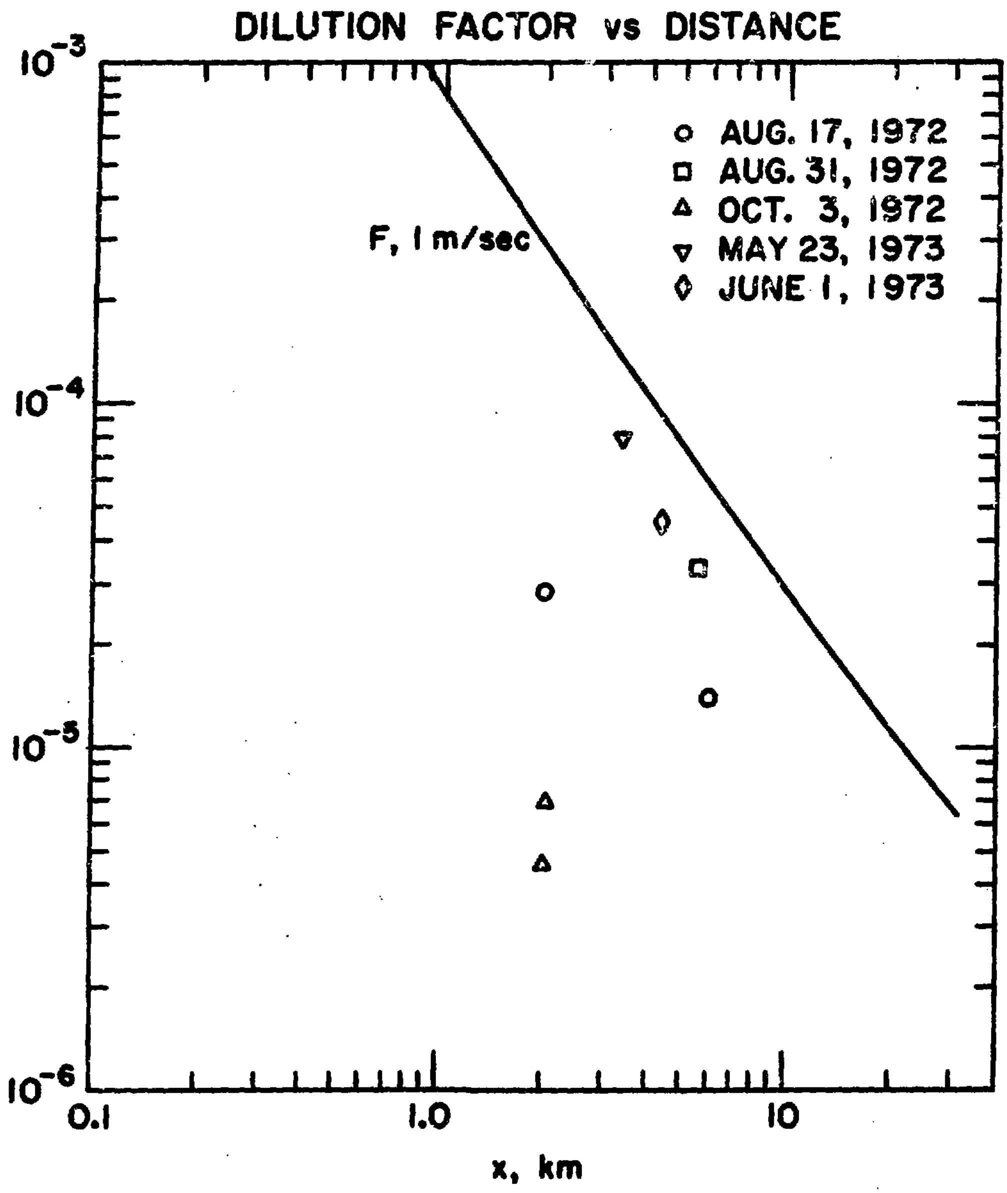

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